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Introduction to NPGS

This manual describes NPGS version 9.1 which runs in 32 bit Windows and uses the high speed NPGS PCI516 board.

NPGS: Overview

The Nanometer Pattern Generation System (NPGS) has been designed to provide a user-friendly environment for the delineation of complex structures sized from nanometers up to the maximum field of view of the microscope. The system is designed to be extremely flexible, yet easy to use. There are three basic steps to the pattern generation process: pattern design, parameter run file creation, and pattern writing with optional auto or semi-automatic alignment for multilevel lithography. Since there are too many features and options to mention in this brief introduction, only the fundamental aspects of each step are described below.

NPGS Menu

All of the NPGS commands discussed below, as well as any other Windows or DOS command, can be executed from within the NPGS Menu program. This program is a 32 bit program that can be run under Windows 2000*/XP*/Vista*/Win7*/Win8* (*some versions are restricted) in an “Office Installation” mode that can be used for pattern design away from the microscope. When used to control the microscope, NPGS v9 or higher can be run under Windows 2000, XP, or Windows 7 (all 32 bit Professional versions).

Pattern Design

Patterns are created using DesignCAD which is a commercial computer-aided-design program. NPGS can be used with DesignCAD Express v21.2, DesignCAD Express v16.2, and/or DesignCAD LT 2000. Any or all of these versions may be installed and used with NPGS at the same time. The NPGS Manual is based on the newest supported DesignCAD version (v21.2), and any information for the other versions is listed separately as needed. The many powerful layout and editing features of DesignCAD simplify all aspects of pattern design. All of the following drawing elements may be used in pattern design: lines, circles, and circular arcs of arbitrary orientation and width, and filled polygons with up to 999 vertices. Text in almost any font, cubic spline curves, bezier curves, and elliptical arcs can also be easily generated and written as series of short lines. Pattern elements that are to have different exposure parameters (such as dose, exposure point spacing, microscope beam current, microscope magnification, etc.) are designed in different drawing layers and/or different colors. This gives an almost unlimited number of exposure conditions within a single pattern. If desired, patterns can also be imported from DWG, DXF, GDSII, CIF, and IGES.

Run File Editor

Once a pattern is designed, the Run File Editor is used to record the exposure conditions for the different drawing elements in the pattern. This approach offers the advantage that the details of the exposure are separated from the pattern design, therefore, to vary the exposure conditions only the run file needs to be changed. The Run File Editor is a menu style program that makes parameter entry and modification extremely easy. For example, a dose may be entered as an area dose ($\mu$C/cm$^2$), a line dose (nC/cm), or a point dose (fC), and the correct point exposure time will be calculated automatically. The Run File Editor will generate a file of parameters that will be used by NPGS, PG, or AL during the pattern writing and/or alignment steps, as described below.

In NPGS v9, a single run file may contain parameters for up to 5000 different entities that will be written sequentially. Options within the Run File Editor allow the user to designate patterns for several modes of processing, including: Auto-Alignment, Semi-automatic alignment, Array Repeat, and Fracturing. Also, other special modes include Global Rotation Correction, Stage Motion, Text Display, and Command Execution of Windows, DOS, VBScript, and JavaScript programs. The “Command” option makes run files especially versatile, since virtually any command can be run from within NPGS during the pattern writing, as designated by the user.

Pattern Writing and Alignment

Once a run file has been created, the pattern(s) it describes may be written using the program "NPGS.exe", which is called by selecting "Process Run File" from the NPGS Custom Command buttons. When processing a run file, NPGS.exe reads the run file and automatically calls the writing
Introduction to NPGS

NPGS: System Installation

PG: PG writes a pattern by simultaneously controlling the x-y scan coils and beam blanking of the microscope. The scan coils are stepped with 16-bit resolution within the field of view of the microscope.

NPGS v9 allows exposure times to be set between 0.2 microseconds to over an hour per point, with a resolution of 0.25% or better for all exposure times. The default mode is to precisely step the beam at the rate to give the desired exposure time per point. The NPGS v9 hardware allows the calculation of the exposure points to be completely asynchronous with the output, which typically allows the calculations to be performed on pattern elements well ahead of when they are actually written.

For v9, the calculation overhead is negligible for almost all patterns. When the patterns are to be written, the software will ask the user when to begin writing the pattern, when to continue if writing has been paused to allow the user to manually change a microscope setting (i.e., magnification, beam current, etc.), or NPGS can write the pattern with no user interaction when an automated stage is being used. The NPGS software can also be configured to operate with no blanker or with only a slow beam shutter installed.

AL: Patterns may be aligned to existing alignment marks without exposing the writing area by using the alignment program AL. An alignment pattern may have several sets of windows. For example, large coarse alignment windows followed by smaller fine alignment windows are very useful. Each set may have up to four user defined windows anywhere within the field of view of the microscope. The images of the sample areas within the windows are simultaneously displayed on the PC screen. User defined overlays are also displayed superimposed on the sample images. The overlays are individually positioned to align with the marks on the sample, either by the user or automatically when AL is used in the Auto-Alignment mode. Once they are aligned, the program calculates a general transformation matrix that corrects for x and y magnification errors of the microscope, as well as sample rotation and offset. Signal averaging, edge enhancement, and spatial averaging can be used to optimize the image of the alignment marks for maximum alignment accuracy. The transformation matrix is subsequently used by PG when writing the pattern to give accurate registration between lithography levels.

NPGS: System Installation

System Installation: Software

When the PC is supplied with NPGS, the NPGS and DesignCAD software is fully installed on the PC and the following procedure will only be necessary if the software ever needs to be reinstalled or when doing an "Office Installation" of NPGS.

Important: Be sure to install proper protection on the PC against malware (viruses, spyware, worms, etc.). Third party software suites will typically include Firewall, Anti-virus, and Anti-Spyware protection. This software is not included with NPGS, since most research labs will already have a site license for such software. Even if the NPGS PC is not connected to the Internet, protection should be installed, since some malware will propagate through portable USB memory devices.

In addition to doing a "Microscope Installation" on the NPGS PC attached to the microscope, the NPGS CD can also be used for an "Office Installation" on secondary PCs for remote pattern design and run file editing. Note that office installation requires a licensed version of DesignCAD Express v21.2, DesignCAD Express v16.2, or DesignCAD LT2000.

1. **Install the NPGS software.** The installation program "InstallNPGSVersion9.exe" should be run from the supplied NPGS CD. Follow the prompts presented which will install NPGS.

   The "Microscope Installation" of NPGS v9 must be on a PC running 32 bit Windows 2000 Professional, XP Professional, or Windows 7 Professional, while the "Office Installation" can be on...
a PC running Windows* 2000/XP/Vista/Win7/Win8. (*Not all versions are supported. Send e-mail for details.)

NPGS will be installed with the following directory structure:

\NPGS\Program ........................................ Contains all NPGS executables and configuration files that are not to be changed by the user.

\NPGS\BasicCAD ...................................... Contains directories with BasicCAD programs for DesignCAD v21.2 Express, DesignCAD Express v16.2, DesignCAD LT2000 for Windows, and for DesignCAD 6.1 for DOS.

\NPGS\Manual ........................................ Contains copies of the NPGS Manual in PDF and compiled Help formats.

\NPGS\Projects ....................................... Contains the working "Project" directories for user files (patterns, run files, and system files). Also contains a master set of system files that are used when new Projects are created.

\NPGS\Projects\Samples ................................ Contains sample patterns and run files.

\NPGS\Projects\* .................................... This is where all new user Projects will be created.

\NPGS\Temp .......................................... Will contain temporary files created during the operation of NPGS.

\NPGS\Background_Files ......................... Contains background images for the Windows desktop.

\NPGS\DC21Exp ...................................... This is where DesignCAD Express v21.2 must be installed, if used.

\NPGS\DC16Exp ...................................... This is where DesignCAD Express v16.2 must be installed, if used.

\NPGS\DC2000LT .................................... This is where DesignCAD LT 2000 must be installed, if used.

2. **Install the Adobe PDF Reader.** If you want to install a copy of the free Adobe PDF Reader program, run the executable in the "Adobe_PDF_Reader" directory on the NPGS CD. (Adobe, the Adobe logo, Acrobat and Reader are either registered trademarks or trademarks of Adobe Systems Incorporated in the United States and/or other countries.)

3. **Select Windows Background Image.** Desktop background images will be found in the directory "\NPGS\Background_Files" after NPGS is installed. To load one of the NPGS background images to the desktop, right click on the desktop (away from any icons) and select "Personalize" or "Properties" (XP). Click the "Background" or "Desktop" (XP) tab, then browse to the directory where the images are located. Highlight "NPGS_Tile_Dark", select "Tile" for Picture Display, and click "OK". (Loading a background image can be repeated for each Windows user account.)

4. **Optional files from NPGS CD.** Copies of the individual NPGS executables and files are on the NPGS CD under "NPGS_91_Files" (or similar). While these files are not needed during a normal installation, they may be accessed if a file is accidentally deleted later. Also, the NPGS User's Manual can be found in PDF and Compiled HTML formats under "Manual" on the NPGS CD, in the "\NPGS\Manual" directory on the NPGS PC, and they are available under the "Help" option in the NPGS Menu program.
5. **DesignCAD Express v21.2** must be installed in the directory "\NPGS\DC21Exp" which was created by the NPGS Installation program.

   A. If the DesignCAD installation does not auto-load when the CD is inserted, run "setup.exe" on the DesignCAD CD.
   B. After the initial dialog box of the DesignCAD installation program is displayed, click "Install Product", then at the "Welcome..." dialog box, click "Next".
   C. Select the choice to accept the license terms, and again click "Next".
   D. Enter the Name and Organization to be listed for the DesignCAD activation, as well as the DesignCAD Serial number from the DesignCAD CD envelope in the NPGS Installation Guide binder. (The serial number should start with "DEAH").
   E. Select "Install this application for: Anyone who uses this computer (all users)", then click "Next".
   F. **Important**: Use the "Change" button to browse to "\NPGS\DC21Exp".
   G. Remove the check mark from "Display the DesignCAD 21 shortcut on my desktop" box, then click "Next".
   H. Select the "Minimal" choice, then click "Next".
   I. Click the "Install" button.
   J. After the installation is done, click the "Finish" button, then the "Exit" button on the initial dialog box.
   K. **Important**: After DesignCAD is installed, you should remove the "DesignCAD 21" menu choice from the "Start - Programs - DesignCAD 21" menu. For pattern design DesignCAD should only be launched from within the NPGS Menu program. (Also, remove the Desktop icon, if step G above was skipped.)
   L. **Important**: The first time DesignCAD is launched, an activation procedure will be required which is discussed below.

   {If used, **DesignCAD Express v16.2** must be installed in the directory "\NPGS\DC16Exp" which was created by the NPGS Installation program.
   A. If the DesignCAD installation does not auto-load when the CD is inserted, run "setup.exe" on the DesignCAD CD.
   B. After the introductory dialog box of the DesignCAD installation program is displayed, click Next.
   C. Select the choice to accept the license terms, and again click Next.
   D. Enter the Name and Organization to be listed for the DesignCAD activation, as well as the DesignCAD Serial number from the DesignCAD CD envelope in the NPGS Installation Guide binder.
   E. Select "Install this application for: Anyone who uses this computer (all users)", then click Next.
   F. **Important**: Use the "Change" button to browse to "\NPGS\DC16Exp".
   G. Remove the check mark from "Display the DesignCAD Express 16.2 shortcut on my desktop" box, then click Next.
   H. Select the "Minimal" choice, then click Next.
   I. Click "Install" button.
   J. After install, click "Finish" button.
   K. **Important**: After DesignCAD is installed, you should remove the “DesignCAD Express 16” menu choice from the “Start - Programs - DesignCAD Express 16” menu. For pattern design DesignCAD should only be launched from within the NPGS Menu program. (Also, remove the Desktop icon, if step G above was skipped.)
   L. **Important**: The first time DesignCAD Express is launched, an activation procedure will be required which is discussed below.}

   {Note that when installing DesignCAD LT2000 (found only in older systems), virus scanners will indicate that the "encrypt.exe" file in the DesignCAD LT2000 installation is infected with "W95.CIH.remnants". This is **NOT** an active virus. To install DesignCAD LT2000, do the following: 1) Disable the active virus checking; 2) Install DesignCAD LT2000 to the directory \NPGS\DC2000LT; 3) Restart the virus checking; 4) Optionally quarantine or delete the "encrypt.exe" file, since it is not used with NPGS.}

6. No entries in "C:\autoexec.bat" or "C:\config.sys" are required for NPGS v9 or higher.
7. **Information Only**: The autocalibration for the NPGS PCI516 board must be set to run every time Windows launches. Each time the NPGS Menu.exe program is run, it will check to confirm that the file:

```
Initialize_NPGS_PCI516.lnk
```

found in the directory:
```
\NPGS\Projects\%
```

has been copied to the directory:
```
C:\ProgramFiles\Microsoft\Windows\Start Menu\Programs\Startup\%
```

(or for Windows 2000/XP)
```
C:\Documents and Settings\All Users\Start Menu\Programs\Startup\%
```

After this file has been copied, it will calibrate the PCI516 board by running the program 
```
\NPGS\Program\SetDACs  Initialize
```

when Windows launches. (This step is skipped for "Office Installations").

Note that the PCI516 output calibration will run every time the PC is rebooted. This calibration sets the PCI516 board output ranges to the values listed in Pg.sys and does not require any connections to the microscope. A separate writing field calibration is described in detail in section **System Installation: Calibration** (page 10) of this manual. The writing field calibration is typically a one-time procedure, and should not be confused with the PCI516 output calibration.

8. **In order to run NPGS in a non-Administrator login under XP, Vista, or Window 7 (Professional versions)**, you must set the file permissions for the NPGS directory to allow other users to have full access to the files. Using Windows Explorer, select the NPGS directory, right click, then select "Properties". On the "Security" tab, set the file permissions to allow "Full Control" to each user that will run NPGS. Alternately, in some Windows versions, you can give "Full Access" to "Power Users", which will allow anyone with Power User accounts to run NPGS. If the Security tab is not present, go to "Tools" on the Windows Explorer menu, select "Folder Options" then the "View" tab and remove the check from "Use simple file sharing" (at the bottom of the list). After completing this step, the "Security" tab should be modified as described above (hit "View – Refresh" on Windows Explorer, if the Security tab is not initially displayed). An alternate sequence to enable the Security tab is from the Control Panel (Classic View) – Folder Options – View tab or Control Panel (Category View) – Appearance and Themes – Folder Options – View tab. Also, if using a non-US version of Windows, set the decimal character to a period.

9. If the NPGS PC is connected to a network with a Domain Administrator, the Domain Administrator may have implemented restrictions that will prevent some parts of NPGS from working. When this happens, the Domain Administrator must remove the restrictions from the NPGS PC.

10. **The "Standby/Suspend/Sleep/Hibernate" modes of Windows should be disabled**. In Win7, create a ‘theme’ named "NPGS Settings" that does not allow the PC to enter these modes. Start by right clicking on the desktop and select “Personalize”, then select ‘Screen Saver’, then select ‘Change power settings’, then select ‘Create a power plan’. Select ‘Balanced’ and enter ‘NPGS Power’ for the name, then click ‘Next’. For ‘Turn Off Display’ enter a value such as 45 minutes. For ‘Put the computer to sleep’ select ‘Never’. Click ‘Save’ then close the remaining window. Once the desired power settings are entered, click on the ‘Save theme’ link under ‘My Themes’. (This step is skipped for "Office Installations").

In XP, right click on the desktop and select "Properties", then the "Screen Saver" tab, and then the "Power..." button under the "Energy saving features of monitor" heading. Either select the "Always On" option for the "Power scheme", or set the "System standby option to "Never", then click "Apply". (This step should be repeated for each Windows user account. For a non-administrator account, you may have to change the account type to administrator, make this change to the Power setting, then change the account back to a limited account.)

11. If doing an "Office Installation", be sure to modify the "mag scale" parameter in the "Pg.sys" file in each project on the office PC, so that the mag scale value is the same as is being used on the "Microscope Installation" of NPGS.
12. The NPGS software is now loaded. **The NPGS Menu.exe icon can be used to launch NPGS.**

   In Win7, right click on the NPGS Menu icon and select ‘Run as Administrator’ to launch NPGS. Doing this one time will allow the required change to be made, so that the prompt will not be displayed each time NPGS starts.

   The first time Menu.exe is run, a prompt will be displayed indicating that the file listed in Step 7 will be copied automatically. Subsequently, the warning will not be displayed, as long as the file is found in the proper location.

13. **Important: Click the <User Notes> Button in the NPGS Menu program.** This will display a text file that can be used to share notes between users. Also, it includes notes about the specific NPGS installation for the system in use.

14. **Check the memory setting for NPGS.** Double click the "NPGS Menu" icon, then use "Options - System Files - Pg.sys" to check the "max memory" parameter (third entry in the "Miscellaneous Parameters" section near the end of the file). This parameter specifies the maximum memory that will be used by NPGS to store exposure points during pattern writing and must be less than the total PC memory. The maximum value that can be entered is 1024, which can be used if the PC has over 2 GB of RAM. If the PC has less than 2 GB, set the value accordingly, such that it does not exceed the available memory and should leave memory for other programs. After making a change in the System File Editor, select "File - Save as defaults" to make the change be the default for all new Projects that are created within NPGS.

15. **Very Important: DesignCAD Express Activation.** (This step may need to be repeated for each Windows 7 login.) Until DesignCAD v21.2 is activated, the "DesignCAD: Program Activation Required" dialog box will be displayed each time DesignCAD is started. The Activation Code that corresponds to the Serial Number must be entered. The Activation Code will normally be found on the CD envelope. Each Serial Number / Activation Code is to be used on only one PC at a time. Once the activation code is entered into the dialog box, click 'Activate'. **As a security measure implemented by the makers of DesignCAD, the activation codes will expire after 6 months from when they were originally issued.** If a notice is displayed saying that the activation code has expired, a button on the screen can be used to immediately get a new activation code, if the PC has Internet access. Otherwise, send the serial number and expired activation code to info@jcnabity.com for assistance. **Once DesignCAD is installed, the software does not expire and will continue to run without needing any subsequent activation codes.**

   The first time DesignCAD v21.2 is launched from within NPGS, a message will be displayed that reminds you to close, then restart DesignCAD to complete the initialization for use with NPGS.

   {If using DesignCAD Express v16.2, the program will need to be activated. In this case, if the activation code is not on the CD envelope, a code may be obtained through an Internet option on the activation dialog box.}

   {If using DesignCAD LT 2000 (for an older installation), install fonts: For Windows XP or 2000, go to the Control Panel and select the Fonts option (switch to Classic View, if needed). Select “File - Install New Font…”, browse to the Windows Fonts directory (typically: \Windows\Fonts), select Simplex and Simplex2, then click OK. For Windows 98 and earlier, you can use Windows Explorer, go to the Windows Fonts directory, and double click on each of the following fonts: Simplex.ttf and Simplex2.ttf, then click "Done" when the font is displayed. This will load the fonts in Windows for use within DesignCAD for pattern design. (To make the files easy to find, click on "Modified" in Windows Explorer to sort the listing by date to have these fonts grouped together at 8/18/2000, 8:00AM.) Note that these fonts are very narrow, which will produce text that looks like single lines, while most Windows fonts will produce an outline of the characters when written as vectors by NPGS.}

16. **Turn any off extra toolboxes on left side of DesignCAD Express display.** There should be two (2) columns of toolboxes to the left of the vertical ruler on the left side of the DesignCAD
Express display. If there are four (4), right click on any one of the columns and turn off the check mark by the “Main Toolbox” and “Snap Toolbox”. The “NPGS Main” and “NPGS Menu” toolboxes have the commands that will be most useful for pattern design and should be used instead. Also, the DesignCAD “Color Toolbox” can be useful to have turned on, but the main “Toolbar” should be left turned off.

{If DesignCAD fails to launch properly after being activated, close the program, and restart it through the DesignCAD Express button in NPGS. In some cases, an error may be generated or the menus on the left may not be initially displayed properly. Any such problems should not persist after one or two launches.}

17. If installing NPGS for use on a dual column microscope such as the Zeiss 1540 Crossbeam, Zeiss Auriga, FEI Nova Nanolab, FEI Helios NanoLab, FEI Quanta3D, or FEI DualBeam 235/237/620/810/820 for dual e/i beam use with NPGS, at least one NPGS Project directory must be created for the FIB use. (The default "Sample" project will be automatically created for e-beam use.) This is a one-time procedure and an easier method will be available for creating new FIB projects once the following steps are completed.

A. From within the NPGS Menu Program, run "Project - Create New Project". For the new project name, enter "FIB_Samples" (or similar). It is suggested to have FIB projects clearly indicated to avoid confusion with e-beam projects.

B. Close the NPGS Menu.exe program.

C. Next, copy the files in the directory "Crossbeam_FIB_Files", "Nova_FIB_Files", "Helios_FIB_Files", "Quanta3D_FIB_Files", "DB235_FIB_Files", "DB620_FIB_Files" or similar on the NPGS Installation CD to the FIB project that has been created.

D. Whenever switching between NPGS control of the FIB or control of the e-beam, the "Cal for I Beam" or "Cal for E Beam" buttons within the appropriate project must be run, if the two columns have different X, Y, and Blanker voltage settings in Pg.sys. These buttons will send the command to switch the relay boxes as needed and will also calibrate the NPGS DACs for the current project.

E. When creating new FIB projects, click the "Create New FIB Project" button and follow the instructions.

Notes regarding Windows 7 Professional (and Vista):

1. The Windows User Account Control (UAC) feature will display user confirmation prompts during the installation of NPGS. Always select the choice to allow NPGS to make changes to the system or you may also choose to turn off the UAC feature completely.

2. Note that selecting a desktop ‘Theme’ in Win7 can change the settings for putting the PC in ‘standby’ or ‘hibernation’ modes, as well as the power control settings for the hard disk and display. An “NPGS Settings” theme should be made to ensure proper settings are used.

3. Microsoft does not include support for the Windows WinHelp32 (.hlp) file format. This format is used for the popup help in NPGS which is very useful, since it provides answers to most new user questions. The following web sites have a free download from Microsoft which will add the WinHelp support under Vista and Windows 7:

   http://support.microsoft.com/kb/917607  - Info and Download Links

   To download WinHlp32.exe for Win 7:
   http://go.microsoft.com/fwlink/?LinkId=166421

   To download WinHlp32.exe for Vista:
Download the “x86” version to use with 32 bit Windows.

4. For a Microscope installation of NPGS, note that any programs to communicate with the microscope or a stage must be tested under the Windows 7 version to be used. Some microscopes have driver software which may not be compatible with the latest versions of Windows 7.

**Notes regarding Windows XP Professional:**

1. **When installing NPGS using a non-US version of Windows XP,** problems may be encountered. The French version of XP Pro requires that the decimal character be set to a period, instead of the default comma, while the Italian version has a different problem that has yet to be resolved. NPGS works properly in the US version of Windows XP and in all versions of Windows 2000 that have been tested.

2. **XP Pro SP2 released between about January 2006 and June 2006:** Microsoft discovered a bug in the Windows processing of help files in the compiled HTML format which could allow unauthorized access and control of the PC through a network. Their short term solution was to disable common types of hyperlinks when any compiled HTML help file is displayed (this even affects the Microsoft help files distributed with XP). This change does affect the HTML help file for NPGS. While the contents of the help file can still be viewed, ordinary hyperlinks within the file no longer function. The PDF version of the NPGS manual is not affected. Recent releases of XP Pro do not have this limitation.

3. **XP Pro SP2:** A new Windows feature called “Data Execution Protection” may prevent some programs from running correctly. Searching the Windows Help (from “Start – Help and Support”) for “DEP” will bring up topics that describe how to disable DEP or how to selectively disable it for individual programs. This has not been a problem for NPGS programs, but this information is provided here to help avoid problems with other programs under XP.

**System Installation: Hardware Overview**

Specific instructions for the installation of NPGS are given in the "NPGS Installation Guide" provided with the system. An overview of the NPGS/SEM configuration for NPGS v9 is shown below. **See Calibrating the PCI516 (page 211) for important information.**
Required Connections (bold arrows):

- Analog XY Inputs (±5v to ±10v range typical, other ranges can be supported; ≥1 kΩ input impedance, typical ≥5 kΩ.)
- Picoammeter; A picoammeter that can read the beam current hitting the sample is required for lithography. Typically, an external picoammeter is connected to the specimen current output from the microscope stage, or less often, a picoammeter will be built into the microscope. In either case, the picoammeter is usually not directly connected to NPGS.

Typical Connections (thin arrows):

- Image Signal (within ±10v)
- Blanker (within ±5v, ≤100 mA); fast blankers, slow shutters, and systems with no blankers are all supported.

Optional Connections (dashed arrows):

- Automated Stage; Interface programs for several common automated stages are available at no charge.
- Digital SEM Control for automatic setting of the magnification, focus, etc.
- Faraday Cup for automated beam current reading and compensation: NPGS can optionally be connected to control a Faraday cup and/or read from a picoammeter, but most systems will have a manually controlled Faraday cup and picoammeter.

PC Requirements for NPGS v9.1:

Windows* 2000/XP/Vista/Win7/Win8 for Office Installation (some restrictions apply).
One PCI slot for NPGS PCI516 board.
CD for installing NPGS.
Serial/Ethernet connections for communicating with SEM and/or stage (optional).

Related Topic: SEM Input Connectors (page 211)

System Installation: Calibration

Absolute Pattern Size

The following procedure describes how to set the absolute scaling of NPGS to ±1% of the absolute scaling of the microscope. If the microscope needs to be calibrated contact the microscope service representative. To obtain a more precise calibration at a higher magnification, the same procedure can be used, but the user must supply an accurate calibration standard and design a pattern similar to "SCALE1.dc2" that matches the standard.

1. This step is most important for Zeiss and older FEI and LEO models that have multiple magnification display modes which may change the corresponding NPGS absolute pattern size by up to a factor of ~3. In normal imaging mode, set the microscope magnification to 100,000x and measure the approximate width of the image on the microscope display. If the width is near 1 micron, set the 'mag scale' value in Pg.sys to 100,000, if the width is near 2 microns, set 'mag scale' to 200,000. For other widths, set 'mag scale' accordingly. This will get the absolute pattern size correct to 10% or 20%.

2. Next, confirm that the NPGS Y output range is set to the maximum allowed input range for the microscope (see "y_mode" and "y_range" in Pg.sys). Do not connect NPGS to the microscope unless the maximum X and Y voltage output ranges from NPGS are below the safe input voltage ranges for the microscope as described in the documentation for your microscope.

3. Mount one of the supplied copper foil calibration standards and put it into the microscope for viewing with the grid bars aligned horizontally on the microscope display screen and optimize the microscope at the typical settings for lithography (usually 30 kV, 5 to 10 mm WD, and 5 to 50 pA of current). Focus on the edge of a grid bar. This is essential in order to get the correct size calibration. If using a PC based microscope, check the "Magnification Calibration" setting in the microscope software, since the value specified must be used for all subsequent lithography. Basically, it does not matter what the microscope magnification calibration is set to, i.e., Display, Polaroid, or VideoPrinter, as long as the setting used during the following calibration is always used for lithography.

4. Change the system to pattern writing mode* and process the run file: "scale1" (found in the "Samples" project) with the calibration standard in view at 200x. (If using an analog SEM, the SEM brightness should be at a low value before changing to the external scan to avoid burning the CRT.) This alignment pattern has a single window in the form of a square frame and the overlay consists of a square with side lengths of 250 μm. See "System Installation: Summary - Check List (page 13)" for color images. A frame is used rather than a filled square for two reasons: 1) To reduce the time needed to acquire the image; 2) To make the scan direction parallel to each side of the structure that will be imaged. The bars are 40 μm and the spaces are 85 μm, therefore, 2 bars and 2 spaces will fit into the highlighted box at 200x when the calibration is correct. (At 100x, 4 bars and 4 spaces will fit.)

*Setting the system to pattern writing mode normally involves selecting external control for the XY scanning of the microscope. This is often done using a manual NPGS/SEM switch box, through software on the microscope, or with the NPGS Remote Enable Switch through software on the NPGS PC. Also, the microscope's blanker may need to be set to external control, usually with a switch on the blanker electronics.
Use the AL command 'a' to autocontrast the image, 'p' to set the pixel size to 1, and use 'c' to set the center-to-center spacing to a high number for coarse alignment and a low number for fine alignment. The AL command '?' will display a brief explanation for all the keystroke commands that are available. (Clicking any of the keystroke commands displayed in the upper left part of the AL screen will run the command.)

If no structure is visible in the image after a full scan and after the 'a' key is hit, the voltage levels going into the "Input" SMA connector on the PCI516 board should be checked. The maximum levels should be between ±10 volts and the minimum voltage change between a black image and white image should be about 0.5 volts. The range in the DATA values correspond to the input voltage where each integer represents 0.3 mV. Consequently, a difference of 1000 between the low and high DATA values indicates a 0.3 volt range in the input voltages.

While viewing the copper grid on the NPGS PC screen, hit "s" on the NPGS keyboard so that "SEM Mode (Overwrite)" is displayed on the NPGS PC screen. This mode causes NPGS to overwrite each scan of the image. It is then useful to change the microscope parameters to see which ones affect the image. For example, the scan rotation should rotate the image and the electronic image shift controls should offset the image. Any microscope parameter that changes the display during the calibration will also have an effect during pattern writing, so this is a good chance to learn which microscope settings are important! See "System Installation: Summary - Check List (page 13)" for more information.

5. If necessary, use the scan rotation (or stage rotation) to make the bars parallel to the overlay lines. (The AL command 'o' should be used to overwrite the previous image after any change in the scan rotation or sample position.) Use the 'Ins' key to select between "Window=ALL" and "Window=MAG". When in the "ALL" mode, the arrow keys will change the position of the overlay, and in the "MAG" mode, the arrow keys will change the size of the overlay. Use the arrow keys while switching between "Window=ALL" and "Window=MAG" until the top and bottom lines of the overlay are aligned such that 2 bars and 2 spaces fit between the horizontal overlay lines (to within one screen pixel). There is no need to align to the vertical overlay lines at this time. (See the "After Absolute Size" image in the "Summary / Checklist" section.) Note that there is a minimum and maximum allowed change for the overlay magnification (0.5x to 2x). Consequently, if the overlay cannot be made to match the grid size, stop at the allowed magnification limit, and continue with the next step. Subsequently, when the process is repeated, it will be possible to make the overlay match the grid.

6. Hit SPACE BAR to calculate the new magnification. If an error message is displayed when the space bar is hit, it means that the "mag scale" value presently being used too far from the correct value to allow the system to be calibrated in a single step. In this case, repeat the previous step, but position the overlay bars such that an error is not displayed, then continue to the next step. When the entire process is repeated, an accurate alignment of the bars as explained in the previous step should be possible.

7. Hit "Ctl-E" to run Pg_Edit to modify the "mag scale" value in Pg.sys. At the top of the AL screen, the new value for the "mag scale" will be displayed, if needed. Enter the new value for the 'mag scale' parameter in Pg.sys, then click "Save" and "Exit" to return to AL. (If the standard feature originally appeared larger than the designed distance, "mag scale" will decrease, and if the standard feature originally appeared smaller, "mag scale" will increase.) Note that changing the "mag scale" parameter does not change the actual point spacing on the sample, but only tells NPGS what the spacing actually is.

8. Process the run file "scale1" again and verify that the vertical size of the highlighted box matches the known feature size. If the match is not satisfactory, repeat the steps 3 to 7. To restart AL, follow the instructions that are displayed after Pg_Edit is closed, or return to step 3.

9. If the "mag scale" parameter has been changed, it should be updated in all "Pg.sys" files. They are found in "\NPGS\Projects", "\NPGS\Projects\Samples", and in each project directory created by the user. Note that from within Pg_Edit, clicking "File - Save as Default" will copy the
Introduction to NPGS

NPGS: System Installation

Currently displayed system file to the master set of system files in "NPGS\Projects" and clicking "File - Load Defaults" will copy the corresponding master file to the current project.

Also, the "mag scale" value must be copied to the projects in any "Office Installations" of NPGS, so that run files made in the office installations will have the correct calibration for use on the microscope.

**Aspect Ratio**

By correctly setting the vertical size the absolute scaling has been determined. To correctly set the aspect ratio use the following procedure.

1. Bring the microscope to normal operating conditions while viewing the supplied copper foil calibration standard with the grid bars aligned vertically on the CRT. **Focus on the edge of a grid bar. This is essential in order to get the correct size calibration.**

2. Change the system to pattern writing mode and process the run file "scale1" with the microscope at 200x. Use the AL command 's' to enter the alignment "SEM" mode, the command 'p' to set the pixel size to 1, and the command 'c' to select the point spacing. A larger point spacing is useful for coarse alignment and a smaller spacing is better for fine alignment.

3. **Once an image of the calibration grid is acquired, hit "Ctl-X" to enter the X adjustment mode.** Adjust the X voltage range until 2 bars and 2 spaces fit into the highlighted box in the viewing window. (The bars should already fit in the vertical direction if the Absolute Pattern Size calibration was done properly.) If necessary, the x and y microscope scan shift controls may be used to make the image line up or mouse can be used to drag the overlay on the AL screen. Do not change the magnification within AL. Note that changing the aspect ratio actually changes the grid point spacing in the horizontal direction. **Do NOT set the X voltage range to a value greater than the maximum allowed X input for the microscope.**

4. After adjusting the X voltage range, hit Enter to terminate the X adjustment mode, then hit Enter again to modify Pg.sys. After making the change to the 'x_range' value in Pg.sys, click "Save" and "Exit".

5. After Pg.sys is saved, hit Enter to have AL recalibrate the board with the new range. (AL does not need to be restarted to verify the results of the Aspect Ratio calibration.)

Note: Whenever the X or Y range is changed, the PCI516 board must be recalibrated to make the change take effect. This can be done manually using the "Commands - Calibrate DACs" function from within the NPGS Menu program.

6. **IMPORTANT** If any parameters in Pg.sys have been changed, ALL "Pg.sys" files must be updated. Copies of Pg.sys are found in "NPGS\Projects\Samples","NPGS\Projects", and in each project directory created by the user. Note that from within Pg_Edit (use "Options – System Files – Pg.sys"), clicking "File - Save as Default" will copy the currently displayed system file to the master set of system files in "NPGS\Projects" and clicking "File - Load Defaults" will copy the corresponding master file to the current project. After finishing the calibration, the Pg.sys file with the correct values should be saved as the default, so that all projects that are created later will be initialized with the proper values.

Note: On many microscopes, the final X voltage range that produces a square writing field will have a value that is about ¾ of the Y voltage range.

Note: On microscopes where the nominal ranges for both X and Y are near +/-10 volts or near +/-5 volts, it may be necessary to leave the X range at the maximum allowed voltage range and reduce the Y range to get the proper aspect ratio. In such a case, the Absolute Size and Aspect Ratio procedures should be performed, however, all references to X, Y, horizontal, and vertical should be
interpreted as $Y$, $X$, vertical and horizontal, respectively. In addition, the $X$ and/or $Y$ mode and ranges in Pg.sys may need to be changed to put the appropriate $X'$/$Y'$ voltage into the variable mode.

**System Installation: Summary - Check List**

The following items should be checked and/or recorded during the NPGS installation. By recording the following parameters, you will have a reference that can be very useful in future years in case the performance of the microscope degrades.

**Initial Test:**
After the NPGS hardware is connected to the microscope, the microscope should be set to the external control mode for the XY scanning and the "Commands - Digital Imaging" function in the NPGS Menu program can be used to acquire a digital image using the Pg_Image program. From within Pg_Image, click on "File - New Scan" (or the blank paper icon), set the Magnification value to match the microscope's magnification, and click "Acquire Image".

If an image appears, it confirms that NPGS is driving the scan coils of the microscope and that the image signal is being acquired. If the NPGS calibration has been done correctly, the scale bar on the image will be correct. You can also right-click on the image to set crosshairs to make measurements. Note that the crosshair markers can be dragged on the screen after they are set. Also, if a sample with features of known size is imaged, the Digital Imaging program can be used to determine the approximate value of the "mag scale" scale value that should be entered in Pg.sys.

If the image is upside-down or is a mirror image, the "xy mirror" parameter in Pg.sys (use "Options – System Files… - Pg.sys" in the NPGS Menu program) needs to be changed.

If no real image is acquired, i.e., only a speckled gray image is seen, right-click on the image and then click "Image Data Histogram". This will display a histogram of the pixel intensities in the acquired image. The data values displayed indicate the voltages acquired by the ADC, where +/-32,768 will typically correspond to +/- 10 volts of signal (the voltage range is set in Pg.sys). If the data range is small (<20) and near zero, it indicates that there is no significant image signal. In that case, you should first confirm that the beam is not being blanked either by a magnetic blanker controlled through the microscope’s software or by an external electrostatic blanker. (A picoammeter connected to the Specimen Current Output can be used to confirm if the beam is hitting the sample.) If the beam is hitting the sample during the image acquisition, the next step is to check the Image cable between NPGS and the microscope and/or confirm the presence of the image signal output using an oscilloscope. If the histogram shows a small range, but is significantly away from zero, or if the image has dislocated stripes, it typically indicates a good image signal, but that the XY scanning is not under the control of NPGS. In that case, check the XY cables between NPGS and the microscope and confirm that the microscope is set to external XY control. For most microscopes, the image signal will have a range of ~1 volt to ~5 volts, which corresponds to ~3,000 to ~15,000 units in the palette range.

**SEM Settings:**
While imaging the calibration grid as done in the NPGS calibration procedure (in the 's' mode which will cause each image scan to overwrite the previous scan), check if the following affect the image displayed by NPGS. The typical response is listed in ()'s. Note that any microscope setting that changes the displayed NPGS calibration will have a similar effect when patterns are written, so it is very helpful to do real time tests using the calibration image, rather than finding problems after patterns have been written. It is recommended that a consistent set of microscope parameters be used for the NPGS calibration and subsequent pattern writing.

- Magnification (yes). The microscope magnification setting must match the magnification value in the NPGS run file, otherwise the writing size will not be correct.
- Microscope scan speed (maybe). In some cases, the fastest scan rate will change the calibration (typically for Hitachi SEMs).
- Reduced scan (maybe). On many microscopes, this mode will also reduce the NPGS writing area.
- Image offset (yes). This can be useful during alignment.
- Scan rotation (yes). This can be useful for lithography.
- Spot Mode (maybe). Often the XY input is disabled in spot mode.
• Dynamic Focus (yes). This mode dynamically changes the focus along the scan axis in the tilted direction and should never be enabled during lithography, unless you have a special application where you are intentionally writing along a tilted surface.
• Tilt Correction (yes). This mode reduces the scan field size along the scan axis in the tilted direction and should never be enabled during lithography, unless you have a special application where you are intentionally writing along a tilted surface.
• Microscope Magnification Mode (yes). PC based microscopes only.

Calibration Images:
The images below display what is seen during the calibration when the "scale1" run file is processed. In these images, the center black square and the outer black edge are the black background of the alignment program display screen. The center area is not scanned in order to reduce the total scan time. The square "frame" of color is the area of the image acquired from the calibration grid. Superimposed on the image is a square yellow marker that is one pixel wide.

After Absolute Size Calibration

The image above shows a typical view after the Absolute Size Calibration has been finished. In this case, it can be seen that two bars and two spaces from the copper calibration grid fit within the two horizontal lines of the marker. (Between the vertical lines the grid doesn't line up properly, because the Aspect Ratio Calibration has not yet been performed.)

After Full Calibration

The second image shows the result after both the Absolute Size and the Aspect Ratio Calibration has also been completed. Notice that in both directions, two bars and two spaces of the copper grid fit within the superimposed marker when the microscope is at 200x.
SEM Configuration:
"Mag Scale" from pg.sys*: ...................... ____________________

(Once calibrated, the "mag scale" parameter is the product of the side length of the square writing field and the magnification of the microscope. By knowing the mag scale, NPGS or the user can calculate the writing field for any magnification by dividing the mag scale value by the magnification. See the section below on determining the optimum magnifications for pattern writing.)

SEM Magnification Mode**: .................... ____________________

(**This only applies to PC based microscopes. Typical settings are: Display, VideoPrinter, Printer, or Polaroid, and will be found in a sub-menu in the microscope software. The setting used for the NPGS calibration must be used for all pattern writing. On new FEI models, the mag mode depends on if full screen or quad display mode is used on the microscope.)

X voltage range***: ..................... ____________________
Y voltage range***: ..................... ____________________

(***Usually, the X voltage range will be adjusted while the Y voltage will be fixed at either ±5 or ±10 volts. However, in some cases, the X voltage should be fixed and the Y voltage adjusted in order to get the proper aspect ratio. In these cases, the System Calibration in section 3 should be followed, but all references to X and Y should be reversed.)

"XY Mirror" from pg.sys****: .................... ____________________

(****It is reasonable to assume that positive x,y voltages will move the beam in the upper right quadrant of the writing field, however, that is typically not the case. This value allows NPGS to write patterns so that the orientation in the CAD program is the same as what is written on the sample, which is accomplished by automatically flipping the polarity of the output voltages from NPGS, as needed. If patterns are written with a mirror image in x or y, or they are rotated by 180 degrees, this value must be changed. Note that the polarity of the voltages measured at the NPGS XY outputs may not match the signs of the values entered in the NPGS "SetDACs" function, depending on the value of the xy_mirror parameter. Most microscopes will require the polarity of either the x or y voltage to be reversed. When the xy_mirror parameter is properly set, features seen when running the NPGS alignment or the NPGS Digital Imaging program will appear with the same orientation as seen on the microscope display. Note that when a digital image is acquired using the NPGS software, if the acquired image looks correct, then it demonstrates that the X, Y, and Image connections to the microscope are functioning as expected.)

Location of XY inputs: ............................ ____________________

Video Output range*****: ......................... ____________________

(*****The maximum readable ADC input range for NPGS v9 or higher is ±10 volts. When using the PCI516 board with NPGS v9 or higher, the maximum safe input voltage is ±15 volts. The ADC input range can be selected in Pg.sys. If the microscope output is greater than ±10 volts, a BNC tee and a 50 to 100 ohm terminator can typically be connected at the cable to reduce the voltage or an inline 50 ohm SMA terminator can be used with NPGS v9.)

Magnification Settings:
Examples of magnification values where the microscope scan coil circuitry changes ranges are shown below. While the range changes have a minor impact on imaging, they are important for lithography, because the low end of each range gives the best signal-to-noise within the microscope and the best lithography will be obtained at a magnification at or above the transition value. In one case, it was seen that the best lines written using a magnification value on the good side of the transition were one half the size of the best lines written on the bad side.
The values shown below have been observed for the models and operating conditions specified, however, the user is always encouraged to check their microscope at their operating conditions to confirm the values of the magnification transitions. See Notes 1-3 below for the typical artifacts used to determine the transition values.

For most PC based microscopes, the transition values will depend on the "SEM Magnification Calibration Mode" as discussed above, but the actual field sizes at the transitions will not. For microscopes where the magnification range transitions depend on the working distance and kV, you should be especially careful about knowing where the transitions occur, since being at the wrong end of the range can make a significant difference in the lithography performance of the microscope. For the best lithography, the magnification should be set just above one of the transition values, as determined for your microscope. Typically, for the finest lines, the ideal magnification will give a writing field between 50 to ~100 microns square, depending on the microscope being used. The "mag scale" parameter can be used to determine the writing field for any magnification, as discussed above.

<table>
<thead>
<tr>
<th>Microscope</th>
<th>Magnification Ranges</th>
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<tbody>
<tr>
<td>Amray 1400:</td>
<td>200x - 2000x - 20,000x</td>
</tr>
<tr>
<td>Cambridge 360:</td>
<td>165x - 1650x - 16,500x - 165,000x (for 30 kV, 7 mm WD)</td>
</tr>
<tr>
<td>FEI XL30 SFEG/Sirion:</td>
<td>400x/450x - 1450x/1750x - 155kx (for 30 kV, 6 mm WD, Display Mode)</td>
</tr>
<tr>
<td></td>
<td>120x/135x - 460x/510x (for 30 kV, 7.5 mm WD, VideoPrinter Mode)</td>
</tr>
<tr>
<td>FEI XL30 FEG/ESEM FEG:</td>
<td>730x/810x - 3800x/4200x - 60kx (for 30 kV, 7 mm WD, Display Mode)</td>
</tr>
<tr>
<td></td>
<td>365x - 1810x/2010x (for 30 kV, 7.5 mm WD, Photo Mode)</td>
</tr>
<tr>
<td>FEI Quanta FEG:</td>
<td>93x/115x - 370x/460x - 1480x/1840x - 7kx - 25kx - 100kx - 400kx (for 30 kV, 7 mm WD, Quad mode)</td>
</tr>
<tr>
<td>FEI Helios E-Beam:</td>
<td>1750x (for 30 kV, 6 mm WD, Quad mode)</td>
</tr>
<tr>
<td>Hitachi 3000:</td>
<td>70x - 700x - 7,000x - 70,000x (for 30 kV, 7.4 mm WD)</td>
</tr>
<tr>
<td>Hitachi 4100:</td>
<td>350x - 3500x - 35,000x (for 30 kV, 10 mm WD)</td>
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<tr>
<td>Hitachi 47/4800 (HM):</td>
<td>900x - 8,000x - 80,000x (for 30 kV, 7.0 mm WD)</td>
</tr>
<tr>
<td>Hitachi 47/4800 (LM):</td>
<td>35x - 80x - 800x (for 30 kV, 7.0 mm WD)</td>
</tr>
<tr>
<td>Hitachi SU70 (HM):</td>
<td>1000x_{min} - 8,000x - 80,000x (for 30kV, 7.0 mm WD)</td>
</tr>
<tr>
<td>Hitachi SU70 (LM):</td>
<td>35x_{min} - 60x - 600x - 2kx_{max} (for 30kV, 7.0 mm WD)</td>
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<tr>
<td>JEOL 840,61/63/6400:</td>
<td>100x - 1000x - 10,000x - 100,000x</td>
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<td>JEOL 5900/6360:</td>
<td>500x - 5,000x - 50,000x</td>
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<tr>
<td>JEOL 6460:</td>
<td>330x - 3,300x - 33,000x</td>
</tr>
<tr>
<td>JEOL 6500F/7000F/7001F:</td>
<td>80x - 800x - 8,000x - 80,000x (for 30 kV, 7.0 mm WD)</td>
</tr>
<tr>
<td>JEOL 7600F (HM):</td>
<td>500x_{min} - 550x - 5,500x - 55,000x (for 30kV, 8.0 mm WD)</td>
</tr>
</tbody>
</table>
Zeiss/LEO 1500’s/Supra/Ultra: 1247 .......... 1440x - 43,500x (for 30kV, 6 mm WD, Printer Mode)  
.......................................................... 594x - 18,000x (for 30kV, 6 mm WD, Polaroid Mode)

Zeiss/LEO 1400’s/Evo: 1247 ...................... 922 - 24,500x (for 30 kV, 7.4 mm WD)

Zeiss Orion: ....................................... 45 um FOV/~2,800x - 3 um FOV/~42,00x  
................................................................ (for 38kV, 9.9 mm WD, Polaroid Mode)

Other: ...................................................... __________________________________

Notes:
1) Has an audible "click" at each transition.
2) Has a "glitch" on screen at each transition. (At a slow scan speed, the “glitch” may only distort a few rows of pixels on the screen. At a fast scan speed, a band which is 1 or 2 cm tall may be seen where the sample is actually imaged at a much lower magnification. This second effect is most obvious when imaging a sample such as the copper calibration grid supplied with NPGS.)
3) A slow scan will restart at each transition.
4) These values depend on working distance and kV.
5) These values depend on if the magnification is being increased or decreased.
6) These values have not been confirmed, since no click or glitch is observed.
7) For PC based SEMs with a user selectable "Magnification Calibration Mode", the transition values shown above may change by ~2x to ~2.5x, depending on the calibration mode selected. Note that the “Display” mode is actually scaled to the size of the monitor. For example, the Display mode values will change if a 17” or 21” display is used and the Display mode is properly calibrated. The important issue is to know where the transitions occur for the settings being used during lithography on your microscope, so the numbers above are to be used only as a general guide.

Writing Field Size vs. Magnification:
Once calibrated as previously discussed, the "mag scale" parameter in Pg.sys defines the numerical relationship between the microscope's magnification and the writing field used by NPGS. Quite simply, the "mag scale" parameter is the product of the microscope's magnification value and the side length of the square writing field used by NPGS. For example, if the "mag scale" is 90,000, then a magnification of 1000x will have a square writing field of 100x100 um².

However, the "Magnification Settings" section above discusses the magnification transition values for common microscopes, where the lower end of the ranges will always give the best signal to noise for pattern writing. When deciding on the magnification to use when writing the finest linewidths, the two most important factors are where the magnification being used falls with respect to the magnification ranges of the microscope and the size of the writing field with respect to the 16 bit resolution of the DACs. In general, to write the finest lines, it is best to select a magnification that is at the low end of the magnification range, but with an actual field size of ~120x120 um² or smaller.

For example, for the older JEOL microscopes where the magnification ranges are always at 100x, 1000x, 10000x, etc., and the "mag scale" is always near 90,000, a magnification of 1,000x is best, since it gives the best signal to noise and the field size is 90 um, which gives a smallest DAC positioning of ~1.4 nm (90/65536). For most microscopes, a magnification at the low end of one of the ranges will give a field size of ~100 um, which is best for doing fine lithography.

In the cases where the smallest magnification in the range gives a field size of above ~120 um, it is recommended to use a magnification with a field size of ~120 um or smaller, so that the DAC resolution will be compatible with fine writing. In the cases where the smallest magnification in the range gives a field size of ~50 um, the highest resolution writing should be done with this small field size, but a field size of ~100 um should be checked to see if the writing resolution will give the feature sizes that are needed.

Origin Offset:
Typically, when a magnification change crosses a transition as described above, the origin of the imaging and pattern writing field will shift, and sometimes shifts will be seen without crossing a transition. The run file "Chk_Off1.rf6" in the Samples project can be used to check the offset between...
two different magnifications. Often, the shift when changing from a small writing field size for fine feature to a large field for big features will be on the order of 5 microns. When lithography is to be done using two such magnifications, the "Origin Offset" parameter in a run file can be used to compensate for the microscope's offset. Note that the "Chk_Off1.rf6" run file should be modified to use the two magnifications of interest for the microscope and writing that is to be done. Also, the same test can be used when the beam current (or spot size) is changed in addition to the magnification.

Origin Offset* from 1000x to 100x: ........ _________________

Scan Rotation:
The scan rotation feature of an microscope is very useful for lithography, since it rotates the image (and writing axes) about the center of the writing field. However, for most microscopes, using the scan rotation will introduce an error in the writing field size aspect ratio calibration of about 1 to 3%. Any change can easily be measured by testing scan rotations of 0, 90, 180, and 270 degrees during the NPGS calibration procedure. (Once NPGS is calibrated at 0 degrees, changing the scan rotation by 90 degree increments should ideally not change the calibration, but will change the apparent x,y offset.). Typically, the error introduced by the microscope's scan rotation will be small enough to ignore, but it may be important in some applications.

Aspect Ratio Change
for Scan Rotation: ________________________________

For old microscopes, if there is an analog knob for adjusting the scan rotation, the potentiometer attached to the knob may have oxidized over time, which will result in "glitches" in the image while the knob is adjusted. A quick solution that often helps is to quickly turn the knob back and forth many times, which can wipe away the oxidation.

For Automated Stage:
For many common automated stages, a program is provided at no charge with NPGS that will communicate with the stage. In that case, please see the separate documentation that is provided for additional information regarding the use of an automated stage with NPGS.

X scaling factor* in pg_stg.sys: ............ _____________________

Y scaling factor* in pg_stg.sys: ............ _____________________

(*The magnitude of the scaling factors will be 1.0, if the stage driver accepts x,y distances in microns, and they will be 0.001, if the driver accepts distances in millimeters. The sign of the scaling factor performs a function similar to the XY Mirror parameter discussed above, namely, it makes sure that when NPGS wants the stage to move to the upper right, that the stage will move in the correct direction. In NPGS, all stage movements are entered as relative moves, where a positive x value means that the location for the pattern writing after the move will be to the right of the previous location and a positive Y value is in the upward direction. Note that the use of the terms right, left, up, and down are relative to the image as displayed on the microscope screen.)

X backlash** (without correction): ........ _________________

Y backlash** (without correction): ........ _________________

(**A standard microscope stage that is "good" will have an uncorrected backlash of 5 microns or less. Low performance stages or stages that are in need of adjustment may have a backlash of 50 microns or more. Depending on how the stage position is displayed, there are a variety of ways to determine the backlash in a stage. If the stage position is displayed to ~1 micron resolution, a simple technique is to move a manual knob or joystick in a positive X direction until a small unique feature, for example a spec of dust, is centered on the screen, and then record the X position. Repeat the procedure, but approach from the negative X direction to the same feature, and again record the X position. The difference between the two values will be the backlash in the stage. The process should be repeated for Y. Note that typically, moving X will have no effect in the Y position, and vice versa, but that is not the case for every stage.)
Position error***: ..................................... ____________________

(**After a 1 mm move away and back a "good" stage with backlash correct enabled will return to
the original location with sub-micron accuracy. After a series of ~10 moves, a "good" stage will
return to the starting location with an accuracy of 1 to 2 microns.)

Blanker Testing:
To be thorough, the blanker should be tested at low and high beam currents, at low and high
accelerating voltages, and at low and high magnifications. With NPGS v9 or higher, the "Hardware
Diagnostics" function under the "Help" menu in the NPGS Menu program can be used to dynamical
control the blanker. Once the NPGS diagnostic program is running, select option #6 to dynamically
blank the beam with variable on/off times. (For earlier versions of NPGS, a function generator should
be used.)

• If successful, this test alone is usually sufficient to check for typical problems of a beam
blanker. The image itself can be used to diagnose the blanker. While the beam is being
dynamically blanked at 50 to 100 kHz, the image should not shift or degrade (other than the
decrease in image brightness caused by the blanking). To make the test the most sensitive,
look at a gold resolution standard while at high magnification so that you can look for small
changes in focus and astigmatism that may be induced by the blanker. When using a digital
microscope, turn off any averaging of the display image. A related test is to use a slow scan
rate and adjust the blanking frequency (to ~1 kHz) to obtain black stripes on the screen that
are relatively steady.

• A simple two step test is to put the beam into a Faraday cup on the sample holder and
measure the steady-state beam current and then to measure the beam while it is being
dynamically blanked with a ~50% duty cycle (i.e., equal beam on and beam off times). For
whichever duty cycle is used, the beam current reading during the dynamic blanking should be
the fraction of the steady state reading that corresponds to the duty cycle. The measured ratio
can be checked at different duty cycles and/or different blanking frequencies.

• Obtain an image of a high contrast structure and then change the microscope to line scan
mode. In this mode, a single line will be scanned and the vertical displacement of the trace on
the microscope display will represent the brightness of the structure being scanned, much like
an oscilloscope display. While observing the line scan mode, blank the beam with the blanker
to see of the entire line scan trace changes to a flat line. If any structure is seen when the
beam is blanked, it indicates that some beam is still hitting the sample, i.e., the blanker is not
blanking completely. To increase the sensitivity of this test, adjust the brightness and contrast
of the microscope so that the blanked signal is at the bottom of the microscope display and the
bright image display is maximized. Ideally, the blanking ratio for the focused beam will be
1:1,000,000 or more. (In other words, if it takes "X" microseconds to expose a small dot with
the beam on, it will take over "X" seconds to expose the same dot with the beam blanked.)

• Check if the settings of the gun tilt/shift or the adjustable aperture affect the performance of the
blanker. If so, be sure that the optimum settings for blanking are the same as the optimum
settings for imaging.

• By using a dual trace oscilloscope to monitor the input signal to the blanker (produced by a
function generator) and an image output signal from the microscope (often labeled Video Out),
the response of the blanker can be measured. Slow gun coil blankers will have a response
time of 1 to 10 milliseconds, while a fast blanker will have a response time of 1 microsecond or
less. If a blanker is consistently in the "on" state for less time than indicated by the input
signal, a compensation for lithography can be made in the Pg.sys file (this typically only
applies to ~1MHz magnetic blankers). A blanking signal with ~10 microsecond on/off times is
a good frequency to start with for a fast blanker. Note that for this test the beam should either
be stationary or be scanning a featureless area of a sample, so that there are no changes in
the microscope output signal due to sample structure. Also, note that the response time of the
image output signal may be slower than the blanker response for fast electrostatic blankers, so
seeing rise/fall times of ~0.2 to ~1.0 microseconds is not a cause for alarm. Unusual behavior
while the beam is being dynamically blanked includes a sloped response on the output signal
when the beam is on and/or a delay which varies with beam current or accelerating voltage.
The steady state "beam on" condition will produce a steady (but noisy) trace on the
oscilloscope screen and the steady state "beam off" condition will produce a different trace on
the oscilloscope screen (typically a relatively low noise signal at a lower voltage than the beam

NPGS: System Installation ● Page 19
on case). Ideally, when the beam is dynamically blanked, the oscilloscope trace will cleanly jump from the "beam on" signal to the "beam off" signal.

Unfortunately, the blanker tests listed above cannot guarantee that a blanker will perform flawlessly for all lithography. However, these tests are relatively simple and are very quick, so they are extremely helpful for finding obvious problems with a blanker, while sometimes more subtle problems will only be observable by writing patterns with fine lines. However, if a problem is observed in the tests described above, it is then much easier to resolve the problem, than the case when an entire lithography processing cycle is involved.

**Beam Stability:**

When patterns are being written, the beam current of the microscope should ideally be at a constant value. For most conventional SEMs, i.e., W or LaB₆ models, the SEM must run for ½ to 1 hour before the beam current will be stable. For W models, the expected stability is on the order of 1% per hour, while for LaB₆ models, it is typically 2-3% per hour. Thermal FE SEMs typically are very stable with a drift of less than 1% in 10 hours. However, cold cathode FE SEMs may have noise and drift ranging from 10% in 10 minutes to 5% per hour, with the typical reported values being 15-20% per hour.

For any microscope, when you are first starting lithography, it is a good idea to characterize the drift in the beam by making periodic measurements in a Faraday cup*. It is recommended that the measurements start just after the microscope is first turned on and continue for up to several hours. In this way, you will be able to determine how long the microscope takes to stabilize and to what level the drift settles to once the microscope has been running for a significant time.

*Copper apertures with a ~75 μm diameter hole are supplied with NPGS to be used to make a Faraday cup on the sample holder. **It is recommended to have both a Faraday cup and a gold standard mounted on the sample holder.** A Faraday cup can easily be made by drilling a blind hole (diameter 1 to 2 mm, depth 2 mm or more) into the holder, coating the inside of the hole with carbon paint, and then using carbon or silver paint to attach one of the supplied apertures over the hole. A picoammeter, such as the Keithley 6485, should be used to read from the specimen current connection on the microscope.

**Focus with Stage Z Position:**
The "Detailed Tutorial on Pattern Writing" in the NPGS Manual describes focusing on the sample by using the fine Z control of the stage, which physically moves the stage in the vertical direction. You should characterize the microscope to see how well the Z control can be used for focusing. Typically, as the Z height is adjusted, the image will shift in X and/or Y, which will make it difficult to use above some magnification. For lithography, adjusting with the Z position at a magnification that gives a field size between ~1 and 3 microns, and then doing a final focus adjustment with the fine electronic focus control will produce good results.

| XY offset in microns when Z position is changed |

**SEM Apertures:**

Most* electron microscopes will have an adjustable aperture mechanism with three to seven positions, however, many users of electron microscopes do not know which sizes correspond to which aperture position or even the significance of the different aperture sizes. In short, the smallest apertures should be used for the highest resolution imaging and lithography, which should be done at a relatively low beam current. Large apertures should be used for the highest beam currents, while the medium sized apertures are for general use, when neither the highest resolution nor highest beam currents are required. **It is not recommended to use high currents with the smallest aperture size, since such usage will typically lead to premature contamination of the small aperture and degrade the imaging and lithography performance that can subsequently be achieved.**

Note that most microscope manufactures refer to using small apertures with "low" currents and large apertures for "high" currents, but they typically do not specify what is meant by "low" and "high". As an approximate guide with respect to aperture selection, a low current may be considered as one below ~100 pA, while a high current would be above ~10 nA. Note that these values are generalized estimates, since they ultimately depend on contamination rates that will depend on the condition of a specific microscope as well as on the sizes of the apertures available.
Aperture Positions and Sizes:____________________

(*The LEO/Zeiss field emission microscopes, i.e., with the "Gemini" column, do not use the typical lens arrangement, so each aperture is only used with one beam current.)

(**The newer FEI SEMs have a heated aperture holder which is intended to minimize contamination, even at high beam currents, however, reserving one of the small apertures exclusively for low current imaging and lithography will ensure that at least one small aperture stays as clean as possible.)

Pattern Writing:
When you first write patterns with NPGS, the two patterns that are best to start with are "Sample0" (which has the "wheels") and "Sample3" (which has the fractal stars). The wheel pattern is the best for checking if the microscope was properly optimized during the writing, and the stars are good because they almost always work, even when the microscope was not well optimized. The "Quick Tutorial" in the NPGS Manual (under "Help" in the NPGS Menu program) has additional information. Note that before the patterns are written, the Measured Beam Current listed in the run file must be set to match the reading from the microscope and the microscope Magnification must be set to match the value in the run file.

When using NPGS with a Dual FIB/E-Beam system or with two SEMs:
When NPGS is used to control two systems, a primary issue is that the X, Y, Blanker, and sometimes the Image signal must be switched between the beam control electronics for the two columns and the NPGS PCI516 board. For the Zeiss/LEO Crossbeam and when using two separate microscopes, the Output Relay Box supplied with NPGS will normally be used for this purpose. For the FEI Nova NanoLab, FEI Helios NanoLab, FEI Quanta3D, and the FEI DB235/635, the XY signals are switched using the FEI External Scan Interface (ESI), however, the blanking signal will be switched using the NPGS Blanker Relay Box. Additional information is provided later in this binder in the instructions for Pg_USB.exe, which is the program used to control the NPGS Remote Enable Switch.

Another issue is that within the NPGS Menu program, each Project directory will be configured for one or the other of the systems under control by NPGS. Whenever control is switched between the two systems, the autocalibration of the NPGS PCI516 board must be run for the system to be used. This can be done by selecting "Commands - Calibrate DACs" from the NPGS Menu program while the appropriate Project is displayed.

During the installation of NPGS, the "System Calibration" described earlier in this documentation must be performed for each of the systems used with NPGS, where the calibration parameters will be stored in a project dedicated to the system being calibrated.

When NPGS is installed from the NPGS Installation CD, the "Samples" project will be created with the initial parameters configured for the e-beam of a dual e/i beam system. The user should use "Project - Create New Project" to create a project such as "FIB_Samples" as a project dedicated to use with the FIB. Then, the NPGS Menu program should be closed and the files in the directory "Nova_FIB_Files", "Helios_FIB_Files", "Quanta3D_FIB_Files", "DB235_FIB_Files", "DB620_FIB_Files", or "Crossbeam_FIB_Files" on the NPGS Installation CD should be copied to "FIB_Samples" using Windows Explorer. Subsequently, the "FIB_Samples" project will have the initial setup appropriate for control of the FIB. (When NPGS is supplied preinstalled on a PC, these steps will already have been completed.) For other Projects dedicated to FIB use, the "Pg_Menu.sys" and "Pg.sys" files can be copied from "FIB_Samples".

Other Information:
If there is a standard serial or Ethernet interface to the microscope or directly to an automated stage, the NPGS Installation Guide will include additional printed documentation on the software used by NPGS to communicate with the microscope and/or stage. This information can be found behind a divider, if present. That documentation should be followed to set up the communication between NPGS and the microscope and/or stage.
**NPGS: Microscope Considerations**

**Microscope: Overview**
An overview of feature size and the corresponding microscope considerations:

**Very Small**
- ~50 to 20 nm (or less) in PMMA
- Typically written with a ~50 to ~200 µm field, where the actual magnification value is selected based on the optimum microscope magnification as described in the previous section
- *minimizing the astigmatism is critical!!!*
- proper focus on the sample surface is also very important, especially when a small working distance is used
- high voltage (≥30 kV)
- beam current (5-10 pA for W, 15-25 pA for LaB₆, or 20-50 pA for FE)

**Medium**
- ~0.2 µm
- typically written with a ~500 µm field
- focus (depth of field) may limit area available for fine features
- linearity of scan coils
- line frequency interference

**Large**
- 1-100 µm
- typically written with a ~500 µm to 2 mm field, depending on the microscope
- electron optics may produce distortions at large beam deflections
- line frequency interference

**Very Large**
- >100 µm with field sizes to several millimeters
- typically written with a ~1 to 10 mm field, depending on the microscope
- electron optics may produce distortions at large beam deflections
- using a long working distance may be helpful
- line frequency interference

Related Topic: [Detailed Tutorial on Pattern Writing](#) (page 128)

**Microscope: Details**
The following items are of greatest importance when writing the finest lines (≤20 nm for field emission, <50 nm for W and LaB₆):

1. All EMI generating equipment should be turned off or properly shielded.
   
   A. Ion pumps may produce significant noise at line frequency. Simply relocating the power supply with respect to the microscope column can significantly reduce line frequency pickup. For example, in a case with a JEOL 840 SEM, placing the power supply on the floor ~6 inches from the console on the side away from the column eliminated the interference problem.
   
   B. The graphics board and monitor of the computer may introduce a small amount of noise into the system. Locating the monitor >1 m away from the column usually is sufficient.

2. If the microscope location has unavoidable sources of magnetic interference, a magnetic shield for the sample chamber or a field canceling system for the room may be necessary. A typical
specification for stray AC is that it should be less than $0.3 \, \mu T (p-p) = \sim 1 \, \text{mG(rms)}$ in the vicinity of the microscope column. See the “Other Resources” page on the NPGS web site for a list of vendors of magnetic shielding and field canceling systems.

3. Using a short microscope working distance (~5 to 10 mm) will also reduce EMI pickup.

4. The XY cables from the computer to the microscope should be kept as short as possible and should be kept away from any other cables, especially power cords.

5. The microscope voltage and probe current should be stable before writing patterns. For a conventional SEM (W & LaB₆), this will typically take 30 minutes to 2 hours after the filament is saturated. For a thermal FE SEM, the filament should always be very stable. For a cold cathode FE SEM, the filament current will always be unstable and will be worse for the first ~2 hours after the tip is “flashed” and will again be worse ~5 to ~8 hours after the flash, as the tip again gets dirty.

6. In general, the highest accelerating voltage will give the least amount of backscattering at the surface and consequently the smallest linewidths.

7. The sample must be perpendicular to the beam and electrically grounded. For more information on minimizing the effect of a tilted sample, see the X-Y-Focus Mode (page 170).

8. The smallest microscope aperture will give the smallest beam size and best depth of field, but be careful to avoid running excessively high currents when using a small aperture; otherwise the aperture may be prematurely contaminated.

9. Increasing the Gun Bias (i.e., decreasing emission current) will reduce the beam size.

10. The objective lens should be "cleared" whenever the coarse focus is changed, in order to minimize effects from hysteresis in lens. On some microscopes a manual momentary switch may be used, the lens may be cleared through software, it may be done automatically, or it may not be an option. The process of clearing the lens may also be called degaussing or hysteresis removal.

11. The condenser lens should be "cleared" whenever the coarse probe current is changed, in order to minimize effects from hysteresis in lens.

12. The aperture centering, focus, and stigmators must be carefully adjusted for optimum writing. This is the most difficult aspect of producing small linewidths.

13. Ideally the sample will have patterning on the surface to use for fine adjustment of the focus. If not, something must be put on the surface such as graphite from a pencil or a scratch from a diamond scribe marked near the edge of the sample, or the Spot Mode of the microscope may be used to make a small contamination spot that can be used for focusing. For making accurate adjustments to the stigmators, it is recommended that a gold SEM resolution standard be mounted on the sample holder. For more information, see Detailed Tutorial on Pattern Writing (page 128).

14. If the microscope is not on the lowest floor of the building, vibrations can be a problem. A typical specification is that the vibrations should be less than $2 \, \mu m (p-p)$ over 5 Hz. Rubber pads may provide a beneficial (and inexpensive) level of vibration isolation. Sources of vibration, such as the roughing pump or water chiller, should also be checked and isolated from the microscope as necessary. Touching all of the cables and hoses that lead to the microscope column can be an easy way to identify significant sources of vibrations.
15. The microscope column should be mechanically “floating” relative to the base. **On most microscopes, gently pushing on the column should make it move back and forth with a period of about one second.** (However, LEO/Zeiss SEMs tend to have an isolation system that is relatively stiff.) If the column does not move freely or if induced motions do not damp out within a few seconds, adjustments to the mechanical vibration isolation are probably required (in some cases, it has been seen where shipping bolts were left installed after microscopes were “professionally” installed or the air shock had the incorrect pressure).

For more information, see [Detailed Tutorial on Pattern Writing](#) and [Patterns for Exposure](#) (page 36). When first learning to optimize the microscope for lithography, it is strongly recommended that the "wagon wheel" patterns in "Sample0.dc2" and "Sample0.rf6" be used to test if fine lines can be achieved.

**Microscope: Typical Limitations**

Typical microscope limitations at field sizes greater than ~500 μm are:

1. While the beam may be properly focused at the center of the field, it will become increasingly out of focus as it is deflected farther from the center. This happens because at low magnifications the focal point of the beam defines a hemisphere as the beam is deflected, while at higher magnifications, the focal surface can be considered to be a plane.

2. Astigmatism may be introduced at large beam deflections that is not present near the center of the field.

3. The response of the scan coils will become less linear for large beam deflections.

Other microscope limitations:

1. **The typical design of the scan coil amplifier circuits in SEMs is such that the best signal to noise for pattern writing will depend on the magnification.** For example, for older analog JEOL SEMs, it has been observed that the best signal to noise is found at the lowest value of each magnification decade, with the signal to noise being about an order of magnitude worse at the high end of each magnification decade. For the analog JEOL SEMs, large patterns over a field of view of ~900 microns square may be conveniently written at a magnification of 100x, however, if 95x is used, the writing quality may decrease significantly because of the change in the magnification circuitry. Microscopes from other vendors will typically have the same effect, but at different values in magnification. For example, on an FEI XL30, Quanta, or NanoSEM, the signal to noise changes significantly around 400x and 1600x, with the exact value depending on the direction of the last change in the magnification (and on the magnification calibration mode, i.e., Display or VideoPrinter). The accelerating voltage and working distance will also affect the location of the magnification range changes for some SEM models. A clue to where the magnification range is divided is that the SEM image will often shift and/or an **audible click** will be heard as the SEM is changed across the range boundary by a mechanical relay. The best signal to noise will be found just above the magnification value where the image shift and/or audible click is observed. The best way to characterize the significance of this effect is to write the same pattern at the magnification values just above and just below the boundary value. At a low boundary value (with a field size of ~1 mm), a large change may be observed in the pattern quality, while at a higher boundary value (with a field size of ~100 microns), the effect may only be observable for fine lines.

2. Even though the external control mode is active during pattern writing, the scan mode (TV, SR, SLOW, etc) of the microscope may still affect the pattern writing. In some cases, a particular scan mode setting will introduce a spurious signal on the x-y scan controls. For example, on the older JEOL 6000 series SEM, the SR (Super Rapid) and TV modes will superimpose a square wave on pattern writing, while the Slow modes do not. Similar scan mode dependent noise has also been seen on other brands and models. Also, the “Spot” mode of an SEM will often interfere with pattern writing. In most cases, the Spot mode will prevent all scanning, however, for the LEO
S440, it has been observed that the spot mode allows patterns to be written, but will introduce undesirable changes in the writing field size. On newer SEMs with a digital scan generator, this effect should not be seen if the SEM turns off the digital scan generator when the microscope is in external control.

3. The stability of the beam and the electron optics in general will vary between microscopes (even between two of the same model of the same brand!). Some microscopes may be stable for more than several hours, while others may drift noticeably within minutes. These differences may result from variations in the local magnetic fields and/or changes in the water temperature used to cool the SEM. Also, the frequency of "arching" at high voltages (typically >35 kV) may be different between two identical models of a microscope.

4. When a microscope is at the lowest magnifications, a large current is required in the scan coils to deflect the beam to the edge of the field of view. It is not recommended to leave the beam under external control at a large deflection at low magnifications (~500 micron field or larger) for more than a few minutes or damage to the scan coils may result.

**NPGS: About this Documentation**

Great effort has been put into making this documentation as helpful as possible and to keep it free from errors. However, if a section seems confusing, does not provide enough details, or if you find any errors, please provide feedback so that future versions can be improved.

Because NPGS has so many options, there are many details to be covered by the documentation. For most pattern writing only the basic functions of the software will be used, however, each option has been designed to handle a specific need for some application. Consequently, many parts of the documentation will go into details that are not needed for the typical application. Throughout the documentation, important points that are common to most applications are highlighted in the same way as this sentence and should be given special attention.

The digital version of this documentation has been optimized for display at 1024x768 or higher with 16-bit color depth or higher.

This documentation may refer to procedures involving equipment and chemicals that have specific safety concerns. It is the reader’s responsibility to ensure that all procedures are performed in a safe manner.

**NPGS: Legal Issues**

**NPGS License Agreement**

The NPGS License agreement gives the original buyer full rights to use the "Microscope Installation" of the NPGS software without any time limitations, as long as it is only installed on a single PC. (The "Microscope Installation" of NPGS contains the full functionality of the system.) The "Office Installation" of the NPGS software may be used on any number of PCs within the facility or university where NPGS is installed on the microscope. For pattern design, each installation of the NPGS software requires a separate licensed copy of an approved version of DesignCAD. Copies of the NPGS software are to be made for backup purposes only. No part of the NPGS documentation may be reproduced for any purpose other than use within the purchaser’s laboratory without the written permission from JC Nabity Lithography Systems (JCNLS). No part of NPGS is to be made available for public access through the Internet. No part of the NPGS hardware is to be duplicated for any reason. This system is intended to be used for writing patterns when installed on a compatible electron or ion beam microscope. JCNLS assumes no liability to damages consequent to the use of this system. Purchase of NPGS indicates acceptance of these terms and conditions.

**DesignCAD License Agreement**

The copy of DesignCAD that is installed on the PC that is connected to the microscope should not be used for other PC installations. Each copy of DesignCAD that is installed on other PCs must have a unique serial number and is covered by a license agreement separate from the NPGS license.
agreement. NPGS presently supports DesignCAD Express v21.2, DesignCAD Express v16.2, DesignCAD LT2000, and DesignCAD 6.1 for DOS (for those people who really don't like change!).

NPGS Documentation
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No part of this manual may be reproduced or distributed for any purpose other than the purchaser's personal or immediate laboratory use without the written permission from JC Nabity Lithography Systems.

The NPGS documentation may NOT be placed "online" for public access through the Internet.

A copy of the NPGS Manual may be placed on a password protected server for access only by the authorized users of the NPGS installation.

Warranty
NPGS is warranted against defects in materials and workmanship for a period of one year from the date of delivery to the original purchaser. Defective hardware will be repaired or replaced upon return of the defective item. On-site service is not included. The warranty does not apply if the system is modified (other than the modifications described in the manual) without written consent from JCNLS. Software updates will be available for download during the warranty period, as needed.

Other Notices
- DesignCAD Express v16 and v21 are a trademark of IMSI.
- DesignCAD LT2000 is a trademark of Upperspace (formerly ViaGrafix).
- MS-DOS and Windows 95/98/NT/2000/XP/Vista/7/8 are trademarks of Microsoft Corporation.
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Quick Tutorial

Getting Help

If you are reading this, you are on the right track! Great effort has been put into making this documentation accurate, thorough, and well organized. If you have any suggestions for improvements, please provide your feedback.

This documentation is provided in two formats (available under the "Help" menu in the NPGS Menu program and the Run File Editor). The two formats are provided because the HTML format is more sophisticated, however, the PDF version is more suitable for making printed copies.

What’s This Icon

In NPGS, the "What's This" icon can be used for help on specific commands. As opposed to many programs that say something like "This is the command that you just clicked", the NPGS "What's This" help provides very detailed and useful information. You are strongly encouraged to use the "What's This" help, especially within the Run File Editor, since the help that is displayed should answer all common questions about each prompt.

The "Solutions to Problems" section of this documentation is also available at the NPGS web site under the "User Notices" page. The web site information is updated as needed, so that it will always have the most current information.

The NPGS documentation has been designed to answer most questions that will arise and to solve most problems that will be encountered and you are encouraged to make use of it.

Of course, additional help on any aspect of SEM lithography is also available at no charge through "info@jcnabity.com" or by telephone/fax at the numbers on the NPGS web site: "www.jcnabity.com".

When reporting problems, the following information should be provided so that your problem can quickly and accurately be evaluated:

General Information:

1. SEM Brand:
2. SEM Model:
3. Beam Blanker (yes/no):
4. Auto-Stage (yes/no):
5. NPGS Version (see "Help - About NPGS")

Exposure Conditions:

1. Accelerating Voltage:
2. Beam Current:
3. Magnification:
4. Aperture Size:

Helpful Questions:

1. Has the problem developed slowly over time or suddenly?
2. If suddenly, was anything else recently done to the SEM or to NPGS that may be related to the problem? (The majority of "sudden" problems turn out to be caused by something being unintentionally unplugged, broken, or deleted!)
3. How long have you been using the SEM for microscopy? For lithography?
4. Have other people using the system experienced the same problem?

If it is related to pattern writing:

1. Can you provide images showing the problem? (Please provide JPG files so that the file sizes are reasonable. TIFF and BMP files are typically about 10 times bigger than a comparable JPG image.)
2. Please provide the pattern and run file that reproduces the problem. Also, send the "Pg.sys" file from the pattern directory.

**Installing NPGS on an Office PC**

Often, it is convenient to install NPGS at locations away from the microscope. NPGS provides an "Office Installation" mode, which installs NPGS for use on a PC with no special lithography hardware. This installation can be used for the design and editing of patterns* and run files.

*To design patterns on an office PC, a separate licensed copy of DesignCAD must be installed on the office PC. Multiple copies of DesignCAD are included with NPGS for Office Installations. To obtain more copies of DesignCAD Express v21.2 or v16.2, send e-mail to Info@jcnabity.com.

The section System Installation: Software (page 2) gives details for installing the NPGS software.

**Getting Started in NPGS Menu**

**NPGS Menu program**

All NPGS projects and files can be accessed from within the NPGS Menu program. This program is the main environment for all actions within NPGS. Typically, a file will be highlighted from the main file list and a Custom Command will be used to act upon the selected file. The three main Custom Commands to use are:

- **"Process Run File"** to write and/or align patterns
- **"Run File Editor"** to edit/create run files
- **"DesignCAD Express"** to edit/create patterns

optional:

- **"DesignCAD LT"** to edit/create patterns (used in older systems)

Any of the Custom Command buttons can be redefined by the user to run an NPGS Menu command, a Windows or DOS command, or VBScript or JavaScript programs. Also, since each set of Custom Commands is unique to each project, the user is encouraged to customize their own project with whatever commands are most convenient for their application. To modify Custom Commands, use "Options - Custom Commands". Note that individual Custom Commands will be disabled when a file type is selected that does not match their assigned function.

**Project Directories**

NPGS allows any number of project directories to be created by the users. Each project directory contains all of files described below, so that changes made by one user will not have any effect on others. The benefit of having this isolation between users should be obvious, especially to those working in universities and/or multi-user facilities. Project directories should only be created or renamed using the commands under the "Project" menu.

**Pattern Files - DesignCAD**

NPGS writes patterns using files in the DesignCAD *.dc2 format. Typically, these pattern files will be created using DesignCAD Express v21.2, DesignCAD Express v16.2, or DesignCAD LT2000 for Windows or earlier versions of DesignCAD for DOS. Within DesignCAD, the default pattern units are interpreted as microns by NPGS (1 foot in DesignCAD = 1 um for NPGS).
Files in many other formats, including DXF, GDSII, and CIF, can easily be imported and saved in the DesignCAD *.dc2 format for use with NPGS. See the “File - Pattern Import...” option in the NPGS Menu program for more information.

**Run Files - Run File Editor**

Run files (*.rf6) are used by NPGS to record the sequence of events to be performed during the pattern writing. A sophisticated Run File Editor is a key part of NPGS that makes it easy to create run files for different lithography applications. Consequently, even complex exposure sequences can easily be repeated, simply by having NPGS process a saved run file.

A run file can be made that just writes a single pattern in a manual mode, or a run file can define the steps to write thousands of patterns using AutoAlignment, Global Rotation Corrections, and Automated Stage control. In addition, a run file can include any custom Windows or DOS command that may be useful for a particular application.

**System Files - System File Editor**

System files contain the parameters that define how NPGS operates. Each project directory has its own unique set of system files, which can be edited using "Options - System Files - System File Editor" within the NPGS Menu program. For a detailed description of each system file, see System Files in each Project (page 172).

**Miscellaneous**

It is recommended to disable all screen saver activity or to at least set the interval to be longer than most pattern writing sessions, because the Windows operating system will not recognize when NPGS is writing patterns. Consequently, Windows may enter a screen saver or power saving mode during lithography. While the basic screen saver mode will normally not cause a problem for NPGS, Windows is unpredictable enough that it is best not to take the chance.

**Creating a new Project Directory**

**Creating a new Project Directory**

When NPGS is installed, a default project directory called "\NPGS\Projects\Samples" is created which contains the sample patterns and run files described later in this documentation. You can either choose to start working within this project, or it is recommended that each user should create their own project directory. The “Samples” project should never be renamed, deleted, or removed from the NPGS Projects list.

To create a new project directory, select "Project - Create New Project" from within the NPGS Menu program. Type in a name for the new project and hit "Create". The new project will be created using copies of the master set of system files from the "\NPGS\Projects" directory. The default location for the new project will be under "\NPGS\Projects", but projects can also be nested anywhere beneath this directory.

**Copying from other Directories**

If you have created your own project, it may be useful to copy the sample patterns and run files from the "Samples" directory. To do so, go into your project and select "File - Copy File(s) To Project". From within the copy window, select the directory "\NPGS\Projects\Samples" as the "Source Directory". You may then highlight as many files as you wish to copy back to your project. Note that the standard Windows mouse conventions apply for highlighting the files, i.e., "Shift - Left Click" will add blocks of files and "Ctrl - Left Click" will add individual files. You should not copy the system files from one project to another, unless you are sure that it is appropriate to do so.

**Creating a Pattern**

**Start DesignCAD**

NPGS can be used with DesignCAD Express v21.2, DesignCAD Express v16.2, and/or DesignCAD LT 2000. Any or all of these versions may be installed and used with NPGS at the same time. The NPGS Manual is based on the newest version (v21.2), and any information for the other versions is listed separately as needed.
From within your project, you should select “DesignCAD Express v21”, “DesignCAD Express v16”, or "DesignCAD LT" either from the Custom Command buttons or from the "Commands" menu. If a DesignCAD file with the .DC2 extension is highlighted in the NPGS Menu file list, it will be automatically loaded, or if no file is highlighted, DesignCAD will start with an empty design area. You should always start DesignCAD from within the NPGS Menu program and not from a desktop icon.

The default units for pattern design within DesignCAD are interpreted as microns by NPGS.

NPGS Menu in DesignCAD
Almost everything you will need for designing patterns can be found under the "NPGS" menu option in DesignCAD. The first sub-menu has a list of the most useful DesignCAD commands, while the other items under the NPGS menu are BasicCAD programs that have been written to optimize DesignCAD for the design and editing of patterns for lithography. All of the BasicCAD programs from the NPGS menu are also accessible from the NPGS ‘Menu’ Toolbox (typically, the 2nd vertical toolbox on the left) which displays the two character labels corresponding to each command. In addition, the NPGS ‘Main’ Toolbox (typically, the vertical toolbox on the far left) has icons showing many of the most useful DesignCAD commands (this menu is not available in the DC LT2000 version).

Keystroke Commands
DesignCAD provides single keystroke commands that can be used to immediately launch useful commands. In DesignCAD and in this documentation, the keystroke commands will be displayed in the upper case, however, the lower case key should be used.

Create Lines
To create a line, simply hit "V" or select “Lines - Line” from the DesignCAD menu, then set the endpoint for the line either by clicking the left mouse button or by hitting "Insert". For precise design work, the mouse is most useful when the "Snap Grid" is enabled. While in a drawing command such as "V", you may hit "G" to enable and disable the snap grid. Hitting "Ctrl - G" will bring up the Snap Grid options box. Absolute, relative, and polar coordinates may also be used for precise positioning of vertices. See the DesignCAD "Point" menu for all of the methods on setting points.

Info Box Icon
If desired, after a line is created, you can click on it then on the Info Box icon to modify the attributes of the line, including the color and width. The Info Box icon is very powerful, so you should become familiar with its functions.

You will also want to become familiar with the Line Style Toolbox, which allows you to easily set the properties of lines before they are drawn.

Create Filled Polygons
Arbitrary filled polygons can easily be designed using the "NPGS - PolyFill" command. After an initial dialog box is presented, prompts will be displayed on the status bar at the bottom of the DesignCAD window, which tell you how to proceed. Hitting Enter for any of the prompts will select the option presented which is enclosed in brackets, i.e., [y] means “yes” is the default response. Typically, the defaults will be used, unless you have a special application that requires one of the other options.

A filled polygon that will be written using back and forth passes of the beam will be displayed as a dashed outline of the area to be filled. Sometimes, the spacing of the dashes will make a dashed line appear to be solid, however, the Info Box icon can always be used to confirm the line type. A dotted outline means that the beam will only sweep in one direction, however, that option is typically not needed.

The command "NPGS - ShowPoints" can be used to display the vertices of an existing pattern element as well as show the sweep side of a filled polygon.

The command "NPGS - ChangeSweep" can be used to check and/or change the sweep side of a filled polygon after it is created.
Check the Pattern for Errors and/or Ignored Entities
The command "NPGS - CheckAll" should be used to check the pattern for common errors and for ignored entities. While ignored entities do not cause any problems, it is good to know when an entity will be ignored, especially, if you had expected it to be written. For example, text must be designed as vectors to be written, otherwise it will be ignored. For more information, see Text (page 73).

Check the Pattern Origin and Field Size
The origin of the pattern will be placed at the center of the writing field of the microscope. Consequently, it is a good idea to check where the origin is and how large of writing field will be required.

The origin can manually be moved by clicking the Set Origin icon at the corner of the position rulers and then setting a point at the desired location.

The command "NPGS - MaxMag" should be used to check the dimensions and centering of the pattern. For any pattern, there will be a maximum microscope magnification at which the pattern can be written. Quite simply, if the microscope magnification were any higher, the writing field would not be big enough to fit the pattern. The Run File Editor will ensure that only an acceptable magnification can be entered in the run file and the "MaxMag" command will allow you to check the pattern size and position relative to the origin during the design stage. If the pattern is not well centered, "MaxMag" will give you the option to automatically center the pattern about the origin. Typically, this will be the best location for a pattern.

Other Useful Commands
For a list of useful commands, see "NPGS - Most Useful DesignCAD Commands" within DesignCAD or see Most Useful Commands (page 74) in this documentation.

Save File
To save a file for use with NPGS, you must use the "NPGS - Save" command as shown below. The normal DesignCAD "File - Save" command should NOT be used, because it will not ensure that the pattern layers are in the correct order.

After the file has been saved, you will typically exit DesignCAD and return to the NPGS Menu program if you want to create a run file for the pattern, however, DesignCAD can remain open as the run file is being created.

Creating a Run File
From within the NPGS Menu program you can select "Run File Editor" from either the Custom Commands or from the "Commands" menu. Since all of the options in the Run File Editor are discussed later in this documentation, only a quick introduction will be given here.
You are strongly encouraged to use the "What's This" icon within the Run File Editor to get detailed information on each data line. The information provided has been selected to answer most questions a new user will have.

For the purposes of this brief tutorial, it will be best to leave the "Number of Entities" prompt at one and to set "Allow Advanced Modes" to "No". (When the Advanced Modes are set to "No", NPGS will not attempt to send any commands to an automated stage or to a digital SEM. If available, these functions can be enabled for fully automated control during the writing, after the SEM is initially optimized.)

For the "Entity Type", leave the prompt as "Pattern", which means the pattern will be written without using any of the other special writing modes.

Double click on the "Pattern Name" prompt to bring up a list of the available *.dc2 patterns in the current project. *The patterns for a run file must always be present in the current project directory.* Select a pattern from the list and double click on it or hit "Open". The pattern will be read by the Run File Editor and the right hand side of the screen will display the exposure parameters that need to be specified to write the pattern. The two prompts below the pattern name can be left unchanged.

Now, take a look at the right hand side of the window, which is labeled "Highlighted Entity Data". When any pattern entity is highlighted on the left side of the window, the right side will display the parameters required for the exposure of the highlighted pattern. The parameters on the right hand side can now be set as desired. *Note that the defaults have been read from a system file and are not optimized for the pattern that was read in. That is left for you! For now, the defaults are probably reasonable, however, you should read the following sections describing each of the parameters in order to optimize them for your particular application.*

After the exposure parameters are set, select "File - Save" and enter a name for the run file. You have now created your first run file and can now exit from the Run File Editor. You are also encouraged to look through the sample run files that are provided.

The patterns defined in a run file can be written by highlighting the desired run file in the file list in the NPGS Menu program, then clicking the "Process Run File" button or the "Simulate Writing" button can be used to simulate the real time writing on the NPGS PC screen. Alternately, right clicking on a file in the file list will bring up a "popup" window of available functions.

*When using NPGS v9 or higher, the following mouse clicks can be used at any prompt in PG (during pattern writing) or AL (during alignment): "double left click" = Space, "double right click" = Enter, and "left click then right click" = Esc.*

**Example Run File Sequence**
The left side of the Run File Editor display is shown below for an example run file that is set up for automated stage control. (Note that even when an automated stage is not present, it can be useful to document the desired stage movements in the run file.)
In this example run file, the first entity is a "Comment" entity that will always be displayed when the run file is processed. The comment text can be anything the user wants to enter, such as reminders to set the SEM to external control mode, to set the blanker to external control mode, to turn off the room lights, etc.

The second entity will write the "Sample0" pattern at two locations (this is the "wheel" pattern that is extremely useful for evaluating the optimization of the SEM during the writing). The first exposure will be written at the initial stage location when the run file is processed. In a typical test run, this may be just to the left passed the end of a horizontal scratch that extends to the right edge of a rectangular sample. In a test run when first learning to do lithography, it is useful to write the first pattern almost exactly on the end of the scratch, since the pattern will then be easy to locate after it is developed and coated. In this run file, a second identical exposure will be done 100 microns directly above the first exposure. The idea is that the first exposure will be easy to find, but may partially overlap the scratch or the location of the final focus position, while the second exposure will be far enough away from the scratch, but still very close to the focus position.

The third entity will expose the "Sample3" pattern (with the "fractal" stars), after moving to a location 200 microns to the left of the second exposure.

The fourth entity will expose the "USA" map after moving to a location 200 microns below the star pattern.

The fifth entity will expose the "Sample0" after moving 200 microns to the right of the map, which will then be 100 microns below the initial pattern. This repeat of the wheel pattern can be compared to the second exposure to see if the SEM optimization drifted any over the duration of the pattern writing.
Note that for this particular set of patterns, the total writing time will typically be less than 5 minutes (when using ~20 pA of beam current), and drift the of SEM optimization is not expected.

The sixth entity is a "MoveOnly" entity, which will move the stage back to the starting location.

For examples of more complex sequences of stage moves for alignment and writing, see Run File Editor: Alignment Entity (page 98).

**Shortcuts in the Run File Editor**

**What's This Help**

The “Arrow - Question Mark” icon in the lower right corner should be used to access the popup help for any of the items in the Run File Editor. This is extremely useful, since detailed information is provided on the selected item.

**Entity Manipulations**

On the left hand side of the Run File Editor, many different “Entities” can be listed. Buttons are provided at the bottom of the screen that allow Entities to be Inserted, Cut, Copied, and Pasted. Note that more than one instance of the Run File Editor can be opened at once, where each may have a separate run file loaded. Entities can then be copied and pasted between the open run files.

**Drag and Drop**

By clicking and holding the left mouse button while positioned over any of the highlighted lines of an Entity, the entire Entity can be dragged to a new position in the Entity list on the left hand side of the Run File Editor. All parameters for the right hand side of the screen will be moved to follow the new position of the Entity that has been repositioned.

**“+” and “-” Keys for the Magnification Prompt**

Within the Run File Editor, the “+” and “-” keys can be used to quickly jump the displayed magnification entries to user-defined values. This can be particularly useful with older microscopes that only allow discrete values for the magnification or for any microscope when optimum values have been determined and a quick means to jump to the preferred values is desired.

User-defined values can be entered in Pg_Mag.sys. See “Pg_Mag.sys (User-Defined Magnification Values) (page 192)” for more information. When the user-defined values are not enabled, rounded values will automatically be generated.

**“+” and “-” Keys for the Spacing Prompts**

When the Center-to-Center or Line Spacing data prompts are active, hitting the “+” or “-” keys will jump the displayed value to 4, 8, 16, or 32 times the smallest possible step size (i.e., the step size corresponding to the least-significant-bit ‘LSB’ of the 16 bit DACs).

When writing the finest lines, it is recommended to use a spacing of 4 x LSB with a writing field size of about 100 microns square. Hitting the “-” key will always jump the spacing value to 4 x LSB. It is still possible to use any multiple of the LSB, but only in special cases would there be any advantage to using a spacing smaller than 4 x LSB.

**Double Click on Data Prompts**

When the run file has more then one of the following data prompts (i.e., in multiple layers or multiple patterns), double clicking on one of the prompts will display an option to copy the value to all similar prompts in the run file: Origin Offset, Magnification, Center-to-Center, Line Spacing, Configuration Parameter, and Measured Beam Current.

The choices are to copy the value to the current layer, current pattern, or to all patterns in the run file. This option is most useful when setting the same Magnification or Measured Beam Current for the entire run file.

**Set Doses Button**

When a pattern has multiple colors in a single layer, the “Set Doses” button allows a series of doses to be easily generated. Generally, an array of different colors will be created by using “NPGS-MakeArray” within DesignCAD, and when the run file is created, the “Set Doses” button will be used to
enter lower and upper limits for a range of doses. When first learning to do lithography, it is very helpful to intentionally enter values that range from “too low” to “too high”, so that under exposed array elements and over exposed array elements can be seen, in addition to elements that are close to the optimum dose. Using the “Exponential” step mode is recommended when a large range is entered, since it will give the best coverage of values over the range.

Optimizing the Microscope and Writing a Pattern

Optimizing the Microscope

Before a pattern can be written onto a real sample, the microscope needs to be carefully optimized. Optimizing the microscope, in particular correcting the astigmatism, is the most difficult part of achieving the finest lithography (≤20 nm for field emission, <50 nm for W and LaB6).

In this brief introduction, only main issues will be mentioned. First, if you cannot obtain a high quality image of a gold standard at a magnification giving a field size of ~1 micron, then either the microscope or your technique needs to be improved. If you want to do fine lithography, then there is no point to even writing a pattern until the microscope can be well optimized. Fortunately, with a high performance conventional microscope, a user new to the microscope should be able to get good images after a week or so of practice, and with a thermal FE model, it may take about a day. The best approach to learn how to optimize the microscope is to be trained by someone who already knows how to optimize the microscope well, and then to practice, practice, practice! Being able to consistently optimize the microscope is a skill that must be developed.

Once the microscope can be optimize well enough to get good resolution images of a gold standard at high magnification, you are ready to start doing lithography. However, be aware that to get the finest lithography, the microscope must be optimized even better than what is required to get good images.

After optimizing the microscope on a gold standard while at the kV and beam current which is to be used for the pattern writing, it is just a matter of moving to the sample and focusing near the location for the pattern writing. It is recommended that after leaving the gold standard that the initial focus be done on the sample using the fine Z control of the stage. A final focus can be done using the fine focus of the microscope, however, the stigmator settings should NOT be changed.

A quick procedure that is useful when first learning lithography is to make ~1 mm scratches perpendicular to one edge of the sample. When you go to write the patterns, you should find a scratch and move to the end away from the edge. You can do your final focus on the bits and pieces seen near the end of the scratch that are directly on top of the resist. The first pattern should be written right at the end of the scratch and then others should be written nearby. The first pattern may fall on top of part of the scratch, but this will make it easy to find after the resist is developed! Putting the patterns close to the scratch where the beam was last focused will minimize any focus errors that can be caused by a tilted sample. Later, you will likely use more sophisticated methods to deal with the focus issue, but when just starting, it is best to use a simple technique like this that is known to work.

Writing a Pattern

Now for the easy part! After the microscope is optimized and in focus, the actual pattern writing is very simple. First, you will typically set the beam blander to "External Control", and the beam will be blanked, since that is the default when NPGS is not actually writing anything. Next, you will switch the microscope XY control to external. (For older analog microscopes, you may need to turn down the SEM brightness before switching to external control in order to avoid burning the CRT.) The external control will typically be enabled using the “NPGS Mode” button on the NPGS Menu program or the blue SEM/NPGS switch box supplied with older NPGS installations, however, some microscopes allow you to switch to external control either through software or through a manual switch on the SEM console.

Finally, to make NPGS write a pattern from within the NPGS Menu program, all you need to do is to highlight the run file that is to be processed and select "Process Run File" from the Custom Commands or use "Commands - Process Run File - Run NPGS" from the menu. This will launch the program "NPGS.exe" which will call "PG.exe" to do pattern writing and/or "AL.exe" to do pattern alignment. For a run file that is not using the advanced modes, you will need to hit the Space Bar to tell the writing program when you are ready to continue (or double left click in NPGS v9 or higher).
Before starting the actual pattern writing, be sure that the microscope is at the magnification defined in the run file.

During the pattern writing, it is highly recommended that you confirm that the stage is moving as expected (when using an automated stage), the microscope magnification has been set correctly (when using a digital interface to set the magnification automatically from NPGS), and that the beam current measured on the specimen holder goes to zero during stage moves and to about ¾ of the Faraday cup reading during the pattern writing (this applies when a blanker is used and a picoammeter is connected to the specimen current output). Doing these simple checks will catch problems early, before samples are removed and processed!

In this quick tutorial, more advanced subjects such as the control of digital SEMs and automated stages are not discussed. When first learning how to do lithography, there is no need for NPGS to control either the SEM or stage, however, if available, such control will typically be useful when patterns are routinely being exposed. It is recommended that the user fully understand the manual operation of NPGS before using the more advanced modes. For more information, see Advanced Features of NPGS (page 142).

After the Exposure
When the patterns are finished writing, a good habit is to always check the value of the beam current. The reason is that if the SEM beam current drifts significantly during the writing, this simple check will alert you to the change. Of course, it will be too late to correct anything, however, you will know that the beam did drift and changes in the exposures will be expected. Also, once the drift problem is identified, steps may be taken to minimize it, i.e., waiting 30 to 90 minutes after a W or LaB₆ SEM is started will typically reduce the drift significantly. (However, for many cold cathode FE SEMs, drift and noise in the beam current will almost always be present.)

Imaging the Sample
When first learning to do lithography, it is strongly recommended that the patterns be developed and then sputter coated with AuPd (or any other metal with a fine grain size) and imaged, without any liftoff. The reason is that if the patterns are poorly exposed, it is quite likely that nothing will remain after a liftoff attempt, however, even underexposed patterns can typically be observed after they are developed and coated with metal and can provide useful information about the exposure conditions and microscope setup.

Diagnostic Patterns
One of the best diagnostic patterns to write when you are first learning lithography is "Sample0.dc2", which is described in the next section. Also, "Sample3.dc2" is a good pattern to include in your initial exposures, since it contains very complex structures and yet is very easy to expose properly.

Sample Patterns and Run Files

Patterns for Exposure
Sample patterns that demonstrate the basic pattern elements will be found in the project directory “NPGS\Projects\Samples”. The pattern writing can be displayed on the NPGS PC screen using the ‘Simulate Writing’ button (which is the same as using ‘Commands - Process Run File - Error Check Mode’). This mode can simulate the real time writing speed or the user can speed up or slow down the displayed speed using the ‘+’ and ‘−’ keys.

For information on changing the SEM to external control for lithography, see the "NPGS Installation Guide" that was provided for your SEM model, or for general comments, see SEM Input Connectors (page 211).

When you are first learning to do lithography, you should view the written patterns after coating them with a metal after development, but without attempting liftoff. For more information, see Detailed Tutorial on Pattern Writing (page 128).
Quick Tutorial

Sample Patterns and Run Files

Start_Here.rf6

As the name implies, this is a good run file to start with. This run file has many Comment Entities that are designed to give useful information on many important topics regarding the writing of patterns. Read them all!

For patterns, this run file is set up to write the Sample0 (wheel) pattern twice, then the USA pattern, then Sample3, then Sample0 again. If the automated stage has been enabled, the run file will move the stage to position the exposures with steps of 100 and 200 microns. It can be very useful to do a ‘dry’ run by having NPGS process the run file while the microscope is left in imaging mode, so that the motion of the sample can be confirmed.

SAMPLE0.dc2

This test pattern should ALWAYS be used when evaluating the performance of the SEM and the operator. It consists of nine “wheels” that will be written at different doses. Any astigmatism in the beam will be obvious in the exposed pattern. The pattern is designed with dump points so that it can be used with or without a beam blanker. The image below shows a lifted off wheel pattern, which demonstrates the results of a very good optimization of the SEM for the pattern writing. Lift off should only be attempted after the patterns look good after development. The scale bar in the image below is 1 micron. The “Sample Pictures” page on the NPGS web site also shows the wheel pattern when the microscope optimization was less than ideal.

SAMPLE0.rf6

This run file will write the above pattern with a different dose for each “wheel”. For 950k PMMA of thickness less than 200 nm on Si at 30 kV, a typical "ideal" dose will be about 1.3 nC/cm, which can yield linewidths down to ~20 nm, and a recommended initial range of doses for testing is from about 0.6 to 3 nC/cm which should go from “too low” to “too high”. The ultimate linewidth will depend on the beam source, i.e., W, LaB6, FE, and the optimization of the SEM. For a W source, the recommended beam current to produce the finest lines is from 5 to 15 pA, for LaB6 from 10 to 25 pA, and for field emission from 20 to 50 pA. For fine lines, the "Center-to-Center" distance should be set to a value between about ½ and ¼ of the desired final linewidth, consequently, ~6 nm is a good choice when 20 nm lines are the goal. If the lines at the ideal dose are underexposed and only much wider lines are defined at much higher doses, then the beam is probably not well focused on the surface of the PMMA. This is a very common problem when first learning to do lithography. For more information and Diagnostic Images of the "wheel" pattern, see the “Sample Pictures” page on the NPGS web site.

SAMPLE1.dc2

This pattern demonstrates different pattern elements: horizontal and vertical lines, lines of arbitrary slope, circles, and individual points (the second set of dots is repeated in the pattern, but is not obvious until the pattern is written with PG). Note that the comments are in drawing layer 20 and are not written. An image of the rose in the pattern is shown below (the pattern was written in a single layer of PMMA with a beam energy of 40 kV and was sputtered with AuPd after development):
SAMPLE1.rf6
This run file will write the above pattern three times with a different dose each time. (Note that for determining the ideal dose for a pattern, a single pattern is recommended that repeats a test structure in different colors. In this way, one pattern can show the results for many different doses, i.e., in sample0 a 3x3 test structure tests 9 different doses in one pattern.)

SAMPLE2.dc2
This pattern contains a 4 by 4 array of a test structure. The rows of the array are written in different drawing layers and the columns are in different colors. Exposure test patterns of this type are easily made using the BasicCAD program MakeArray. For more information, see BasicCAD Programs Supplied with NPGS (page 76).

SAMPLE2.rf6
This run file will write the above pattern once, but each test structure is written at a different exposure point spacing and exposure combination. The rows (layers) are each written at a different “Center-to-Center” distance and the columns (colors) are each a different exposure time with the values such that the doses along the downward slanting diagonals are the same. Typically, the exposure point spacing can be varied over a wide range without affecting the resulting pattern as long as the dose is kept constant. For fine lines, the “Center-to-Center” distance should be set to a value between about ½ and ¼ of the final linewidth.

SAMPLE3.dc2
This pattern contains a 3x2 array of a variety of complex filled polygons as shown below. Each array element is designed in a different color so that different doses may be assigned. When first learning to do lithography, this is a very good pattern to include, because it is reasonably impressive and it almost always works. For 950k PMMA on Si at 30 or 40 kV, a typical “ideal” dose will be about 200 to 250 $\mu$C/cm$^2$ and a recommended range of doses for testing is from 100 to 400 $\mu$C/cm$^2$. This range should produce patterns that are clearly underexposed, as well as some that are obviously overexposed. The image below shows nicely formed structures, even though during the writing, the beam had astigmatism that was obvious in the wheel patterns that were written at the same time.

SAMPLE3.rf6
This run file writes the above pattern.

SAMPLE4.dc2
This pattern contains a relatively large structure including contact pads. The pattern is designed in two layers so that the writing can be paused between layers to change the microscope magnification and beam current. This pattern is included to show a simple approach for device design, however, it is not intended as a pattern to write when learning lithography.
SAMPLE4.rf6
This run file writes the above pattern.

SAMPLE5.dc2
This pattern contains a very large, very sparse pattern, with user-defined sub-fields in layer 20. The sub-field centers are at the long end of the markers. Note that the groups of sub-fields are arbitrary distances from each other, however, within each group, the centers are spaced apart by the sub-field width of 500 \( \mu \text{m} \). This pattern included to show an example of how the NPGS Fracturing feature can be used and is not intended as a pattern to write when learning lithography.

SAMPLE5.rf6
This run file will fracture the above pattern using the user-defined sub-field centers defined in layer 20.

SAMPLE5A.rf6
This run file will fracture the above pattern in the automatic mode.

USA.dc2
This pattern contains a map of the United States at a scale of about 1:28,000,000,000. For 950k PMMA on Si at 30 or 40 kV, a line dose of about 2 nC/cm should produce linewidths of about 0.1 microns. After development, this pattern is best viewed in a high quality optical microscope.

Optical Image:

![Optical Image](image)

SEM Image: (note the dashed line effect, which is caused by having digital scan lines that are approximately the same width as the features)

![SEM Image](image)

USA.rf6
This run file writes the above pattern.

USA_FR.rf6
This run file will automatically fracture the map into 50 \( \mu \text{m} \) sub-fields with 5 \( \mu \text{m} \) "borders". (Typically, a larger pattern would be fractured into much larger sub-fields.) To see an example of how the Fracture mode works, select this file in the NPGS Menu program and run "Commands - Process Run File - Fracture Test Mode". Afterwards, use the "GetFract" command in DesignCAD (under the NPGS menu) to view the fractured sub-fields. This run file is included to show an example of how the NPGS Fracturing feature can be used and is not intended for use when learning to do SEM lithography.
USA_AR.rf6
This run file will write the map in a 10 x 10 array, using the Array Mode with a linear stepping of the dose for each exposure. *This run file is included to show an example of how the NPGS array mode can be used and is not intended for use when learning to do SEM lithography.*

Other sample patterns and run files besides those listed here may also be included in the "\NPGS\Projects\Samples" directory.

Patterns for Alignment
*The first three patterns and run files that follow demonstrate a simple two level alignment procedure.*
The first step is to write the pattern DEVPAT1.dc2 by highlighting the run file DEVPAT1.rf6 and using the "Process Run File" button (this is the same as "Commands - Process Run File - Run NPGS.exe. After processing (development, metatization, and lift-off) the alignment pattern ALIGN.dc2 may be written by selecting the Align.rf6 run file and using the “Process Run File” button. Once the alignment is complete, the pattern DEVAT2.dc2 can be written by running PG with the run file DEVAT2 with the NPGS Menu command "Commands - Write Only - Use info in Pg_Align.sys".

*The processing of the Align.dc2 and DEVAT2.dc2 patterns can either be done with individual run files as described above or by combining the two steps in a single run file, which is then processed with the “Process Run File” button. This is the recommended approach and can be tested with the Device2withAlignment.rf6 run file listed below.*

To get the basic idea of how alignment patterns should be made, simply view the following patterns in DesignCAD and write the patterns in the above sequence on a dummy sample without doing the processing. (A sample with some surface structure will best demonstrate the alignment windows.)

DEVPAT1.dc2
This is a pattern with a center test structure and two sets of alignment marks. Once this pattern is written onto a sample, the following alignment pattern may be used to align to the marks without exposing the test structure.

DEVPAT1.rf6
This run file writes the above pattern when used with PG (do not run with AL). If the “Process Run File” button is used, the run file will be processed correctly.

ALIGN.dc2
This alignment pattern is to be used with the program AL. If the “Process Run File” button is used, the run file will be processed correctly. It contains six "windows" with crosshairs that match the pattern "DEVAT1".

ALIGN.rf6
This run file will cause AL to write the above pattern with only the two outer alignment windows open; then when the user continues the program, the four inner windows will open. The run file is set up for the coarse alignment to be done at 200x and the fine alignment at 1000x.

DEVPAT2.dc2
This pattern contains contact pads that line up with pattern "DEVAT1".

DEVPAT2.rf6
This run file will write the above pattern when used with PG (do not run with AL). The pattern writing will pause for the user to change the microscope magnification and coarse beam current.

Device2withAlignment.rf6
This run file includes both the alignment using ALIGN.dc2 and the subsequent writing of the pattern DEVAT2.dc2. *Normally, alignment and pattern writing will be done using a single run file as shown in this example.*

SCALE1.dc2
This pattern contains one window that forms a square frame structure. This pattern is used in the procedure for calibrating the aspect ratio and absolute magnification of NPGS for the microscope. See the "NPGS Installation Guide" for complete details.
Exposure Parameters

Determining the correct dose for a pattern involves much more than just the sensitivity of the resist being used. The situation is complicated because the primary dose only describes the electrons coming down the microscope column, while the exposure is determined by the actual dose, which includes the secondary electrons created by the primary beam. Note also that the secondary electrons that contribute to the exposure at one location may originate at another location. This is known as the proximity effect. Other factors that influence the actual dose include: Beam Energy, Substrate Composition, Pattern Linewidth, and Pattern Density.

Beam Energy: A higher beam energy will cause deeper penetration into the substrate and consequently fewer secondary electrons will reach the surface. Using a very high beam energy will be similar to using a very thin substrate, i.e., few secondary electrons will be at the surface to expose the resist. The end result in both cases is that a larger primary dose will be required and finer lines can be obtained when compared to lower beam energies and thicker substrates.

Substrate Composition: For a high Z material, there is less penetration by the primary beam and there are more secondary electrons created near the surface. For example, the same pattern on GaAs requires slightly less primary dose than on Si. Also, proximity effects on GaAs are much more pronounced than on Si because the range of the secondary electrons is much shorter.

Pattern Linewidths and Density: Every pattern element receives exposure from secondary electrons when nearby pattern elements are exposed. For example, an isolated 50 nm wide line will require more primary dose than a group of 50 nm lines, and an isolated 1 micron box will require more primary dose than a 1 micron box in a closely packed array of boxes.

The example values given below will be useful as starting points, but it is recommended that test patterns be used to precisely determine the best values for your own structures. A test pattern is easily made by designing a test structure that contains the essential pattern elements of the final pattern and then using MakeArray to create an array with each copy of the test structure set to a different color. For more information on MakeArray, see BasicCAD Programs Supplied with NPGS (page 76). Each color can then be given a different dose in the run file. In this way a range of doses can easily be tested and compared by writing a single pattern.

The following are typical exposure parameters for 950,000 MW PMMA:

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Linewidth</th>
<th>Beam Energy</th>
<th>~Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>≤ 50 nm</td>
<td>30 kV</td>
<td>1 nC/cm</td>
</tr>
<tr>
<td>Si</td>
<td>~ 1 µm</td>
<td>30 kV</td>
<td>300 µC/cm²</td>
</tr>
<tr>
<td>Si</td>
<td>≥ 1 µm</td>
<td>20 kV</td>
<td>160 µC/cm²</td>
</tr>
<tr>
<td>GaAs†</td>
<td>≤ 50 nm</td>
<td>30 kV</td>
<td>1 nC/cm</td>
</tr>
<tr>
<td>GaAs†</td>
<td>≥ 1 µm</td>
<td>20 kV</td>
<td>150 µC/cm²</td>
</tr>
</tbody>
</table>

Beam Current: Another issue to consider is the choice of what beam current should be used, because the magnitude of the beam current will affect the spot size. In every electron microscope, the size of the beam hitting the sample, i.e., the spot size, will be the smallest at the highest possible accelerating voltage and the lowest beam current. Consequently, similar conditions will typically be used for writing the finest features.

Note that while many SEMs have a “Spot Size” selection that includes only 5 or 7 discrete values (each giving a different beam current), other SEMs include a “Coarse Beam Current” (functionally equivalent to the Spot Size) and also a “Fine Beam Current” adjustment. When a limited number of Spot Sizes are available, typically the smallest will give a measured beam current at the sample between ~10 to 40 pA, which will be used for the finest lithography. However, on some SEM models, the SEM can be set to ~1 pA, which is typically lower than is practical for the best lithography, because at such a low current, the image quality is very poor which makes the SEM very difficult to optimize. In such cases, the beam current used for the smallest lithography will typically be set to 5 to

SCALE1.rf6
This run file will write the above pattern.
10 pA when using a W filament, 10 to 20 pA for a LaB6 filament, and 20 to 50 pA for field emission microscopes.

An important note about drawing very fine structures is that the consistency of the microscope setup is critical. *If the astigmatism of the beam is not properly corrected, the quality of the exposed lines will vary with orientation.* For example, a single pattern may have underexposed vertical lines and overexposed horizontal lines even when both are given the same primary dose! To check for proper astigmatism correction, test patterns should include circles drawn with a single pass of the beam as in "Sample0.dc2". When exposed with astigmatism present, circles typically will appear (when viewed in the resist after development and coated with metal) wide with little depth on two opposite sides and narrow at 90° in between. Narrow, uniform circles indicate that there was little astigmatism when the sample was written.

When writing larger structures, it is often desirable to use a high beam current so that the writing time can be minimized. The question then becomes: How high can the beam current be for a given feature resolution? The answer will vary depending on the type of filament in the microscope, however, the imaging resolution can give a reasonable estimate of the spot size, which for high currents can be used to estimate the expected minimum feature size. For example, if the image at a high beam current shows a resolution of ~0.2 microns (as seen in the sharpness of structures in the image), then that beam current would typically work fine for 10 micron features, but would be unusable for 0.1 micron features. The image resolution can also be used to determine a reasonable choice of the Center-to-Center and Line Spacing parameters in the Run File, since these spacing parameters should provide overlap of the exposed spots in order to give smooth edges on the written structures.

When extremely high currents are used to write very large structures, it may be advantageous to defocus the microscope so that the beam will give a more uniform exposure and avoid making exposed dots or leaving bits of unexposed resist within large areas. When defocusing the beam, the image can be used to quantify how large the beam size has become, and the discussion above regarding feature sizes and the spacing of the exposure points will again apply.

**Common Exposure Questions**

For each of the discussions below, the values provided are general guidelines and will vary depending on details of the processing and the materials used.

Resist Thickness vs. Metal Thickness for Lift-off
When resist is used for lift-off of a metal coating, the resist thickness should typically be ~3x thicker or more than the metal to be lifted off. In general, if the resist is much thicker than the metal, the lift-off will be more successful, because the sidewalls of the resist will typically be less likely to be coated during the metal coating process.

Resist Thickness vs. Feature Size
When writing narrow lines, the resist thickness should typically be in the range of 1x to 5x thicker than the lines are wide. In some cases, a ratio up to 10x may be possible. When narrow lines are closely spaced, the resulting structure will have narrow “walls” of resist between the lines. In this case, a resist that is too thick will often droop or tip over, resulting in poor lithography.

Resist Thickness for Etching
The required thickness of the resist for etching will depend on the etch resistance of the resist as compared to the substrate being etched. For example, if the substrate etch rate is twice as fast as the resist etch rate, the resist must be at least twice as thick as the desired depth to be etched into the substrate.

Controlling the Resist Thickness
When the resist is spun onto the substrate, the spin speed and concentration of the resist will determine the final thickness. For PMMA, typically a spin speed of about 4000 rpm is used and the thickness is selected by using different concentrations of PMMA in the solvent. For research applications, the most cost effective approach can be to purchase a relatively concentrated PMMA/solvent solution, and then to dilute some of the solution to lower concentrations by mixing with the correct amounts of pure solvent. For PMMA, the solvents are either Anisole or chlorobenzene, where Anisole is the less hazardous chemical. While the thickness vs. concentration vs. spin speed...
charts will be different for the two solvents, the ultimate performance of the PMMA for lithography should not depend on the solvent.

**Optimum Beam Current for Exposure**
The optimum beam current will depend on the microscope and the desired feature sizes. In general, the best beam current will be the one that is as large as possible, but still small enough to produce the desired feature sizes. For fine features, it is recommend to start with a beam current between ~5 and 50 pA, depending on the microscope. For more information, see Writing Tutorial: Microscope Optimization (page 129).

For large features, the beam current may be increased substantially, which will greatly decrease the total writing time. Using 1 to 10 nA is quite common and some applications benefit from currents up to 100 nm or more. Note that when using very high beam currents, the writing time per exposure point may become very short. In that case, NPGS may exceed the maximum scan speed for the scan coils in the microscope. When this happens, distortions in the pattern will be seen where the beam has not “kept up” with the writing. For example, when the writing exceeds the scan coil speed, a box that is scanned with a horizontal serpentine sweep will have the correct vertical height, but the width will be too short.

**Optimum Accelerating Voltage for Exposure**
In general, for the finest features, the highest possible accelerating voltage will be best, which will be 30 kV for most SEMs. For applications requiring a large amount of undercutting, typically when using a bilayer resist, an accelerating voltage between ~10 and 20kV may be better.

**Optimum Working Distance for Exposure**
The finest features can typically be written when the working distance is between 5 and 10 mm. A short working distance will improve the resolution, while a long working distance will improve the depth of field. When writing features with a large writing field size, a longer working distance may be advantageous. However, when using a long working distance, the beam will be more susceptible to external magnetic fields in the room.

**Optimum Magnification for Exposure**
When deciding on the magnification to use when writing the finest linewidths, the two most important factors are where the magnification being used falls with respect to the magnification ranges* of the microscope and the size of the writing field with respect to the 16 bit resolution of the DACs. In general, to write the finest lines, it is best to select a magnification that is at the low end of the magnification range*, but with an actual field size of ~120x120 um² or smaller.

Note that when a pattern is read into the Run File Editor, the value initially displayed will either be the default value as entered in Pg_RFE.sys, or if the pattern is too big to fit at the default magnification value, a magnification value which is low enough to produce a writing field that fits the pattern will be displayed. It is recommended that the user set the default magnification in Pg_RFE.sys to be compatible with the magnification ranges* for the microscope being used.

Also, note that in the Run File Editor a maximum value will be displayed in the status bar when the magnification prompt is selected. This is not necessarily an "ideal" value for lithography. Instead, it is simply the highest magnification that can be used where the pattern will fit within the writing field. Usually, the best choice for the magnification will be somewhat lower than this maximum value, since having a somewhat larger writing field will allow the pattern to be moved during alignment, if needed.

*The magnification transition values which define the magnification ranges for an electron microscope are where relays in the microscope will switch between different circuits. In general, the best signal-to-noise in the microscope will be at the low end of a magnification range, and the transition values between the ranges can usually be heard as an audible click in the microscope circuitry. See the “Magnification Settings” section in System Installation: Summary - Check List (page 13) for additional information.

Large patterns can be written by using a lower magnification value. Depending on the microscope in use and on the size of the features being written, the magnification transition values may be less of an issue than when writing the finest features. In general, using a lower magnification will reduce the ultimate writing resolution and using low magnification values may introduce pattern distortions from
the 'pin cushion' and 'barrel' effects, as well as cause defocusing at large beam deflections. NPGS can be used at the very lowest magnification of the microscope, but at the low magnifications, microscope issues will degrade the quality of the writing.

Using a Bilayer Resist
A bilayer resist is produced by first spinning on a more sensitive layer, then a less sensitive, higher resolution layer. There are many possible resist combinations, but the most common is where a high molecular weight PMMA is spun on top of a low molecular weight PMMA. The result will be that the lower layer will develop more than the upper layer, which will produce a larger undercut, which can lead to a cleaner lift-off. However, in many cases, good lift-off can be achieved with only a single layer of 950k PMMA. Also, using a bilayer resist is not recommended when closely spaced features are to be written, since the resist between the features may have no support when the under layer fully develops.

Optimum Lift-Off Technique
There are many different techniques for the lift-off step and the best technique is the one that gives consistently good results with the least amount of effort. For PMMA, the simplest approach is to let the sample sit in room temperature acetone for 10 to 30 minutes, and then to squirt the sample with acetone from a squeeze bottle. When working with acetone, never let the acetone dry on the surface of the sample. Instead, always rinse with alcohol, i.e., IPA, without letting the sample dry. For more information, see Writing Tutorial: Lift-Off & Etching (page 137).

Common Exposure Problems
The "wheel" pattern (sample0) and the "star" pattern (sample3) are very good patterns to write when first learning to do lithography. For more information, see Patterns for Exposure (page 36). The star pattern is good because even with a relatively poor SEM optimization, it will typically look OK, while the wheel pattern allows the SEM optimization to be evaluated at a higher level and can show if the optimization was marginal, good, or excellent. Note that after a poor SEM optimization for the pattern writing, the wheel pattern can be completely unobservable.

The "Sample Pictures" page on the NPGS web site shows Diagnostic Images for the wheel pattern that can be extremely helpful when first learning lithography. The user is encouraged to write the wheel pattern at high kV (30 to 40 kV) with a low beam current (5 to 50 pA, depending on the microscope) on a silicon substrate with 950k MW PMMA that is about 50 to 200 nm thick. These conditions will allow the resulting patterns to be directly compared to the wheel patterns on the NPGS web site.

Focus
Often, the first difficulty a new user will experience is to carefully focus the SEM on the surface of the resist before the pattern is written. The most common mistake is to focus at the edge of the sample and then move several millimeters to the writing location, without checking if the sample is level. Another mistake is to start writing patterns before learning how to run the microscope well enough to take good pictures of a gold standard. When the beam is not well focused, the result is that the pattern will appear underexposed, however, if the applied dose is increased, the pattern will only appear with very wide lines and overexposed areas at the junctions of lines. The common mistake is to simply increase the dose, rather than to address the fundamental issue of the poor focus.

Astigmatism
Ultimately, the most difficult aspect of SEM lithography when writing fine lines is to minimize the astigmatism in the beam before the patterns are written. When there is astigmatism in the beam during pattern writing, the result is that lines written at different angles will effectively have a different dose. The wheel pattern is designed so that astigmatism in any direction will be easy to identify.

A very useful approach when adjusting the focus and stigmator settings of the microscope is to watch the image change from "bad" to "better" to "bad" and then return the setting to the middle. The goal is to precisely check that equal displacements in either direction for the parameter being adjusted will degrade the image quality by an equal amount. When this situation is confirmed, the parameter is then in the "best" position. When using a microscope with a knob that changes the parameter (or a mouse that has no on-screen display), a certain amount of skill is required to be able to return the parameter to the ideal midpoint between the two positions that produce an equally bad image.
However, on some PC based microscopes, it is possible to make equally spaced reference marks on the edge of the screen (using a felt tip marker) to allow precise displacements of the parameter to be consistently repeated, which then allows a relatively simple and systematic approach to be used to achieve very good results.

**Contamination Spot Diagnostic**

*A very good diagnostic technique is to make a contamination spot directly on the surface of the resist using the beam immediately before writing.*

![Contamination Spot Diagnostic](image)

When making a contamination spot, it can be very easy to make spots in a microscope with an oil diffusion pump and/or a rotary vane roughing pump, but it can be much more difficult in a clean, oil-free system. In most cases, one of the following approaches will work:

1) **Clean field:** Set the magnification to produce an image field of 5 to 10 microns, then step the stage to get to an area which has not yet been imaged. Using either the microscope “Spot” mode or the external mode with the NPGS DACs at (0,0), park the beam at the center of the image area for 1 to ~30 seconds. After restarting the normal imaging, zoom into the area to locate the newly created contamination spot. A slow scan speed may be necessary to locate the spot. When a clean field is needed, additional spots will require moving to a new area.

2) **Exposed field:** Set the magnification to produce an image field of 0.5 to 1 microns, then park the beam for 1 to ~30 seconds as in case (1), but without moving the stage so that the area where the spot will be made has already been imaged. When the normal imaging is restarted, the newly created spot should be visible. If this technique works, additional spots can be made within the same image area.

In either case, once the initial spot has been made, try repeating the process with a shorter exposure time to make a smaller spot. When the beam is well optimized, a circular spot with a ~10 to 30 nm diameter will be produced with a field emission SEM or ~30 to 50 nm with a conventional SEM. If the spot is too large or not circular, the beam optimization should be checked before writing patterns. However, many other factors besides the beam optimization can also cause the spot to be elongated. These include beam drift, stage drift, external magnetic fields, acoustic noise, and vibrations.

In some cases, the contamination spots will be well defined and can be used for additional optimization of the focus and/or stigmators. In other cases, the spots will quickly degrade during imaging, such that they can only be used to evaluate the optimization of the beam, but are not useful for making adjustments to the focus and/or stigmators.

*Additional information is provided in the sections "Optimizing the Microscope and Writing a Pattern" and "Detailed Tutorial on Pattern Writing", and on the NPGS web site on the “Sample Pictures” page.*

**Common NPGS Questions**

**How do I install NPGS on my microscope?**

NPGS is shipped with a printed NPGS Installation Guide in a white 3-ring binder. This guide will have detailed instructions for the microscope that was specified when NPGS was ordered. If NPGS is to be
moved to another microscope, it is typically just a matter of changing some values in the NPGS system files, getting the proper connector for the new microscope, and adding the appropriate NPGS communication program for the new microscope.

**How do I make NPGS control the microscope stage?**
The typical microscope stage will either have its own serial connection (for a 3rd party stage controller) or it will be accessed through the serial or Ethernet interface to the microscope. For NPGS to control the stage, the appropriate cable must be connected and the software configuration in NPGS and on the microscope or stage controller must be performed. If the stage was specified when NPGS was ordered, the NPGS Installation Guide will have detailed information on communicating with the stage in a section behind a tab in the binder. See *Pg_Stg.sys (Stage Interface Parameters)* (page 196) for more information.

**How do I make NPGS control the microscope column parameters such as magnification and beam current (i.e., spot size, condenser lens, beam aperture)?**
The typical microscope will either have a serial or Ethernet interface for controlling the column parameters. For NPGS to control the microscope, the appropriate cable must be connected and the software configuration in NPGS and on the microscope must be performed. The *NPGS Installation Guide* will have detailed information on communicating with the microscope specified when NPGS was ordered in a section behind a tab in the binder. For most recent model microscopes, a batch file named ‘Scope.bat’ will be supplied in \NPGS\Projects which will allow the magnification from each layer in a run file to be automatically passed to the microscope when ‘Scope.bat’ is entered on line #9 in *Pg_Cmd.sys* (use ‘Options - System Files - Pg_Cmd.sys’). Also, depending on the microscope, batch programs named ‘Scope2.bat’ and ‘Scope3.bat’ may be supplied which can set both the magnification and the beam current (through the ‘Configuration Parameter’ in the run file). Batch files used in NPGS can be modified using ‘File - Edit Batch Files’ from within the NPGS Menu program.

**How do I make NPGS read a picoammeter?**
Software is available with NPGS that allows it to read multiple values from a Keithley 6485 picoammeter (through a serial interface) and then use the average value as the beam current during the pattern writing. Please refer to the NPGS Installation Guide for more information or send e-mail for older installations which did not have this software included.

**How do I put the SEM into external control mode?**
This will vary depending on the microscope being used. On most older NPGS installations, a blue box with a two-position switch labeled “NPGS” and “SEM” will be used to select the mode. On most new installations, the NPGS Remote Enable Switch will be used. This switch connects to a USB port on the NPGS PC and to the appropriate Enable input on the microscope. The NPGS Installation Guide will have detailed instructions on the required connections.

The commands for the Remote Enable Switch will be included in the “NPGS Mode” and “SEM Mode” buttons on the NPGS Menu program. The “Pg_USB.exe” program is used to control the Remote Enable Switch. Full instructions are included behind a tab in the NPGS Installation Guide. The Remote Enable Switch is used for most Hitachi, JEOL, and Zeiss/LEO microscopes, while the FEI and Tescan models do not need this switch. When an external switch is not needed, the microscope software will have an “Ext Scan” (or similar) option in the microscope software. In this case, the “NPGS Mode” and “SEM Mode” buttons in NPGS may be programmed to activate the external mode of the microscope through a digital interface.

**I have made my pattern, now what should I do?**
A pattern in NPGS defines the geometry of the pattern, while a ‘Run File’ defines the sequence of the processing for multiple patterns and the exposure parameters for each pattern to be written. After one or more patterns have been designed, one or more run files should be made that contain the desired patterns and exposure parameters. Note that a single run file may process a single pattern or it may contain a complex sequence of pattern writing, alignment, and stage moves, as defined by the user, which may involved tens, hundreds, or even thousands of patterns and may take seconds, minutes, hours, or even days to complete.
I have made my run file, now what should I do?

Once a run file has been created, it is a good idea to use the “Simulate Writing” button to see how it will be written. (If this button does not exist in the Custom Commands, you can create a button that links to “Commands - Process Run File - Error Check Mode”.) For complex run files, the button “Estimate Total Time” will give a faster summary of the pattern writing and it can display an interactive graphical overview of the pattern locations for run files that include stage moves. For each pattern location, the write field can be displayed for the lowest magnification used in the pattern and also the area for the largest area written in a layer. (If this button does not exist in the Custom Commands, you can create a button that links to “Commands - Process Run File - Time Test Mode”.)

After a sample has been loaded into the microscope and the microscope has been optimized, the stage should be set to the desired starting location, and the “Process Run File” button can be used to process the run file. For a microscope with a properly configured digital interface and automated stage, the pattern writing will then be performed without any user intervention. More information on the steps for optimizing the microscope can be found at Detailed Tutorial on Pattern Writing (page 128).

My run files always start with a Comment entity that reminds me what I must do manually before writing and then a Command entity to put the SEM into NPGS Mode, can I have these be the defaults when I start a new run file?

Yes, you just need to create a “template” run file with the desired entities. The template file must be given a name that starts with “_Template” and when the Run File Editor is launched when no run file is highlighted, a list of template run files will be displayed.

I would like to have a run file ‘call’ another run file. Is that possible?

Yes, in the Run File Editor, simply use the ‘RunFile’ choice in the ‘Entity Type’ pull down list and double click on the ‘Nested Run File Name’ entry to select the run file to be called from the available run files in the current project. Note that once the nested run file name is entered, selecting the name then hitting Enter will launch another Run File Editor for editing the nested run file.

How do I view and/or change the Custom Commands buttons in my NPGS Project?

Use “Options - Custom Commands” to view and/or edit the button definitions for the current NPGS Project. Each button can be programmed to run a choice from the NPGS Menu items or a button can call any external program on the NPGS PC. A very powerful option is to use the Batch File mode for a button, where multiple command line programs with arguments can be executed in response to a click of a single button. The default buttons have been configured for the microscope specified when NPGS was ordered, but often custom modifications will enhance the functionality of NPGS.

Why does the ‘User Notes’ Custom Command button just load a text file into Windows Notepad?

This function is very simple, yet very powerful because it makes it easy for every NPGS Project to access the same text file. This file can then be used to share notes between users which can easily be read by clicking the button. Also, when NPGS is shipped, this file will be customized with installation notes regarding the specific microscope being used. The typical name for this button is “<Click Me - User Notes>” which is intended to get users to click the button and see both the installation notes and the usefulness of the shared file.

What is a ‘system file’ and what is it used for?

NPGS uses text ‘system files’ to store parameters that the user can customize within each NPGS Project. These files can be accessed through “Options - System Files…” on the NPGS Menu. Detailed information on the parameters in each file is available in the section System Files in each Project (page 172).

Can NPGS automatically run commands when the Menu program is opened or closed or when I enter/leave my Project?

Yes, if they exist, the files Pg_Menu_Start.bat and Pg_Menu_end.bat that are in ‘NPGS\Projects will be run whenever the NPGS Menu program is opened or closed. Also, if additional copies exist in individual Projects, they will be run whenever that particular Project is opened or closed. For microscopes with a digital interface, it can be a good idea to have commands in \NPGS\Projects\Pg_Menu_end.bat which leave the microscope in normal imaging mode, so that
simply closing the NPGS Menu program will run the commands. The ordering of the execution of these files is shown below:

**Launch NPGS Menu**
1st: `Pg_Menu_Start.bat` in `\NPGS\Projects`
2nd: `Pg_Menu_Start.bat` in initial user Project

**Change between Projects in Menu**
1st: `Pg_Menu_End.bat` in Project being closed
2nd: `Pg_Menu_Start.bat` in new Project

**Close NPGS Menu**
1st: `Pg_Menu_End.bat` in Project being closed
2nd: `Pg_Menu_End.bat` in `\NPGS\Projects`

When these files exist in a user’s Project, they do not need to duplicate the commands in the files in `\NPGS\Projects`.

**What are all the options for running external programs when a run file is processed?**
NPGS provides many ways to call external programs when a run file is processed. The names for these external programs are entered into system files as shown below, with the exception of ‘Command Entities’ in a run file which explicitly list the commands to run. In the case of the commands entered in `Pg_Cmdnd.sys`, it is often very useful to list the name of a batch file which then calls a lists of other programs as needed.

**Process X-Y-Focus before writing**
Line #7: `Pg_Cmdnd.sys`

**Before 1st Pattern**
Line #12: `Pg_Cmdnd.sys`

**Command Entities in Run File**
As listed in Command Entity

**Before each Pattern**
Line #10: `Pg_Cmdnd.sys`

**Before each Layer set Magnification/Beam Current**
Line #9: `Pg_Cmdnd.sys`
(*will be skipped for layers with no changes)

**Before each Layer Move Stage**
Line #1: `Pg_Stg.sys`

**Before each Layer set Focus**
Line #7: `Pg_Cmdnd.sys`

**After each Pattern**
Line #11: `Pg_Cmdnd.sys`

**After last pattern**
Successful Finish = Line #13: `Pg_Cmdnd.sys`
End on Error = Line #14: `Pg_Cmdnd.sys`

For each execution point above, if the corresponding line in the system file is blank, no external program will be run. Also, any programs listed in the system files as shown above should exist in the `\NPGS\Projects` directory. Usually lines #10, #11, #12, #13, and #14 in `Pg_Cmdnd.sys` will be left blank, but when needed, they provide a powerful level of control for automating advanced functions within NPGS. For example, one student used lines #13 and #14 to have NPGS automatically send e-mail from the cleanroom when NPGS had finished his patterns which would usually take about 3 hours. This was done by calling a command line e-mail program that he installed on the NPGS PC.
See Pg_Cmd.sys (External Program Names) (page 189) and Pg_Stg.sys (Stage Interface Parameters) (page 196) for more information. Also, if the microscope being used has a digital interface (usually serial or Ethernet), then documentation for the NPGS programs provided to communicate with the microscope will be behind a tab in the NPGS Installation Guide (a white 3-ring binder). This documentation will give full details on what to enter in the system files listed above.

**Why does NPGS use 'old-fashioned' batch files rather than newer options such as VBScripts or JavaScripts?**

NPGS uses batch files for the simple reasons that they are easy to understand, they do not require any programming experience, and they do not require any special software on the PC. Since a batch file is basically a list of commands that can be typed at a command prompt, it is also easy to test and debug them. Batch files used in NPGS can be modified using ‘File - Edit Batch Files’ from within the NPGS Menu program.

If you are more comfortable with a scripting language, the NPGS Custom Commands buttons in the Menu program as well as the Command Entities in run files do support both VBScripts and JavaScripts.

**How do I change the polarity of the blanking signal (and when do I need to do this)?**

The blanker electronics for most microscopes will need a TTL compatible voltage to turn the beam on and off. NPGS is shipped with the on/off voltages that normally work with the specified blanker, however, in some cases, the blanker may need the opposite polarity. In this case, the blanker electronics may have a simple polarity switch or jumper. Alternately, the NPGS blanker on/off voltages can be changed in the Pg.sys file (use "Options - System Files - Pg_Stg.sys"). When the blanker voltages are changed in Pg.sys, the menu item “Commands - Calibrate DACEs” must be used to update the settings on the NPGS PCI516 board. Note that all changes to system files are unique to each user's Project. To make a change that will be applied to all new Projects, be sure to use the “File - Save as Default” menu choice in the NPGS System File Editor.

**How do I import GDSII or CIF files?**

Once a GDSII file (with extension ".gds" or ".sf") or a CIF file (extension ".cif") is copied to a Project directory, select “All Pattern Files” in the “Display File Type” box to make them visible, highlight the file to convert, and use the NPGS Menu choice “File - Pattern Import - GDSII (or CIF) Conversion”. The appropriate conversion utility will be launched, which will convert the file to the DC2 format for use within NPGS. After a file is converted, the DC2 pattern should be viewed in DesignCAD to confirm that the conversion has been successful.

See File Import: GDSII (page 88) and File Import: CIF (page 89) for more information.

**How do I keep other people from modifying files in my NPGS Project?**

NPGS does not include a security scheme to limit the access to individual projects. However, through Windows, individual logins and file access permissions can be set up to limit access to personal projects.

In general, there isn’t a need to stop malicious access, so the color schemes within NPGS can be used to color code each project, which can be very effective at stopping accidental modifications to other people’s files. Use “Options - Color Schemes” to customize the colors within each project.

It is always recommended to keep complete backups of NPGS files.

**How do I set the default choices for the Advanced Modes in a new run file?**

These choices are set in the Pg_RFE.sys file. For additional information, see Pg_RFE.sys (Run File Editor Defaults) (page 194).

Note that most of the choices in the Advanced Modes list first need to be enabled in one of the NPGS system files. Use the “Arrow - Question Mark” icon in the lower right corner of the Run File Editor and then click one of the prompts in the Advanced Modes list to get additional information on how to enable it in your Project.
Why is there a ‘Blank Screen’ button?
This is a default button that runs the command “Commands - Blank Screen”, which will make the NPGS PC screen turn completely black. When optimizing any electron microscope, the best optimization will be obtained when the room is relatively dark. Consequently, making the NPGS screen turn black during the microscope optimization can be a useful function. This is especially true for older microscopes where it is almost essential to have the room nearly completely dark.

Why are there ‘DAC (0,0)’ and/or ‘DAC(+10,+10) buttons?
These are default buttons that will force the NPGS DACs (Digital to Analog Converters) that produce the XY voltages that control the beam position to go to one of two locations. The (0,0) choice will position the beam at the center of the NPGS writing field, which is also the center of the microscope display screen. The (+10,+10) choice will position the beam at the maximum upper right corner of the writing field, which will usually be off the microscope display area. (In this latter case, the voltages will be set to the maximum allowed values for the NPGS configuration, which will usually not actually be exactly 10 volts.)

Why does the black ‘DOS’ box pop up with the DAC calibration when I log in to Windows and/or when I start NPGS after it has not been used overnight?
The NPGS PCI516 board must run a self-calibration whenever the PC is started. Consequently, the file “Initialize_NPGS_PCI516.lnk” must be listed in the Windows “All User” Startup directory. This will cause the self-calibration of the PCI516 board to be performed whenever a Windows login is completed. The calibration on startup will be completed once, then there will be a delay of 20 minutes (specified in “NPGS\Projects\Pg_Cal.txt”) before the self-calibration is performed again. This delay allows the NPGS PC to warm up, so that the second calibration should be at a steady-state temperature.

When the NPGS Menu program is launched, it checks to see how long it has been since the last self-calibration of the PCI516 board. If the interval has been longer than the time specified in “Pg_Auto.sys” (the default is 10 hours), the self-calibration will be launched. This ensures that a periodic self-calibration will be performed, which will maximize the performance of the PCI516 board.

If a pattern writing session extends longer than 10 hours, the self-calibration will be performed as needed during the processing of a run file. During this calibration, the Beam Blanker setting will remain in the blanked condition, so that no exposure of the sample will occur. If very long writes are to be performed without a beam blanker, the default interval time can be extended to avoid having the calibration occur during the processing of a run file.

I am using NPGS to control a FIB and need very long dwell times. Can I change the default units for the Dwell Time and Doses in the Run File Editor?
Yes. Nearly all of the units in the Run File Editor can be customized for each NPGS Project. See the section “Exposure Time Limits” in Run File Editor: Pattern Entity (page 103) for the steps on changing the limits and units for the dwell time and doses.

Is there more information available, besides what is in this manual?
The printed NPGS Installation Guide provides step-by-step instructions on installing NPGS (a generalize version is also available in this document at NPGS: System Installation (page 2)), a Check List section that describes how to characterize many of the capabilities and limitations of the microscope (this is also available in this document at System Installation: Summary - Check List (page 13)), and information on any supplemental NPGS software, such as that used by the Remote Enable switch and/or a digital interface to the microscope.

Also, see www.jcnabity.com for more information on NPGS; especially the Diagnostic Images on the Sample Pictures page which are particularly useful for new users.

Why doesn't NPGS do what I want when I have it process my run file?
NPGS is very good at doing what you tell it to do, although, this is sometimes not what you want it to do. If you have a run file with complex stage moves, it is recommended that you perform a “dry run” with the microscope in the imaging mode. This will allow you to watch the results of the stage moves and to confirm that the commands you have entered into the run file are giving the results that you want. Also, the “Simulate Writing” button described above is very useful for checking that the designed pattern is written as intended.
Are there updates to NPGS available?
See www.jcnability.com/download.htm for access to the latest NPGS update. NPGS v9 is typically updated every 6 to 12 months, as needed, with a new version that adds new features, enhances the documentation, and fixes bugs. The NPGS Menu choice “Help - Password for Updates” must be used to generate the required passwords to download and to run the NPGS update.

At night and before weekends, should I turn the NPGS PC off or always leave it on?
It is recommended that the NPGS PC be turned off before any extended period when it will not be used. It should be turned off before weekends, and it is suggested to turn it off every night when it is not being used. Also, after each use of NPGS during the day, the NPGS Menu program should be closed which will return most newer microscopes to the normal imaging mode.

What is the meaning of life, the universe, and everything?
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The NPGS Menu program "Menu.exe" provides a 32 bit graphical interface where all aspects of pattern writing can be performed. In short, this interface is based on a file display window and custom command buttons that allow you to select files and do whatever processing is desired. The following sections describe the various commands within the NPGS Menu program.

The NPGS Menu program has been optimized for display at 1024x768 or higher with 16-bit color depth or higher. The minimum resolution supported is 800x600 with 256 colors. For NPGS v9 or higher, if Windows is using a dual display, NPGS will default to the primary display screen and will leave the second screen available for other programs.

Note that every time Menu.exe is launched, it does an integrity check on the key NPGS files. If files are found to be missing, the user will be informed of the exact file names, and Menu will then either terminate or continue depending on the importance of the missing file(s). A similar check will be performed on the files within each project, however, Menu.exe will give the user an option to copy the missing files from another project. System files with an old format will automatically be updated to the current format.

For maximum flexibility, Menu.exe can execute the following external programs every time it is started and when it terminates: "Pg_Menu_Start.bat" and "Pg_Menu_End.bat", respectively, as well as when the current project directory is changed. When starting, Menu.exe first runs "Pg_Menu_Start.bat", if it exists in \NPGS\Projects, then it will also run "Pg_Menu_Start.bat", if it exists in the initial project directory. Whenever the current project directory is changed, Menu.exe will run "Pg_Menu_End.bat", if it exists in the project directory that is being left, and it will run "Pg_Menu_Start.bat", if it exists in the project that is being loaded as the new current project. When Menu.exe is terminated, it will run "Pg_Menu_End.bat", if it exists in the current project directory, and then it will also run "Pg_Menu_End.bat", if it exists in \NPGS\Projects.

By default, "\NPGS\Projects\Pg_Menu_End.bat" will call SetDACs to zero the DACs whenever Menu.exe terminates. Note that these programs will not be called when NPGS is in the Office Mode.

When the NPGS Menu is launched, it will either always start in a specified project, start in the project which was used last, or display a listing of all projects for the user to select from. This behavior is set in the Menu program by using “Project – Set Default Project”.

Menu Program: Main Window

What’s This Help
The "What's This" icon is displayed in the lower right of the window. Clicking it then clicking any item on the window other than the menus, will bring up help on the selected item.

Custom Commands
The custom command buttons provide easy access to common commands. Several buttons are predefined, however, others are available to be customized by the user through the command "Options - Custom Commands".

Note that these buttons are uniquely defined for each project. If you have customized the buttons for one project and would like to copy them to another project, see Copying Custom Commands Between Projects (page 246).

When external programs are called through a custom command, the default directory will be the current project. Consequently, for external programs that are located elsewhere, it is necessary to include the full path to the external program. The NPGS software will offer to add the path to commands that have been entered without one.

The buttons have been designed with user-defined text labels, rather than graphical icons, simply because text is always easy to understand, while icons must be memorized. Since many NPGS users will find themselves alternating between doing lithography and doing experiments with a timescale that may extend into months, the text labels will make it much easier to get back into
lithography mode without requiring a relearning of icons. Also, any of the larger buttons with the word “Click” (as in “<Click Me - User Notes>”) will be flashed in bold text a few times whenever a project is loaded.

**Current Project Directory**
The "Current Project Directory" selection box is located at the top left above the file display box. The pull down list box shows all projects that are currently active and allows the user to easily switch between them.

**Display File Types**
The "Display File Type" selection box is located at the top right above the file display box. The pull down list box shows the file filters that are currently active and allows the user to easily switch between them. These filters limit the file display box to show only a specific subset of the files that are in the current project.

**File Display Box**
This is the large file list box that occupies most of the main window. It will show the files in the current project that are indicated by the selected "Display File Types" parameter. A file can be highlighted for processing by clicking on the file name using the left mouse button. Clicking on a file name with the right mouse button will bring up a quick command box, which shows commands appropriate for the selected file. Note that the Custom Commands and many of the menu commands are dynamically enabled or disabled, depending on the type of file that is currently highlighted.

The widths of the columns in the file display box can be changed by dragging the vertical divider bar that is between the column headings. To save the changes, click the column heading on the left of the divider after setting the new column width. To reset all columns to the default widths, set the width of the first column to less than half the default width and then click any column header twice. (Note that a quirk in the Microsoft compiler used to create Menu.exe causes the column divider to jump to the right when the column header is first clicked after the position is changed. So far, a solution for this behavior has not been found. In the meantime, when dragging the column divider, setting it approximately the width of a file icon to the left of the desired location will make the final location end up close to the desired location.)

**Auto Logging Mode**
When this box is checked, NPGS will automatically use the Auto Logging mode and display a logging file before any patterns are written. This logging file will allow the user to document the microscope parameters and any other aspects of the lithography. The file will be appended to a file called "Project.log" in the current project directory. *Note that this feature is especially helpful because all of the information in the logging file can be customized by the user.* For more information, see Auto Logging Mode (page 142).

**Exposure Scale**
When this box is checked and a run file is processed, all of the exposure times for the pattern(s) in the run file will be multiplied by the "Exposure Scale" factor. This option is intended for correcting relatively small changes to the exposure times. If large changes are entered that exceed the hardware limits on the exposure times, an error message will be displayed when the run file is processed.

**Beam Current**
When the selected run file only contains a single value for the "Measured Beam Current", this option will be enabled. The initial value in the box will be the Beam Current as listed in the run file. *The value displayed is not a measurement from the microscope, unless the Get Beam Current button configured and used!* If the user adds a checkmark to the small box, then the value entered for the Beam Current will determine the Exposure Scale in the box above. This allows a run file to be processed when the actual microscope beam current does not exactly match the value listed in the run file. Instead of changing the run file, the actual beam current reading can be entered for the "Beam Current" parameter, which will allow NPGS to compensate for the difference.

For example, if a run file has a "Measured Beam Current" value of 20 pA and the user enters a value of 19 pA for the "Beam Current" on the Menu.exe window because the beam has dropped slightly, then the "Exposure Scale" parameter will be automatically set to 1.053. When the patterns are
written, this scaling value will slow down all of the exposures by the specified amount, such that the
doses will match the values entered in the run file.

**Get Beam Current Button**

*The small button to the left of the Beam Current prompt can be configured and used to activate an*
*external program that can acquire the microscope beam current.* To enable this feature, the name of
*a program in the \NPGS\Projects directory that can read the beam current and save it to a file called*
*“%pg_io.tmp” in the current project must be entered on the second line of the file Pg_Beam.sys (use Options - System Files… - Pg_Beam.sys to modify this file). Note that the first line of the file will*
*typically be left at zero. If the external program does not automatically insert a column mounted*
*Faraday cup into the beam path or move the stage so that the beam hits a Faraday cup on the*
*sample holder, the user must manually perform this step before acquiring a new reading. The button*
*will show an equal symbol (=) when it is available for use.

For example, on a microscope with a Faraday cup in the column, the external program could be
*named \NPGS\Projects\GetBeam.bat. This batch program would consist of a list of commands that*
*would do the following:

1. Insert the Faraday cup into the beam path.
2. Turn the beam on (optional).
3. Measure the beam current and save the value (in pA) to the file %pg_io.tmp in the current project
directory.
4. Turn the beam off (optional).
5. Retract the Faraday cup.

In the case where the Faraday cup is mounted on the sample holder, either the external program
would need to move the stage to preprogrammed coordinates for the Faraday cup or the user would
manually move the stage to the Faraday cup position before running the external program.

**Status Bar**

The status bar is used for text display and occupies the very bottom of the NPGS Menu program
window. When a run file is selected in the file display window, the status bar will show a summary of
the advanced modes and entities in the selected run file. *If the summary extends passed the end of*
*the status bar, you can click and drag on the status bar to view all of the text.*

**Menu Program: Menu Commands**

**Menu Program: File Menu**

**Copy File(s) From Current Project**

This option allows one or more files to be easily copied *from the current project* to any other directory.
Note that the software will remember the previous destination directories, so it is easy to repeat
similar copy commands.

This command is very useful when copying groups of patterns and run files between another
computer and the main NPGS computer that is attached to the SEM. It can also be used to copy all
of the files within a project to another location on a network, to a Zip drive, to a floppy, or to a RW CD
for backup purposes. *You are encouraged to always maintain current backups of all of your files!*

**Copy File(s) To Current Project**

This command allows one or more files to be easily copied *to the current project* from any other
directory. Note that the software will remember the previous source directories, so it is easy to repeat
similar copy commands.

**Rename/Copy File in Current Project**

This command allows the selected file to be renamed or copied within the current project. If the
extension for the new file is not entered by the user, the extension of the original file will be used.
Since some files within the projects must not be renamed, NPGS will issue warnings if inappropriate changes are attempted.

**Delete File(s) in Current Project**
This command allows individual or multiple files to be deleted from the current project only. If a file is highlighted in the main file display box before this command is called, the selected file will be deleted after the user confirms the delete. If no files are selected, a secondary window will be displayed where multiple files can be selected and deleted simultaneously. Since some files within the projects must not be deleted, NPGS will issue warnings if inappropriate changes are attempted.

**View Text File**
This command opens the selected file in a read-only viewing window, if the file is recognized as an ASCII text file. Accepted text file extensions are listed in "\NPGS\Program\Pg_View.sys".

**Update System Files**
This command launches a window where multiple system files can be copied to and from the current project. For installations with more than one microscope or with a dual beam that has two columns, default files for each column can be kept in a separate directory. The ‘Help’ button provides additional information regarding the use of the functions on the window.

**Log Files...**
The commands in this sub menu allow the "LastRun", "Project", and "Master" logging files to be viewed. They also allow the logging files for use before and after pattern writing to be manually called. When saved, these files will be appended to a file called "Project.log" in the current project directory.

NPGS maintains three sets of log files:

- **NPGS_Master.log File**
  This file is kept in "\NPGS\Projects" and contains a time stamp entry for every pattern that is written in any of the projects.

- **Project.log File**
  A unique version of this file is kept in each project. By default, each copy will contain a time stamp entry for every pattern that is written in the local project. Also, "Pre-Write" and "Post-Write" comments can be added by using the Auto Logging mode or the manual "Pre-Write" and "Post-Write" commands under the "Files - Logging" sub menu. For more information, see Auto Logging Mode (page 142). Errors or warnings generated by the pattern writing software will also be automatically appended to this file.

- **LastRun.log File**
  A unique version of this file is kept in each project. By default, each copy will contain a time stamp entry for the most recent pattern that is written in the local project. Errors or warnings generated by the pattern writing software will also be automatically appended to this file.

**Edit Batch Files...**
This command launches a window where batch files in the \NPGS\Projects directory can easily be viewed and modified. The ‘Help’ button provides additional information. The ‘Command Prompt’ button can be used for manually testing batch files before they are set for use within NPGS.

**Display File Types...**
This command provides an alternate way to set the file filter displayed in the "Display File Type" selection box above the main file list. These filters limit the file display box to show only a specific subset of the files that are in the current project.

**Pattern Import...**
If a file is selected, this command will allow the "GDSII" and "CIF" conversion utilities that are provided with NPGS to be run. The "GDSII" command will be enabled when a file with extension "gds" or "sf" is selected. The "CIF" command will be enabled when a file with extension "cif" is selected. The "Other" choice will display information on how to convert other file formats, such as DXF or DWG, from within DesignCAD.
Printer Setup
This command calls the standard Windows printer setup utility.

Print Run File
This command will produce a printed version of a run file similar to what is seen in the Run File Editor.

Command Prompt
This command will open a command prompt window.

Exit
This command will terminate the NPGS Menu program.

Menu Program: Project Menu
This menu will be unavailable when the NPGS Menu program is started using the "Locked" command line option.

Create New Project
This command will open the dialog box for creating a new project. Each user is encouraged to have their own project, so that they can customize their own environment for NPGS without affecting other users.

Edit Project List
This command allows projects to be removed from the list of currently active projects. This command can affect other users if you remove their project, so please use it with caution! However, it will not delete the actual files, but it will prevent the NPGS Menu program from opening any projects that have been removed. If a project is accidentally removed, it can be added back by using the "Create New Project" command.

Set Default Project
This command is used to set the behavior of what the NPGS Menu program does when it is started. Specifically, it will either open a default project or prompt the user for which project to open as defined in this command. The settings entered here will affect all users.

Rename Current Project
This command allows the currently active project to be renamed. This will be most useful to users who have upgraded an older system and wish to give the projects more descriptive names than were allowed in the previous versions of NPGS. However, any project that will continue to be used with the DOS version of DesignCAD should not be given a new name with more than 8 characters.

Menu Program: Options Menu
Custom Commands
This command will open a window that allows the user to modify the Custom Command buttons that are displayed on the main menu. Note that some commands that are used in all NPGS installations are predefined, however, there are many available buttons for user-defined commands. The definitions for these buttons are unique for each project. You are encouraged to use this command to customize the buttons to call any commands that you frequently use.

Note that the Cut/Copy/Paste buttons on the Custom Command dialog box can be used to copy or move custom commands from one project to another.

When ‘Batch’ commands are entered, NPGS will run an “Integrity Check” on the commands when the ‘OK’ button is clicked. This will check if the commands have valid paths and that the actual programs being called already exist* on the hard disk in the specified directories (*this check is skipped in the NPGS Office mode). Also, when a command does not have a path, the software will offer to add “\NPGS\Projects\” or “\NPGS\Program\” to the beginning of the command, as needed.
Directory List
This command allows the list of source/destination directories presented in the Copy To/From commands to be edited. Note that if only one entry is in the list, it cannot be removed. This list is unique for each project.

File Types
This command is quite advanced and will seldom be used by most users. It allows the file filters that are presented in the "Current File Types" box to be edited. The expected use for this command will be when a user has a CAD file format that has an extension that is not already displayed. This list is unique for each project.

System Files...
This command allows the user to easily modify the system files for the current project directory. Selecting one of the system files displayed in the sub menu will immediately open the file in the system file editor, while selecting the "System File Editor" sub menu option will open the Pg_Edit.exe program for general use. The latter option will allow other files to be edited besides the standard files listed on the System File sub menu. For example, if external drivers are used by NPGS to control the SEM and stage, the system files for these drivers will show up in the list of editable files when the "System File Editor" is selected, even though they are not standard NPGS files.

Color Schemes
This command allows the user to customize the colors used in the NPGS Menu program and in the Run File Editor. While color may seem like a fairly trivial issue, for users with non PC based microscopes that are typically used in dark rooms, it can be quite handy to define a dark color scheme for NPGS. Most of the predefined color schemes make use of a 16-bit color palette, however, the last scheme uses only the standard colors of a 256-color palette.

Select Color Scheme...
This command allows the user to select any of the defined color schemes for immediate use.

Menu Program: Commands Menu
Process Run File...
All of the following sub menu options will process the run file using NPGS.exe. In turn, NPGS.exe will call PG.exe for pattern writing and AL.exe for alignment, as required by the run file. Typically, only the first choice will be used for routine pattern writing, but the others can be useful in special cases as described below.

When using an "Office Installation" of NPGS for pattern design and run file editing away from the microscope, the following programs will be used instead of the normal versions listed above: NPGStest.exe, PGtest.exe, and ALtest.exe. These versions will process run files for testing purposes, however, they will not actually interact with any hardware.

The NPGS pattern writing and alignment programs will run in a full screen mode. For the best performance, you should not change this mode during the pattern processing.

Run NPGS.exe*
This is the command that is predefined on the first "Custom Command" button. Typically, it is the command used for all pattern writing.

Non-Stop writing mode*
This command will force the run file to be processed as if the "Non-Stop..." advanced mode in the run file were set to "Yes". Specifically, in this mode the pattern writing will only pause before each pattern layer that has the "Pause" parameter selected.

Error check mode
This command will cause the run file to be processed in an error-checking mode, which will not actually write the pattern to the microscope. The elements in each pattern will be calculated, so that any errors can more easily be isolated. It is typically used when an invalid pattern is causing the pattern writing to terminate prematurely. In NPGS v9, this mode will display the pattern on the NPGS PC screen as it is calculated, and the user can select between real time display or a faster
Time test mode
This command will cause the run file to be processed in a special mode to estimate the writing time for each pattern. In NPGS v9 or higher, a summary of the run file which contains the total estimated exposure time for all patterns in the run file and estimated times for stage moves will be displayed. The number of points in each pattern will be calculated, but the actual exposure points will not be calculated and the pattern will not be written. This command is very useful when creating new patterns and the total writing time for each pattern is not known.

No prompt to repeat mode*
This command will eliminate the prompt asking if each pattern should be repeated.

Fracture test mode
This command is only to be used with run files using the Fracture mode. It will fracture the pattern, but set the file names so that they can be loaded into DesignCAD for viewing. For more information, see Run File Editor: Fracture Entity (page 108).

Disable all stage control*
This command will process the run file, but all stage control will be disabled.

*These modes will activate the Auto Logging Mode (page 142), if it is enabled.

Write Only…
All of the following sub menu options will process the run file using PG.exe, which only performs pattern writing, not alignment. Also, note that PG.exe does not support many of the advanced options that are handled by NPGS.exe. Typically, the following commands will only be used in special cases as described below.

Run PG.exe*
This command will process the run file using PG.exe in the default mode.

Error check mode
This command will cause PG.exe to process the run file in an error-checking mode where all of the exposure points are calculated and a detailed summary is provided for each pattern element.

Error check mode (Non-stop)
This command will cause PG.exe to process the run file in an error checking mode where all of the exposure points are calculated, but the processing doesn’t stop until the entire pattern is finished or an error is encountered. In NPGS v9, a graphical display of the pattern writing will be shown on the NPGS PC. Note that the graphical display will always be lower resolution than the actual writing, so some distortions in the display on the PC screen may result. While the graphical display does follow the exact sequence of the pattern writing by NPGS, the relatively low resolution of the PC screen (when compared to the 16 bits used by NPGS) may produce misleading results. For example, when a Filled Polygon is filled in the serpentine mode, the beam will sweep back and forth to fill the area, however, the graphical display on the PC screen will often be too coarse to show every pass of the beam. This will result in an image on the PC screen that appears not to sweep in a uniform back and forth sequence. Such artifacts are caused by the PC screen resolution and do not indicate any problem with the actual pattern writing.

Time test mode
This command will cause the run file to be processed in a special mode to estimate the writing time for each pattern and to display a graphical overview of the pattern locations when stage moves are used. The number of points in each pattern will be calculated, but the actual exposure points will not be calculated and the pattern will not be written.

Use info in Pg_Align.sys
This command will cause the run file to be processed while using the alignment results contained in the file "Pg_Align.sys", which has previously been created by AL.exe. This is only needed when separate run files are used for the alignment pattern and the patterns to be exposed. Typically, a
single run file with both alignment and pattern entities will be processed using NPGS.exe, which will automatically enable this mode as needed.

Disable all stage control*
This command will process the run file with PG, but all stage control will be disabled

*These modes will activate the Auto Logging Mode (page 142), if it is enabled.

**Align Only...**
All of the following sub menu options will process the run file using AL.exe, which only performs pattern alignment, not writing. Also, note that AL.exe does not support any of the advanced options that are handled by NPGS.exe. Typically, the following commands will only be used in special cases as described below.

Run AL.exe*
This command will process the run file using AL.exe in the default mode.

Error check mode
This command will cause AL.exe to process the run file in a simple error-checking mode.

Manually test AutoAlign setup
This mode will use the parameters in the run file and the Auto-Alignment system file selected by the run file, but will not automatically perform the alignment. This mode should be used to view the registration marks with the microscope in the same setup that will be used for the actual alignment in order to determine how much signal averaging will be necessary. This mode can also be used to see the effects of various image-filtering combinations. Once the optimum parameters are determined, they can be entered into the appropriate AutoAlign system file and the results can be viewed using the following command.

See results of AutoAlignment
This mode will run the same as the normal Auto-Alignment mode, except it will pause after the alignment is finished for each set of windows. This mode is useful when evaluating the overall speed and accuracy for a given set of Auto-Alignment parameters. Once satisfactory results are obtained, the run file and AutoAlign system file are ready for use on a real sample.

Disable all stage control*
This command will process the run file with AL, but all stage control will be disabled

*These modes will activate the Auto Logging Mode (page 142), if it is enabled.

**Direct Stage Control**
This command will run NPGS.exe in a special stage control mode. For more information, see Direct Stage Control (page 159).

**Digital Imaging**
This command will launch the NPGS Digital Imaging program. If a supported image file is highlighted when this command is called, the file will be loaded by Pg_Image. For more information, see Digital Image Acquisition (page 153).

**Run File Editor**
This command will start the NPGS Run File Editor. If a run file is highlighted when the command is called, the selected file will be loaded, otherwise the editor will create a new run file. For more information, see Using the Run File Editor (page 94).

**Show Run File**
If a run file is highlighted, this command will start the Run File Editor in a display only mode. This can be useful when a run file is to be viewed, but not modified.

**Print Run File**
If a run file is highlighted, this command will bring up a window from which the run file can be printed to any printer recognized by the Windows operating system.
**DesignCAD Express v21**
This command will start DesignCAD Express v21.2. If a *.dc2 file is highlighted when the command is called, the selected file will be loaded into DesignCAD, otherwise DesignCAD will be started with a blank design screen. (This command is not active if DesignCAD Express v21.2 is not installed in `\NPGS\DC21Exp`.)

**DesignCAD Express v16**
This command will start DesignCAD Express v16.2. If a *.dc2 file is highlighted when the command is called, the selected file will be loaded into DesignCAD, otherwise DesignCAD will be started with a blank design screen. (This command is not active if DesignCAD Express v16.2 is not installed in `\NPGS\DC16Exp`.)

**DesignCAD LT**
This command will start DesignCAD LT2000. If a *.dc2 file is highlighted when the command is called, the selected file will be loaded into DesignCAD, otherwise DesignCAD will be started with a blank design screen. (This command is not active if DesignCAD LT2000 is not installed in `\NPGS\DC2000LT`).

**DesignCAD (DOS Version)**
This command will start DesignCAD 6.0/6.1 for DOS. If a *.dc2 file is highlighted when the command is called, the selected file will be loaded into DesignCAD, otherwise DesignCAD will be started with a blank design screen. (This command is not active if DesignCAD v6.0 or v6.1 is not installed in `\DC6`).

**Calibrate DACs**
This command will manually activate the auto calibration procedure for the DACs of the custom, high speed PCI board that will be used by NPGS v9.

**Set Blanker…**
This command changes the state of the blanker to turn the beam on and off. Note that the terminology used is the intuitive "Beam On" and "Beam Off", while the blanker itself may have "Blanker On" and "Blanker Off" settings.

If the blanker in use is always under the control of NPGS (as opposed to the more convenient models with an internal/external control setting), it can be useful to add the "Beam On" and "Beam Off" commands to the "Custom Commands". This can be done by selecting the "Beam On" and "Beam Off" choices from the "Existing Menu Command" list or by using the command `\NPGS\Program\BCC On for Off` in any Batch mode command. For more information, see “Blanker Control Connector (BCC) (page 214)".

**Set DACs**
For NPGS v9, the output voltage range on the X and Y SMA connectors will be determined by the settings in "Pg.sys" for the current project directory. Note that the values entered by the user always range within ±10 volts, while the actual output range is scaled according to the settings in "Pg.sys".

Also note that in all cases the polarity of the output voltages will be set according to the "xy mirror" parameter in the "Pg.sys" file. The end result is that a (+10v,+10v) value entered by the user will always put the beam in the upper right corner of the field of view, while the voltage into the SEM may actually be something like (-5v,+3.75v), or some other values appropriate for the SEM in use.

When defining Custom Command buttons, the following command can be used to set voltages on the DAC outputs: "\NPGS\Program\SetDACs X Y", where "X" and "Y" are values from -10 to +10. Note that the actual output voltages will be scaled as discussed above. For more information, see "PCI516 DAC Outputs (page 212)".

**Blank Screen**
This command will blank the PC screen until the mouse is clicked. It is intended for use when the lights must be dimmed to enhance the image on the SEM screen.
**Menu Program: Help Menu**

**NPGS Manual (PDF Version)**
This command displays the NPGS Manual in the PDF file format, if a PDF reader program is associated with the “pdf” file format in Windows. **This version is recommended when a printed manual is desired.** For information on printing PDF files, see Help Files (page 208).

**NPGS Manual (HTML Help Version)**
This command displays the NPGS manual in the HTML Help format

_All versions of the NPGS Manual contain the same information._

**Hardware Diagnostics**
In NPGS v9, this command launches "SetDACs.exe" with the "d" command line argument, which runs the PCI516 diagnostics program in a DOS Window.

**Password for Updates**
This command launches a "Keyword" to "Password" generation program which only functions on an authorized NPGS PC. This feature is only needed when downloading updates from the NPGS web site at "www.jcnabity.com/download.htm". Protected files will require a password before downloading and possible another password when decompressing the downloaded file. In each case, a "Keyword" will be provided which can be converted into the required password using this feature.

This approach allows NPGS Updates to be immediately available to authorized users at any time, while preventing unauthorized access to the NPGS files. An authorized user may only use the generated passwords to access the NPGS files for updating their own system. Note that other security measures are also in place to prevent NPGS from functioning on unauthorized systems. These security measures are necessary to ensure that NPGS can continue to provide the highest performance at the lowest cost to authorized users.

**About NPGS Menu**
This command brings up a dialog box showing information on the version of NPGS in use, and shows the dates for the main NPGS files. It also indicates if the software is running in the “Microscope” mode or the “Office” mode.

**Menu Program: Command Line Options**
There are two command line options for the NPGS Menu program that can be set in the properties of the Windows Desktop icon used to start the program. When neither of these options is specified, the NPGS Menu program will start as specified by the "Project - Set Default Project" parameters.

**Directory Mode**
This mode makes the NPGS Menu program start in the specified project directory, effectively overriding the "Project - Set Default Project" parameters. **The Directory Mode can be useful in multi-user facilities when unique icons on the Windows Desktop are desired for each user.** On the "Shortcut" page of the icon properties, enter a "Target" as shown below:

```
x:\Npgs\Program\Menu.exe /Dx:\npgs\Projects\UserProject1
```

where the two "x:" strings must specify the disk partition where NPGS is installed and "UserProject1" is the name of the project to start in. The name of the icon should also be set to indicate the user and/or project.

**Locked Mode**
This mode makes the NPGS Menu program start in the specified project directory, effectively overriding the "Project - Set Default Project" parameters, and prevents the project from being changed within the menu program. This mode also disables the "Projects" menu, so that new projects cannot be created and existing projects cannot be removed. **The Locked Mode can be useful for new or infrequent users, since it will limit what they may accidentally change within the program.** On the "Shortcut" page of the icon properties, enter a "Target" as shown below:
x:\Npgs\Program\Menu.exe /Lx:\npgs\Projects\LockProject1

where the two "x:" strings must specify the disk partition where NPGS is installed and "LockProject1" is the name of the project to start in. The name of the icon should also be set to indicate the user and/or project.
**Pattern Design**

**Using DesignCAD**

To design complex patterns is very easy, however, to fully optimize the writing of a complex structure requires that the user understand how DesignCAD creates pattern elements and how the NPGS Run File Editor, PG, and AL interpret the elements of the patterns.

**NPGS is currently shipped with copies of DesignCAD Express v21.2**, while previously NPGS releases included DesignCAD Express v16.2 or DesignCAD LT2000. These versions are almost identical, and any differences are noted below.

**Getting Started with DesignCAD**

**Starting DesignCAD**

From within the NPGS Menu program, DesignCAD Express v21.2 can be started using the "DesignCAD Express v21" Custom Command button or the "Commands - DesignCAD Express v21" menu option. If a *.dc2 file is highlighted when DesignCAD is started, the file will be loaded, otherwise DesignCAD will start with an empty design screen. When DesignCAD is started, it is uniquely initialization for the project directory in use.

**Getting Help in DesignCAD**

Specific instructions for using DesignCAD for pattern design are available through the "NPGS - Help" option.

DesignCAD Express v21.2 also includes a PDF file of the DesignCAD Manual, which is available under the DesignCAD Help menu. (Note that the DesignCAD v21 and v16 manuals also include information about 3D commands that are only included in the “3D Max” version, which is not used with NPGS.)

**DesignCAD Commands**

There are often four ways to run a command in DesignCAD:

1. **Menu Commands** - DesignCAD commands are listed in the menus at the top of the window. (Note that the menu selections have been customized for use with NPGS and commands that are not useful for pattern design have been removed.) Using the menus is the easiest approach for new users, since you can browse through the menus looking for commands. The DesignCAD commands that are most useful for lithography are also listed under the "NPGS" menu option.

2. **Keystroke Commands** - Many common commands can be called by hitting a single key. For example, to draw a line, you may simply hit "V" (for vector). The standard keystroke commands are displayed on the right side of the pull down menus. In DesignCAD and in this documentation, the keystroke commands will be displayed in the upper case, however, the lower case key should be used. User defined keystrokes may also be specified through the "Tools - Customize - Keyboard" command. Once the common keystroke commands are memorized, they become extremely efficient.

3. **Command Line** - Hitting the Space Bar within DesignCAD will bring up the command line prompt. Any DesignCAD command can then be typed in, or ESC will close the window. A pull down list will also show previous commands that have been used.

4. **Toolbar Icons** - DesignCAD offers a wide range of toolbars with icons that include virtually every command. If the mouse pointer is held stationary over any icon for about 1 second, a pop up label will appear and a description line will be displayed in the status bar at the bottom of the DesignCAD window. The NPGS ‘Main’ and NPGS ‘Menu’ toolbars have been added specifically for pattern design.
Adding Pattern Elements
Detailed information is provided below and only a few quick tips are mentioned here. To draw a filled polygon, use the "NPGS - PolyFill" command. Other pattern elements will be found under the "Draw" menu. In general, you will start a command and then set the points required to define the structure being created.

Setting Points
One of the first things that is needed when designing patterns is how to set points to define the pattern elements. Within DesignCAD, there is a menu item called "Points" which provides all of the standard ways to set points within a CAD program. Also, once a command such as "Draw - Lines - Line" has been activated, the left mouse button can be used to set a point at any location. In addition to the mouse, the arrow keys can be used to position the cursor and then the "Insert" key will set a point, if a drawing command is active. When finished setting the points, hit Enter. Hitting ESC will delete the last point and terminate the command if no points are set.

Opening a File in DesignCAD
Once within DesignCAD, you may use the 'NPGS:Open' command that is under the NPGS menu at the top left of the window to open additional pattern files as shown below. Using this command, you may browse to other pattern directories and/or open pattern files in any DesignCAD format or in the CIF or GDSII formats. Do not use the standard "File - Open" command for NPGS patterns.

Saving a File in DesignCAD
To save a pattern file for use with NPGS, you must use the 'NPGS:Save' command that is under the NPGS menu. This utility will ensure that the pattern is saved to the NPGS Project directory that was in use when DesignCAD was called. It will also order the file by layer and save to the DesignCAD 2D ASCII format (*.dc2) for use by NPGS. Do not use the standard "File - Save" command to save NPGS patterns. Also note that the "File Save" prompt that is displayed when DesignCAD is terminated should not be used for NPGS patterns.

Importing Files
To import a file in one of the following formats: DWG, DXF, IGES, WMF, HPGL, or XYZ, use the DesignCAD 'Import' command under the 'File' menu.

To import a GDSII or CIF file while inside of DesignCAD, select the "NPGS - Open" command and then select a file with a "*.gds" or "*.sf" extension for GDSII or a "*.cif" extension for CIF.

Exporting Files
To export a file to one of the following formats: DWG, DXF, IGES, RIB, VMRL, WPG, or WMF, use the DesignCAD 'Export' command under the 'File' menu.

Overview of Pattern Design

Drawing Layers and Colors
The drawing elements within a pattern are differentiated by NPGS according to the drawing layers and colors.

Use of Layers
Only drawing layers 1 through 19 are to be used for pattern elements, while layers 20 through 100 can be used for comments. DesignCAD Express supports layers up to 1000, but the .DC2 file format only works with layers up to 255. Pattern entities are limited to keep layers 101 through 255 available during processing by BasicCAD programs.

For each drawing layer, the following parameters may be uniquely specified in the Run File Editor:

"Origin Offset".................................allows the entire pattern to be shifted
"Magnification"..............................must match the magnification of the SEM
"Center-to-Center"............................distance between adjacent exposure points
"Line Spacing"...............................distance between adjacent passed of the beam
"Configuration Parameter".................an arbitrary parameter for SEM control
"Measured Beam Current" must match the beam current hitting the sample

The "Center-to-Center" and "Line Spacing" parameters define the spacing of exposure points as shown in the figure. The "Center-to-Center" is the spacing along a line or arc for any orientation of the structure, and the "Line Spacing" is the spacing in the perpendicular direction for wide lines, arcs, or filled areas.

Use of Colors
Within a DesignCAD pattern, up to 256 unique RGB colors (out of the palette of 2^24 colors) may be used and each may be given a unique exposure Dwell and Dose within a run file. Within the Run File Editor, each dose may be set as an "Area Dose", a "Line Dose", or a "Point Dose". For patterns designed with older DOS versions of DesignCAD, the first 16 of the 255-color palette may be used. When using DesignCAD, patterns will be saved with RGB colors specified for each pattern element. Within the Run File Editor (RFE), the colors will be ordered by the following ranking: \((256 \times R) + (65536 \times G) + B\), where R, G, and B are the components of the RGB color value and each ranges from 0 to 255. These values can be viewed on the status bar in the RFE by selecting the corresponding Dwell prompt. Note that the "MakeArray" command in DesignCAD has been programmed to always produce a range of colors that vary from blue to red to yellow (where yellow = red + green). When processed by the color ranking scheme given above, the MakeArray color range will be ordered correctly within the run file, i.e., from blue (1st) to red to yellow (last).

Summary
Before a pattern is designed, the user should have in mind which layers and colors will be used to differentiate between the different exposure/spacing conditions desired for the various parts of a complex pattern. For example, if a pattern to test a variety of exposure times is desired, then a test structure may be duplicated using MakeArray and each copy may be set to a unique color. This allows each color of the structure to be given a different exposure time. If both the point spacing and exposure time are to be tested, a similar pattern may be made using MakeArray, but the test structures would be arranged in an array of drawing layers and colors.

If an entire pattern is to be repeated with different doses, the "Array" mode can be set in the Run File Editor and the "Edit - Set Doses" command can be used to step the dose for each exposure. In this case, nothing special needs to be done during the pattern design.

Related Topics: BasicCAD Programs Supplied with NPGS (page 76) and Patterns for Exposure (page 36).

**Line types**
There are five line types that have special significance in a pattern designed for lithography.

**Single Pass and Wide Lines**
A solid line \((\text{line type}=0)\) will be written as a single pass of the beam if the linewidth is set to zero, or it will be filled with multiple passes, if the width is greater than the Line Spacing defined in the NPGS
run file. Note that when a wide line is displayed, either the outline will be shown (default) or the wide line can be filled in as a solid color.

Filled Polygon: Serpentine Fill
A dashed line (line type=1) indicates a polygon that will be filled by NPGS where the beam will move back and forth in a serpentine fashion. Note that the Line Scale will only affect the display within DesignCAD and will not change how the filled polygon is written by NPGS.

Filled Polygon: One Sided Fill
A dotted line (line type=5) indicates a polygon that will be filled by NPGS where the beam sweep will always start on one side of the structure. Note that the Line Scale will only affect the display within DesignCAD and will not change how the filled polygon is written by NPGS. Unless a pattern specifically needs the "One Sided Fill", it is recommended that the "Serpentine Fill" be used instead.

The Info Box icon can be used to check the line type, linewidth, and line type scale (and many other parameters) for individual or groups of pattern entities.

Wide Lines: Perpendicular
The line type 3 can be used for wide lines. When a wide line is designed with a line type of 3, the sweep will be perpendicular to the starting side of each segment in the wide line. When the default line type is used, the normal writing direction is parallel to the length of each segment. This feature is typically used in FIB milling applications, where the direction of the sweep can be very important.

Filled Circle: Out-From-Center
The line type 4 can be used for filled circles, wide circles, and wide arcs. When these entities are designed with a line type of 4, the sweep will be from the inside towards the outside of the structure. When the default line type is used, the normal writing direction is from the outside towards the inside. This feature is typically used in FIB milling applications, where the direction of the sweep can be very important.

Other Essential Tips
Filled Polygons
To make a filled box or a filled polygon, run "PolyFill" from the NPGS menu.

Dashed and dotted lines (line types 1 and 5, respectively) are reserved for filled polygons and cannot be used for any other pattern element. All other line types besides those discussed above are allowed and are interpreted the same as solid lines by the NPGS software, however this may change in future versions.

Single Pass Lines
A linewidth of zero will produce a single pass of the beam for any "Line Spacing", which is typically the best way to make the finest lines. Note that setting the linewidth in DesignCAD does not guarantee what linewidth will be produced when the pattern is written.

DesignCAD Info Box
The Info Box is called by clicking on the top icon on the NPGS toolbox or by hitting "Ctrl I". Note that the Info Box will also appear if you double click on an entity, however, this approach is not recommended, because of the likelihood of accidentally moving the entity during the double click process. If an entity is accidentally moved, immediately use "Edit - Undo" or "Alt Backspace" to restore it to the original location. The info box is very powerful for editing the properties of existing pattern elements and can remain displayed as you click from entity to entity.

Drawing Layers
To draw on other layers use the keyboard command "L". Note that the drawing and editing commands are set to operate on all layers, not only the current layer. The "Origin Offset", "Magnification", "Center-to-Center" distance, "Line Spacing", and "Measured Beam Current" are set for each layer by the Run File Editor.
Drawing layer 0 (zero) is not to be used in a final pattern, however, it may be used in an intermediate step while creating a pattern. Any drawing entities in layer 0 will be written by NPGS as if they belong to layer 1.

**Drawing layers 20 to 100 are to be used for pattern comments only.** Anything written in layers 20 and above will be ignored at run time.

**Dump Points**
To set dump locations when writing with no (or a slow beam) blanker run "SetDump" from the NPGS menu. SetDump uses dotted circles of RGB colors (0,0,0)=white on black background, (128,0,0)=red, and (0,128,0)=green to designate dump points and these elements should not be used in a pattern for any other purpose.

**Writing Field Size**
The pattern generator has a square writing field that is centered on the origin (0,0) of the pattern. The size of the writing field is determined by the magnification of the microscope. When properly calibrated, as described in the "NPGS Installation Guide", NPGS calculates the field size based on the "mag scale" parameter listed in the system file "Pg.sys", and from the magnification entered in the run file. For more information, see Pg.sys (General System Parameters) (page 172).

When the microscope magnification is relative to the size of a Polaroid, at 1000x the writing field size will be around 100 \( \mu m \), but this will depend on the model being. For the writing field to be the correct size, the SEM magnification calibration mode must be the same as it was during the NPGS calibration, as described in the NPGS Installation Guide. For example, on some SEM models, the magnification displayed on the SEM screen can be selected to match the screen display, a Polaroid print, or a video printer output. Changing this selection will change the actual field size on the sample that corresponds to a given magnification, which means only the mode calibrated for NPGS should be used for lithography.

The command "NPGS - MaxMag" can be used to display the maximum magnification that the current pattern can be written at, according to the current calibration found in Pg.sys.

**Designing Patterns on other PCs**
If patterns are to be designed on a PC other than the pattern writing system, the NPGS Installation program can be used to install the appropriate NPGS files so that patterns and run files can be created just as on the original PC. The NPGS files that are installed may be used on any number of secondary PCs without violating the license agreement, as long as they are only used in conjunction with the original NPGS system. Each secondary PC must have a separate licensed version of DesignCAD installed. Send e-mail to Info@jcnability.com for information on obtaining additional licenses of DesignCAD.

**Pattern Design Primitives**

**Filled Polygons**

**Command:**
Run "NPGS - PolyFill" from the NPGS menu. (It should not be confused with the regular DesignCAD command Polygon.)

**Comments:**
PolyFill makes the design of filled boxes and polygons simple and error free. Simply follow the prompts that are provided. If help is needed, enter "h" at the prompt and additional information will be given. Note that polygons which enclose an unexposed area can be designed as shown by the ring structure in Sample3.dc2.

**Vertices:**
If only two vertices are entered, PolyFill assumes that the points are the diagonal corners of a rectangle. The relative positions of the two set points determine the direction of the fill lines. Lower-Left then Upper-Right will use horizontal lines sweeping up and the opposite order will sweep down.
Lower-Right then Upper-Left will use vertical lines sweeping to the left and the opposite order will sweep to the right. This fill convention is the same as filled polygons if it is assumed that the points of the box command are set in the counter-clockwise sense starting with the first point (see below).

If more than two points are entered, they are interpreted as the vertices of an arbitrary polygon. If the first and last points entered do not coincide, PolyFill will automatically add another point to close the polygon.

**Sweep Side:**
The order in which the polygon vertices are set determines the “sweep side” used during the writing. The first side of the polygon will be "swept" across the area if the vertices are ordered in a counter-clockwise sense. If the points are clockwise, then the last side of the polygon is swept. The figure shows how the points are ordered to fill the area from the bottom up.

PolyFill will display a marker on the polygon and ask the user if the design is OK. The marker is placed at the midpoint of the sweep side.

**Modifications:**
The BasicCAD program "ChangeSweep" can be used to change the sweep side of an existing Filled Polygon. The current sweep side will be displayed and the user will be allowed to change the sweep side if desired. (If a mirror image of a Filled Polygon is made using any of the "MIRROR" commands, then the sweep side of the mirror image will not be the same as the original and "ChangeSweep" would be needed to correct it.) Filled polygons and the subset of filled boxes may also be rotated or changed into any shape (such as by using the move point command "**", or the stretch command "STRETCH") as long as the edges of the polygon do not cross.

**Fill Lines:**
The area will be filled in with adjacent fill lines that have a slope determined by the "sweep side" as discussed above. Each line will have an exposure point spacing set by the "Center-to-Center" distance and the space between adjacent lines will be the "Line Spacing" in the run file for the appropriate drawing layer. Depending on the values used, some edges of a filled polygon may not be smooth. If this is the case, drawing a single pass line along the edge will eliminate any roughness.
The fill lines are always parallel to the original sweep side even if the polygon requires several splits and/or reverses of the sweep direction.

Filled polygons with fill lines that start from one side only are displayed as line type 5 (dotted), and filled polygons with serpentine fill lines are displayed as line type 1 (dashed). When the fill lines start from one side only, the beam will be positioned at the start of each fill line and allowed to settle before writing begins, while the serpentine fill does not pause at all. Consequently, the overall writing time for one-sided fills will be slightly greater than serpentine fills because of the extra settling time.

**Exposure Points:**
The exposure point spacing will be determined by the "Center-to-Center" and "Line Spacing" parameters in the run file. The number of beam passes is determined the same way as for wide lines as described above, however, instead of the pattern linewidth, the maximum dimension of the filled polygon in the direction perpendicular to the sweep side is used. Along each pass of the beam, the spacing of the points is the same as for the length of a single line as described above, where the segment length is determined by the distance along the pass from one end of the filled polygon to the other.

For identical rectangular areas (of any orientation), the exposure point locations will be the same if the area is defined by a wide line or by a filled polygon, as long as the length of the line and the sweep side of the filled polygon are parallel. The sequence of point exposure may vary, but the identical locations will be exposed.

**Capabilities:**
A filled polygon can be almost any shape defined by up to 1000 set points when using NPGS v9. The sweep side will split and/or reverse direction as needed to fill the entire area. **The obvious restriction is that the line defining the perimeter of the polygon should not cross itself.** For examples of complex filled polygons see "SAMPLE3.dc2" at Patterns for Exposure (page 36).

Also, note that filled polygons with very small spacings between vertices should be avoided. If the spacing between the vertices is smaller than the "Line Spacing" value entered in the run file for the pattern, the error PG(6) will typically be generated and in special cases, no error message will be displayed, but the pattern will have some distortion to the written area. The function "CutPoints" under the NPGS menu in DesignCAD can be used to reduce the number of vertices in a filled polygon.

**Circles:**
Filled circles can be approximated by creating a many-sided regular polygon shape that has a dashed line type. Alternately, in NPGS v9 or higher, a circle with a dashed line type will be filled with circular, counter-clockwise passes of the beam.

**Size:**
Any size of area may be filled. Areas requiring more than the maximum number of DMA exposure points will be broken into smaller sections automatically when the pattern is written. When the area is broken into smaller sections for any reason (including when the sweep direction reverses or splits) the beam will be positioned and allowed to settle between sections.

**Manual Entry:**
Filled boxes and polygons may also be created manually. The DesignCAD box command, "[]", and Polygon commands (Draw - Lines - Polygon) may be used to quickly make filled polygons if the line type has been set to dashed (linetype 1) for serpentine fill, or dotted (linetype 5) for one-sided fill. Curves, elliptical, and circular arcs may also be converted to vectors and used as part of a filled polygon. The ‘Line Type Scale’ may be set to any value since it only affects the display within DesignCAD. In general, the best line type scale value will be large enough to show that the feature is dashed or dotted when viewed at a typical size in DesignCAD, but not so large that the corners of the features are not obviously defined. For filled polygons, the linewidth should always be set to zero.

**Advanced Use:**
It is possible to fill structures with segments defined by combinations of lines, arcs, bezier curves, and/or cubic splines. The steps are:

1. Draw all of the sides of structure such that the endpoints of the adjacent segments coincide.
2. Select the entire entity.

3. Execute the DesignCAD "Edit - Selection - Combine Lines" command. This will combine all of the segments into one many-segmented vector. (Arcs and curves will automatically be converted to many short lines.) If more than 300 points are required to define the combined entity, the command will fail and the structure must be simplified. In some cases it may be necessary to convert the segments to vector entities using the "Vector Convert" command before using "Combine Lines" command.

4. Select the combined structure and then use the Info Box icon to bring up the Entity Info box. From there, you can set the Line Type to 1 (for serpentine fill) or 5 (for one-sided fill), or if it is desired to set the sweep side for the structure, set one point on the combined entity and run the BasicCAD program "ChangeSweep". Follow the prompts to select the sweep side.

**Lines**

**Command:**
Hit "V" (for Vector) or use "Draw - Lines - Line" and then set the points. Also, "Ortho Line" or "H" will create horizontal or vertical lines. The DesignCAD commands listed below can also generate lines suitable for pattern writing when the "Save as a Line" prompt is checked when the entity is created.

- "Curve" or "C" (for cubic spline curves)
- "Bezier Curve"
- "Arcs" - All
- "Circles" - All
- "Ellipse"

When designing multi-segmented lines, as produced by the non-linear entities listed above commands, see the discussion below on "Segments" and the BasicCAD program CutPoints at BasicCAD Programs Supplied with NPGS (page 76). The command "Edit - Selection - Vector Convert" can change almost any entity to line segments that can be written by NPGS.

**Dots:**
Single dots can be made as very short lines of zero width. Quite simply, the first and last points of a line can be made at the same location.

*However, the best way to make an array of dots is to define a filled rectangle that covers the desired area and then set the "Center-to-Center" and "Line Spacing" parameters in the Run File Editor to the desired spacings for the dots.* In this approach, the "Point Dose" should be used in the Run File Editor. Even hexagonal arrays can be made by designing two filled rectangles with rectangular point spacings such that the rectangles overlap and are offset by the correct distance.

**Slope:**
Lines of any slope are acceptable. There is little difference in calculation time for sloped versus horizontal or vertical lines.

**Width:**
Lines may be designed to have any width. The linewidth may be changed after a line is created by double clicking on the line and using the entity information box that will pop up.

**Line Style Toolbar:**
The pull down option on the left side of the Line Style Toolbar allows the current line style to be quickly changed. Note that only the "solid", "dashed" (1st choice below solid), or the "dotted" (5th choice below solid) should be used for pattern design.
The pull down option on the right side of the Line Style Toolbar allows previously used line type and linewidth options to be easily reselected.

**Line Style Icon**
To set the linewidth before a line is created, you must use the Line Style icon on the Line Style Toolbar, which will activate a line style and linewidth dialog box. Note that the "Fill Wide Lines" option only affects the display of entities within DesignCAD and has no effect on how the lines are written by NPGS.

**Activate Line Style Toolbar Icon**
If the Line Style Toolbar is not visible, use this icon to enable it. Alternately, it can be activated on the “View” tab of the Options dialog box under “Options - Options”.

If the designed width is greater than the "Line Spacing" given in the run file, then the beam will be swept back and forth in adjacent passes to cover the desired area. (Note that the actual linewidth produced is determined by the exposure conditions and microscope setup.) Each section of a wide line will be calculated as a filled trapezoid, such that adjacent segments will be written with matching ends. See "Segments" below.

The number of beam passes is given by:

\[
\text{#BeamPasses} = \text{Round} \left( \frac{\text{Pattern Line Width}}{\text{Line Spacing}} \right)
\]

where the right hand side is rounded to the nearest integer. Adjacent beam passes are always separated by the value of the "Line Spacing" parameter. The equation above is used for any line orientation.

**Sweep Direction:**
The default sweep direction for wide lines is along the length of each segment in the line. However, if the line type is set to 3, the sweep will be parallel to the starting edge of each segment. For a square end, this will be perpendicular to the normal sweep direction. This feature is typically used only for FIB milling applications.

**Length:**
Any length is allowed. (The number of points that may be exposed using a single DMA transfer is limited, therefore, if necessary, long lines will automatically be broken into shorter pieces when written.) For each pass of the beam, the number of points along the pass is given by:

\[
\text{#Points} = \text{Round} \left( \frac{\text{Segment Length}}{\text{Center to Center Distance}} \right)
\]

This equation is used for any line orientation. To have complete control over the beam sweep motion for long wide lines, see the filled polygon option described below.

*For single-pass lines, the recommended "Center-to-Center" distance is between ¼ and ½ of the desired linewidth.*

**Segments:**
A line may have up to 999 segments for NPGS v9. When a wide line (one requiring more than one pass along its length) is encountered by PG or AL, each segment of the line is calculated as a filled trapezoid with ends that match the adjacent segments as shown in the figure. If the first and last points of the line do not coincide, the ends will be square as shown in the upper wide line. If they do coincide, the ends will be written to match as shown in the lower wide line. The only change between the two wide lines shown is that the 4th point of the lower line has been moved to coincide with the 1st point. When the first and last points coincide, they will appear in DesignCAD as any other vertex of a
Pattern Design

Segmented Line. In contrast, if the points are close together but do not actually coincide, a starting and ending edge to the line will be visible. The filled trapezoids that make up segmented wide lines will be filled in the serpentine mode. See the discussion on "Filled Polygons" below.

Some care must be taken when the distance between adjacent vertices is comparable to the linewidth. If the width of the lower line in the figure were increased, an invalid wide line would be created, because the edges delineating the central opening would not be properly defined. When wide segmented lines with closely spaced vertices are designed, the BasicCAD program CutPoints should be used to cut out points that are too close together. For more information, see the discussion on CutPoints at BasicCAD Programs Supplied with NPGS (page 76).

Other Notes:

1. The 'Double Line Mode' should not be used for NPGS patterns.
2. The 'Multiline Mode' should not be used for NPGS patterns.
3. The 'Fill Wide Line' option in the 'Info Box' only affects the display within DesignCAD and does not affect the writing of the entity by NPGS.

Circular Arcs

Command:
Use "Draw - Circles - Circle" or "O", then set the center and radius, or use the keyboard or menu commands for the various circle and circular arc options.

Size:
Large circles and circular arcs will be automatically broken into smaller arcs that will fit within the available DMA transfer limit. The number of exposure points is determined by the designed arc length and width and the "Center-to-Center" and "Line Spacing" parameters entered in the Run File Editor for the pattern. For circular arcs, the "Center-to-Center" distance lies along the tangent to the arc, and the "Line Spacing" is in the radial direction.

Width:
Circles and circular arcs may have any width (up to 32,767 passes of the beam). The beam will be swept back and forth in adjacent passes tangent to the arc to fill wide structures. Note that setting the width to X and drawing an arc of radius X/2 will produce a filled fraction of a circle, i.e., a pie slice. See the Advanced Use of the PolyFill option for a quick way to fill arbitrary shapes.

Writing Direction:
NPGS v9 or higher provides a special feature for wide circles and wide arcs that are within 1% of a full circle. These structures will be written with the beam making concentric passes that all move in the
same counter-clockwise direction. This is in contrast to the normal writing for wide arcs where the beam will move back and forth in concentric passes to fill the structure.

**Filled Circles:**
NPGS v9 or higher provides a special feature for filling circles. If a circle is designed with a linewidth of zero and the dashed line type (1st line type option below solid), then NPGS v9 will fill in the circle when the pattern is written. When writing the filled circle, the beam will be swept in the same fashion as for wide circles, i.e., by using counter-clockwise circular passes with a decreasing radius.

**Sweep Direction:**
The default sweep direction for wide circles/arcs and filled circles is from the outside towards the inside. However, if the line type is set to 4, the sweep will be from the inside to the outside. This feature is typically used only for FIB milling applications.

**Special Note:**
Wide circles and arcs are filled slightly differently than wide lines. For wide lines the line spacing is kept constant giving an ideal total width equal to the number of beam pass times the line spacing. However, for wide circles and arcs, if there are more than 2 passes of the beam, the spacing will be adjusted slightly so that the ideal edge of the outermost/innermost passes of the beam will match with the designed width of the pattern. When the number of passes is odd, the adjustment is made on each side of the middle pass. When the number of passes is even, the adjustment is made on each side of and between the middle two passes. All other passes have the "Line Spacing" given in the run file. The maximum adjustment is 1/4 of the "Line Spacing" in the run file.

**Orientation:**
Any orientation is allowed. The exposure points of circles and circular arcs are calculated using floating point arithmetic and will be the best smooth curves possible for the given magnification. (Note that to get a true circle the system aspect ratio must be properly set, as described in the NPGS Installation Guide.)

**Speed:**
The calculation time for circles and circular arcs is several times longer than for lines and may be a factor if using a slow PC. However, for Pentium based machines, this is seldom an issue. If the calculation time is too long, "Ctrl O" and "Ctrl A" will produce circles and arcs that are made of short line segments which do not require the slower floating point calculations.

**Dump Points**
**Command:**
Run "SetDump" from the NPGS menu. SetDump uses dotted circles of RGB colors (0,0,0)=white on black background, (128,0,0)=red, and (0,128,0)=green to designate dump points and these elements should not be used in a pattern for any other purpose.

**Comments:**
For a complete discussion on the use of dump points, see Pattern Writing with No (or a Slow) Beam Blanker (page 164).

Also, note that if the DesignCAD “Scale” command is used on any circle or circular arc, the entity will be changed to an ellipse or an elliptical arc, respectively. In NPGS v9 or higher, dump points changed by the scale command will still be interpreted as dump points.

**Text**
**Command:**
*When using DesignCAD Express v21.2 or v16.2, the command “NPGS - AddText” should be used to add text to a pattern.* Choices will be available to add vector text which will be written as part of the pattern, normal text which can be used for comments which will not be written as part of the pattern, and the ‘##’ characters to use with the MakeArray AutoText marker option.
When using DesignCAD LT 2000, use the commands "Text 2D", "Text 3D", "Text Block", or "Text Arc" under the "Draw" menu, or the keystroke command "Ctrl T", while the "Save in Vector Form" box is checked (click the "Font/Text Size" button to verify).

Comment:
Text is not actually a primitive entity for pattern design, however, it can very easily be included in the pattern by having DesignCAD save it in vector form. If the "Save in Vector Form" box is not checked, the text will be ignored when the pattern is written, unless it is used for the Auto Text Mode (page 144). This can be useful when comments are to be included in the pattern file, but are not desired as part of the written pattern.

When DesignCAD creates text in the "Vector Form", the outline of the characters will be defined by lines with a width of zero. To obtain text that looks filled, it is recommended that the "Simplex2" or "Simplex" fonts be used.

Note that in DesignCAD LT 2000, after text is created in the "Vector Form", it will be "grouped" so that it can be selected and edited as a single entity. To edit the individual lines within the text, you must first use the command "Tools - Explode Group".

See Also: Auto Text Mode (page 144).

Most Useful Commands
Some of the most useful DesignCAD commands are listed below. For most editing commands, the entity or entities to edit should be selected before running the command.

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Menu Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Help - DesignCAD Help</td>
<td>launches DesignCAD Help</td>
</tr>
<tr>
<td>Ctrl I</td>
<td>NPGS Toolbox:</td>
<td>used to modify line type, layer, color, etc.</td>
</tr>
<tr>
<td>Alt Backspace Delete</td>
<td>Edit - Undo</td>
<td>undo last command</td>
</tr>
<tr>
<td>(none)</td>
<td>Edit - Erase</td>
<td>erases any selected entities</td>
</tr>
<tr>
<td>* (asterisk) _ (underline)</td>
<td>Edit - Section - Stretch</td>
<td>stretches existing pattern elements</td>
</tr>
<tr>
<td></td>
<td>Edit - Trim… - Point Move</td>
<td>move point</td>
</tr>
<tr>
<td></td>
<td>Edit - Trim… - Extend</td>
<td>changes only the length of a line, not the slope</td>
</tr>
<tr>
<td></td>
<td>Point - Origin</td>
<td>sets pattern origin (0,0)</td>
</tr>
<tr>
<td>. (period)</td>
<td>Point - Gravity</td>
<td>gravity set point</td>
</tr>
<tr>
<td>, (comma)</td>
<td>Point - Gravity Move</td>
<td>gravity move</td>
</tr>
<tr>
<td>: (colon)</td>
<td>Point - Point XYZ</td>
<td>set point absolute (x,y)</td>
</tr>
<tr>
<td>; (semicolon)</td>
<td>Point - Point Polar</td>
<td>set point relative (polar)</td>
</tr>
<tr>
<td>' (apostrophe)</td>
<td>Point - Point Relative</td>
<td>set point relative (x,y)</td>
</tr>
<tr>
<td>L</td>
<td>Options - Layer</td>
<td>brings up the layer processing options</td>
</tr>
<tr>
<td>V</td>
<td>Draw - Lines - Line</td>
<td>draws a vector</td>
</tr>
<tr>
<td>H</td>
<td>Draw - Lines - Ortho Line</td>
<td>draws orthogonal lines</td>
</tr>
<tr>
<td>Ctrl T</td>
<td>Draw - Text 3D</td>
<td>draws text for comments (will not be written) or draws text as vectors (will be written) if &quot;Save in Vector Form&quot; has check mark</td>
</tr>
<tr>
<td>Ctrl W</td>
<td>View - Fit to Window</td>
<td>zooms to display entire pattern</td>
</tr>
<tr>
<td>+ (plus)</td>
<td>View - Zoom In</td>
<td>zooms in (can be hit several times)</td>
</tr>
<tr>
<td>- (minus)</td>
<td>View - Zoom Out</td>
<td>zooms out (can be hit several times)</td>
</tr>
<tr>
<td>Ctrl M</td>
<td>View - Zoom Previous</td>
<td>returns to the previous zoom value</td>
</tr>
<tr>
<td>Z</td>
<td>View - Zoom Window</td>
<td>zooms into a window</td>
</tr>
<tr>
<td>Ctrl Shift P</td>
<td>View - Pan</td>
<td>shifts viewing area by dragging</td>
</tr>
</tbody>
</table>
Pattern Design

Toolbar Icons
DesignCAD offers a wide range of toolbars with icons that include virtually every command. If the mouse pointer is held stationary over any icon for about 1 second, a pop up label will appear and a description line will be displayed in the status bar at the bottom of the window.

One toolbar that is particularly useful for pattern design is the Line Style Toolbar shown below.

This icon displays a dialog box where the linewidth and line style can be set before drawing lines, circles, and arcs.

Ignored Pattern Elements
All DesignCAD commands may be used, however, the following commands will produce pattern elements that will be ignored by PG and AL. *In other words, these pattern elements cannot be used as part of the pattern to be written, however, some are useful for comments and documentation of the pattern.*

- Arrow
- Attribute
- Balloon (caution: the circle will be written)
- Bezier Curve (ignored unless "Save as a Line" is checked)
- Cone (only found in 3D mode, which should not be used)
- Cylinder (only found in 3D mode, which should not be used)
- Curve (ignored unless "Save as a Line" is checked)
- Dimension − all
- Ellipse (ignored unless Line mode is used)
- Elliptical Arc (ignored unless "Save as a Line" is checked)
- Extrude (only found in 3D mode, which should not be used)
- Hatch
- Hatch Fill
- Hatch Line
- Hemisphere (only found in 3D mode, which should not be used)
- Line to Curve
- Load Image File
- Load Symbol (ignored unless "Explode Symbol" is checked)
- Make Plane
- Plane
- Point Mark (used in Alignment patterns only, see section on AL)
- Pullout
- Shading
- Smooth
- Sphere (only found in 3D mode, which should not be used)
- Sweep (only found in 3D mode, which should not be used)
- Symbol
- Text 2D (unless marked "Save in Vector Form" under "Font/Text Size")
- Text 3D (unless marked "Save in Vector Form" under "Font/Text Size")
- Text Arc (unless marked "Save in Vector Form" under "Font/Text Size")
- Text Block (unless marked "Save in Vector Form" under "T" icon)

BasicCAD Programs
BasicCAD is a programming language that is supplied with DesignCAD. BasicCAD programs are ASCII (text) files that will run within DesignCAD. The power of this language is that it combines a BASIC type of programming language with all of the DesignCAD commands.
BasicCAD Programs Supplied with NPGS

The following commands are available under the "NPGS" menu in DesignCAD, and each command calls a corresponding BasicCAD *.bsc programs found in "NPGS\BasicCAD\DC21E". (Or in "NPGS\BasicCAD\DC16E" when using v16 or in "NPGS\BasicCAD\LT2000" when using the LT2000 version.) These programs should be self-explanatory when run and often additional information will be available by hitting "h" for help. Note that in most cases, if an entity is selected before the command is run, the initial introduction will be skipped, and the selected entity will be used, if appropriate.

NPGS_Open
This program should be used whenever loading a new pattern for lithography. Patterns in the GDSII and CIF formats can also be imported using this command.

NPGS_Save
This program should be used whenever saving a pattern for use with NPGS.

NPGS_Help
This program will launch a special help document that highlights the most important aspects of using DesignCAD for lithography pattern design.

PolyFill
This program facilitates the creation of filled polygons. To ensure the proper design of Filled Polygons, it is recommended that this command be used. For more information, see: Filled Polygons (page 67).

AddText (not used in DesignCAD LT2000)
This program will create text as Vector Text (written as part of the pattern) or as Normal Text (for comments - not written). For fun, it also has an option to write the Windows ‘WingDing’ font as vectors. Any Windows font can be written as part of a pattern.

DotArray
This program will generate a rectangular array of circular dots. It will either make the dots using Filled Polygons, Filled Circles (NPGS v9 or higher), or by using the circle pattern element with a width equal to the dot radius. It will prompt for array center (x,y), dot diameter, number of rows, number of columns, row spacing, and column spacing. For dots smaller than about 0.1 micron, it is recommended to simply use a large filled rectangle, where each exposure point will be spaced to produce discrete dots.

CircleArray
This program can generate an array of concentric circles or regular polygons. The modes include a linear array of circles with a specified center XY position, linewidth, inner diameter, and pitch, or a Fresnel lens with a specified wavelength (nm), focal length (um), and number of zones, or a gradient of colors (for different doses) using circles or regular polygons with 3 to 100 sides. The gradient mode may be useful for ion beam milling.

MakeArray
This program is extremely useful for making exposure test patterns. It allows the user to select an area to be copied to create an array. If the total number of array elements is \( \leq 256 \), then each element may be set to a different color, or if the total is \( \leq 19 \), then each element may be set to a different layer. Or if the number of rows is \( \leq 19 \), then each row may be set to a different layer, and if the number of columns is \( \leq 256 \), then each column may be set to a different color. Note that dump points that are copied using MakeArray will be unchanged with respect to their color, so that they will still be interpreted as dump points.

ShowPoints
This program will display the points of a pattern element along with other information about the entity, such as layer, color, and number of points. The points of the pattern element will be temporarily marked with the "Point Mark" entity, and the size of the mark will be scaled to the size of the entity. When the points of a Filled Polygon are displayed, the midpoint of the "Sweep" side will be indicated with a white marker. Note that using this program will delete any "Pointmark" entities in layer 255.
CheckAll
This program will check the current pattern for occurrences of Curves, Bezier Curves, Ellipses, Elliptical Arcs, 2D Text Strings, 3D Text Strings, Arc Text, Arrows, Symbols, Invalid Circles, Invalid or Questionable Filled Polygons, and Entities with too many points. A Questionable Filled Polygon is one where the first and last points do not coincide. Questionable Filled Polygons can be corrected using "NPGS - CutPoints" by selecting the questionable polygon and entering a small point spacing. An invalid Filled Polygon is one with fewer than 4 vertices and must be deleted or modified. No changes will be made to the pattern. When CheckAll finds one of the above pattern elements, it will display information about the element, including the Entity #, which can be used in OrderCheck to find the entity, if needed.

A secondary use for CheckAll is to watch the writing order for the pattern. To make use of this mode, the pattern should either be just loaded or to have been recently processed by OrderCheck. When the display mode is used, the pattern will be processed in a non-stop mode that highlights the pattern elements in the order in which they will be written.

CheckText
This program will check the current pattern for occurrences of Text strings only. (For large patterns, it is much faster than CheckAll, but it does not look for other ignored or invalid pattern elements.) No changes will be made to the pattern. Vector text is not counted since the vectors will be written as part of the pattern and are not in the text format. Text strings can be converted to vectors using "NPGS - ToVector".

MaxMag
This program will calculate the maximum microscope magnification that will allow the pattern to fit within the writing field. In order to determine the microscope calibration factor, the program reads the "mag scale" parameter from the "Pg.sys" file in the current project. It will also suggest a location for a new pattern origin if the pattern is not well centered, and will change the origin if the user hits "o" at the prompt. This program looks at the total pattern size, therefore, text or other ignored pattern elements may cause the calculated magnification to be incorrect. However, the Run File Editor determines the maximum magnification using only allowed pattern elements, so it will always perform the correct calculation.

ChangeSweep
This program will indicate the current sweep side of a filled polygon and allow the user to change it. While the program is running, prompts will be displayed in the DesignCAD status bar at the bottom of the window.

ToVector
This program will allow the user to selectively change occurrences of the following pattern entities so that they will be written as part of the pattern as vectors.

- Curves
- Bezier Curves
- Ellipses
- Elliptical Arcs
- 2D Text Strings
- 3D Text Strings
- Arc Text Strings

The following occurrences will be counted, but not changed.

- Circles and Circular Arcs
- Dump Points
- Arrows

CutPoints
This program has two primary uses:
1. **It can be used to convert any curve or line entity to a Filled Polygon.** For this use, simply create a line or curve with a linewidth of zero, and select "NPGS - CutPoints". The program will prompt if the structure should be a Filled Polygon with a serpentine or one-sided sweep direction and will allow the minimum point separation to be set. If CutPoints is used on a non-vector curve, the curve will automatically be converted to a vector entity.

2. It will allow the user to easily modify a segmented wide line so that it will be written properly by NPGS. It is most useful when vector entities (i.e., vector circles, arcs, ellipses, curves) are to be written with a large linewidth. CutPoints will prompt the user for the desired linewidth and for a minimum separation for the vertices of the entity. Adjacent vertices in the line that are closer together than the minimum separation will be eliminated. A separation value greater or equal to the linewidth will typically result in a structure that will be properly written, unless the curvature is very large. Using a smaller separation value will generate a smoother structure, however, if the vertices are too close together an error will result when the structure is written. Typically, a separation of one-half the linewidth will yield an acceptable structure with a reasonably smooth appearance, however, structures with a large curvature may still have problems. To be a valid wide line, both edges of each segment must be distinct and they must not overlap. The segmented line should be created before using CutPoints. If CutPoints is used on a non-vector curve, the curve will automatically be converted to a vector entity.

**OrderCheck**

This program will allow the user to manually step through the entities of a pattern in the order that they will be processed by NPGS. For OrderCheck to display the entities in the correct order, the pattern will be first be saved to the hard disk, reordered, and then reread, if necessary. This program will copy the pattern to a file called "Pg_Back.dc2" in the directory "\NPGS\Temp". Keystroke commands are displayed in the startup window that allow the view to be zoomed as the order is being displayed.

**OrderEntities**

This program allows the user to change the writing order of entities within a layer. First, the user will set points on one to fifty entities in the order that they are to be written by NPGS, then a point is set on the entity that will follow the changed entities. For example, if the pattern entities \texttt{a,C,b,F,D,g,E,h} are originally written in that order and the desired order is \texttt{a,b,C,D,E,F,g,h} then the entities, \texttt{C,D,E}, and \texttt{F} would be selected in that order and \texttt{g} would be selected to follow. This program will copy the pattern to a file called "Pg_Back.dc2" in the directory "\NPGS\Temp".

**OrderGroups**

This program works the same as OrderEntities, but groups of entities are selected within blocks instead of individually. All entities within the selected blocks must be in the same drawing layer. This program will copy the pattern to a file called "Pg_Back.dc2" in the directory "\NPGS\Temp".

**WinCalc**

This program will allow the user to easily determine the area of alignment windows and will give a suggested range of point spacings to use for the windows when the run file is created in the Run File Editor. Typically, the point spacing for alignment windows should be about one half of the desired accuracy for the alignment procedure. For example, if alignment is required to be accurate to 100 nm, then the point spacing should be about 50 nm. It may be useful to design an alignment pattern with two sets of windows. The first set may have fairly large windows for coarse alignment and the second set may be smaller for fine alignment. In the Run File Editor, the large windows would be given a relatively large point spacing and the small windows would be give a point spacing compatible with the desired alignment accuracy. If the point spacing entered in the Run File Editor results in too many points, AL will automatically increase the spacing until the windows can be displayed. A warning will be displayed whenever AL changes the point spacing.

**GetFract**

This program will load the temporary files generated by NPGS.exe when using the "Fracture Test Mode" option within the NPGS Menu program. This option tells NPGS to fracture a pattern designated by the Fracture mode, but not to write the fractured sub-fields. Instead the temporary files will be named "fr00001.dc2", "fr00002.dc2", and so on, so that they can be loaded into DesignCAD for viewing. This program will automatically load as many "fr*.dc2" files as the user requests. In this way the results of the fracturing can easily be viewed. Another difference between the "%fr*.dc2" files and
the "fr*.dc2" files is that the viewable files are not offset as are the files to be written. The written files are all offset so that each file is appropriately centered in the writing field that will be offset by the stage motion. The viewable files are not offset, so that when they are loaded into DesignCAD, they will match up to recreate the original unfractured pattern.

**SetDump**
This program will create a "dump" point in the pattern. *Dump points are typically not necessary if the microscope has a fast beam blanker, but are almost always used when there is no blanker available.* The user will be prompted for which type of dump point is to be created. For more information see: Pattern Writing with No (or a Slow) Beam Blanker (page 164).

**SavelInfo**
This program will create a text file with the same name as the current pattern, but with the extension ".txt". The user may enter any number of lines of text and they will be saved in the current project directory. This is an easy way to save descriptions or comments about a pattern without putting the text in the pattern itself. Use GetInfo to view the saved text.

**GetInfo**
This program will display a text file that has the same name as the current pattern and ends with the extension ".txt". The file may be created using SavelInfo from within DesignCAD or with any editor in the ASCII mode.

**Fractal**
This program is meant to demonstrate how useful BasicCAD programs can be for repetitive pattern design. It will modify each side of a polygon (or any other segmented line) with one of two patterns: a single point or an inverted triangle. Repeated use of the program will generate very intricate patterns. For the best effect, the starting line should have a linewidth of zero.

**NPGS_Init**
This program is automatically called every time DesignCAD is started (but is not displayed in the "NPGS" menu). The user may wish to modify this program, although doing so will affect all other users, so please use caution.

### Making your Own BasicCAD Programs

The BasicCAD command language is a simple, yet powerful way to control the creation and editing of patterns. All of the commands under the NPGS menu in DesignCAD are actually BasicCAD programs that can be found under the "NPGS\BasicCAD" directory and can be viewed as examples. Programs used with DesignCAD Express v21.2 are in “DC21E”, programs used with DesignCAD Express v16.2 are in “DC16E”, programs used with DesignCAD LT2000 are in “LT2000”, and programs used with DesignCAD 6.0/6.1 for DOS are in “DC6”. These programs are all text files and can be modified using any text editor.

The help file "Macros17.hlp" in “DC21E” and in “DC16E” from the DesignCAD v17 Developers Kit has been included (the commands that are version specific are noted). The help file "Macros2k.hlp" in “LT2000” from the DesignCAD 2000 Developers Kit has been included.

For even complex pattern creation tasks, BasicCAD programs are relatively easy to design. The ‘fractal.bsc’ program is a good example of such a program. If you write your own BasicCAD programs, you can also add them to the menu or add them to custom toolboxes, which will make them easily accessible within DesignCAD.

The easiest way to make a BasicCAD program is to use the 'Tools - MacroRecord' function. These macros will be saved with the *.d3m extension, however, they are functionally identical to BasicCAD commands.

*If any BasicCAD program stops functioning properly, the DesignCAD menu command 'Tools - Stop Macro' can be used to terminate the program.*
Customizing DesignCAD
When DesignCAD is called from within an NPGS Project, the settings for DesignCAD are unique for that Project. In other words, each user can customize DesignCAD independently from other users.

The four main ways to customize DesignCAD are described below:

ToolBoxes
Using the menu item: 'Tools - Customize - Toolbar' you may create custom toolboxes that can be displayed within the DesignCAD window. The default ToolBoxes loaded by NPGS are:

- Contains NPGS Main toolbox for DesignCAD Express v21.2:
  NPGS_DC21e_NPGS_Tools1.dct
- Contains NPGS Menu toolbox for DesignCAD Express v21.2:
  NPGS_DC21e_NPGS_Tools2.dct

- Contains NPGS Main toolbox for DesignCAD Express v16.2:
  NPGS_DC16e_NPGS_Tools1.dct
- Contains NPGS Menu toolbox for DesignCAD Express v16.2:
  NPGS_DC16e_NPGS_Tools2.dct

- Contains NPGS Menu toolbox for DesignCAD LT2000:
  NPGS_DC_Tools1.dct

Keyboard
Using the menu item: 'Tools - Customize - Keyboard' you may define custom keystrokes that will activate the DesignCAD commands of your choice. The default Keyboard file loaded by NPGS is:

- For DesignCAD Express v21.2:
  NPGS_DC21e_NPGS_Keyboard1.dkf

- For DesignCAD Express v16.2:
  NPGS_DC16e_NPGS_Keyboard1.dkf

- For DesignCAD LT2000:
  NPGS_DC_Keyboard1.dkf

Menu
Using the menu item: 'Tools - Customize - Menu' you may modify the DesignCAD menu items. The default menu has already been optimized for use with NPGS, therefore, significant changes are not recommended. The default Menu file loaded by NPGS is:

- For DesignCAD Express v21.2:
  NPGS_DC21e_NPGS_Menu1.dkf

- For DesignCAD Express v16.2:
  NPGS_DC16e_NPGS_Menu1.dkf

- For DesignCAD LT2000:
  NPGS_DC_Menu1.dma

Workspace
Using the menu item: 'File - Workspace - Setup DesignCAD Workspace' you may set the defaults for many of the DesignCAD parameters. This is also where you tell DesignCAD which custom ToolBoxes, Keyboard, and Menu files are to be loaded. The default Workspace loaded by NPGS is:

- For DesignCAD Express v21.2:
  NPGS_DC21e_Workspace(Default).dws

- For DesignCAD Express v16.2:
  NPGS_DC16e_Workspace(Default).dws
For DesignCAD LT2000:
NPGS_DC_Workspace.dws

Note that you should save any custom ToolBoxes, Keyboard, or Menu files you have made to the hard disk, otherwise they may be lost.

**Miscellaneous Tips**

**Pattern Writing Order**
The elements of a pattern are written by NPGS in the order in which they are stored in the pattern file. (Only layers 1 through 19 can be used for pattern elements.) The BasicCAD programs OrderCheck, OrderEntities, and OrderGroups allow the user to check the writing order of pattern entities, change the order of individual pattern entities, and change the order of groups of entities, respectively. For more information, see *BasicCAD Programs* (page 75).

Drawing elements added to an existing file will be appended to the end of the appropriate drawing layer of the file. If the writing order is important, you can use OrderEntities and OrderGroups to change the order of pattern elements. The order of the pattern elements is most significant when no beam blanker is available.

Note that DesignCAD Express v21.2, DesignCAD Express v16.2, and LT2000 will save DC2 files in whatever order the layer information is created, while NPGS expects that the information will be grouped by layers in ascending order. Consequently, it is required that patterns be saved using the "NPGS - Save" command, which will ensure that the layer information is properly ordered. This command also ensures that line entities with more than 200 points are not split into separate entities by v21.2 or v16.2.

**DesignCAD Units**
The units displayed by DesignCAD are interpreted as microns by the NPGS software. Within the DesignCAD command "File – Workspace… - Setup…- Startup Settings - Details", the units must be set to inches.

**Closely Spaced Vertices in Wide Lines**
If an entity, such as a multi-segmented line, vector circle, vector arc, or vector curve, has a width requiring more than one pass of the beam, you may use the BasicCAD program CutPoints to cut out vertices that are too close together.

**Information on DesignCAD LT2000**

**General Comments**
The DesignCAD Express v21.2, v16.2 and LT2000 versions are identical for most commands, and the “**Miscellaneous Tips** (page 81)” section also applies to LT2000.

While the newer Express v21.2 and v16.2 versions of DesignCAD require a Product Activation Code, DesignCAD LT2000 only requires a serial number.

**Getting Help in DesignCAD LT2000**
The general DesignCAD help can be accessed using "Help – DesignCAD LT Help", by hitting "F1", or by using the "What's This" icon and clicking a command

![What's This Icon](image)
![Paperclip Icon](image)

*Note that within the general DesignCAD help, commands marked with a paperclip icon also have specific comments regarding how to use that command for pattern design.*

**Creating Patterns for Semi-Automatic Alignment**

**Alignment Windows and Overlays**
The focus of this section is to describe the special considerations that must be given to the design of alignment patterns, i.e., the patterns that define the areas to be scanned during alignment. The
following information assumes that the reader is familiar with using DesignCAD for normal pattern design, as previously discussed.

**When designing alignment patterns, it is essential that the origin in the alignment pattern matches the desired placement of the origin in any normal writing patterns that will use the alignment.**

In general, alignment patterns are almost identical to normal writing patterns, however, alignment patterns have the following special considerations:

A. Filled polygons and/or wide lines in an alignment pattern become "windows" onto the sample.

B. Zero width lines become part of the "overlay" used to define the location and shape of registration marks.

C. Each "window/overlay" pair must be in a separate drawing layer.

**Alignment Pattern "Windows"**

Within NPGS, an alignment "window" is made up of any number of filled polygons and/or wide lines in the same DesignCAD drawing layer. Quite often, alignment windows will simply be designed as filled polygons in the shape of squares, however, virtually any shape can be used. The most common mistake is to design several windows, but to put them all in the same drawing layer. By requiring each window to be in a separate layer, NPGS allows multiple filled areas to be used to define a window and also allows the windows to be grouped for display within the Run File Editor.

Each window must also have an "overlay" drawn in the same layer.

**Alignment Pattern "Overlays"**

Within NPGS, an alignment "overlay" is designed by creating lines, circles, or arcs that have a linewidth of zero. All of these lines will be used together by NPGS as the overlay for the window that is designed in the same drawing layer. Note that an overlay must have at least one vector entity.

A simple "overlay" can be designed as a crosshair that marks the center of the registration mark. However, a much more accurate approach is to design the overlay to match the edges of the alignment marks on the sample. While in general it is relatively difficult to pick out the center of a registration mark, it is quite easy to align an overlay that defines the outline of the registration mark.

When using NPGS to also write the marks, you have full control over the shape of the marks to be located. Rather than using simple square or "+" shaped marks, "L" shaped marks are recommended.

In NPGS v9, the alignment overlays can be moved by clicking and dragging with the mouse or by using the arrow keys. For rough positioning, the mouse is useful, however, accurate positioning will
generally be easier using the arrow keys, once the overlay is near the correct position. If more than one alignment window is displayed, positioning the mouse cursor in the center of the displayed windows will allow all overlays to be dragged at once. (The mouse cursor will change to indicate whenever an overlay or all overlays can be moved.)

**Selecting the Size of the Alignment Window**
When determining how large to make the windows, there are two important points:

**Uncertainty of Sample Position**
The uncertainty of the sample position when the alignment is initiated is a primary concern. For example, if the sample can initially be positioned to within ±X μm of the correct location, the windows should be at least ±X μm wide. This will ensure that the registration marks will always be at least partially visible when the windows are initially scanned.

**Desired Accuracy**
The desired accuracy of the alignment must also be considered. Typically, the spacing of the alignment pixels (defined in the Run File Editor) should be about one half of the desired accuracy of the alignment. The size of the alignment pixels will impose a limit on the size of the alignment windows, as discussed in the section "Selecting the Pixel Size for Alignment Windows (page 83)."

Usually, the alignment accuracy will be 1:1000 to 1:3000 relative to the writing field size, although accuracies to 1:7000 have been reported. For example, with a 100 micron field size, the alignment accuracy can be between 100 nm to ~30 nm. Note that the point space defined in the run file will be the limit of the expected accuracy, so if a 30 nm alignment is desired, then the point spacing for the alignment windows should not be larger than 30 nm.

Note that when using a very low magnification (i.e., a field size >1x1mm), the scan coils of the microscope may not be linear, which can cause alignment errors. Also, if the stage and/or beam position is drifting, the pattern alignment may have an offset relative to the alignment marks.

**Using Groups of Alignment Windows to Optimize Speed and Accuracy**
If the initial uncertainty of the sample position is large and/or the desired accuracy is very small, too many points may be required to achieve both objectives using a single set of windows. In that case, an initial set of large windows should be designed that will have a coarse pixel size and a second set of smaller windows with a fine pixel size should follow. Each set may have from 1 to 4 individual windows, and a total of 19 windows may be used in a single alignment pattern. Typically, the initial set should have 2 windows so that a coarse offset and rotation can be determined. The second set should have 3 or 4 windows so that the full 2x2 alignment matrix will be generated by the fine alignment.

**Selecting the Pixel Size for Alignment Windows**
When an alignment pattern is displayed, each screen pixel has a size equal to the "Center-to-Center" distance entered in the run file. Therefore, it is recommended to use a "Center-to-Center" distance that is approximately one half of the final alignment accuracy that is desired. The following table can be used to determine a good match between window size and pixel size. The entries in the table are the recommended maximum side length (in microns) for "N" square windows.

<table>
<thead>
<tr>
<th>Pixel Size</th>
<th>N=1</th>
<th>N=2</th>
<th>N=3</th>
<th>N=4</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 nm</td>
<td>10</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>50 nm</td>
<td>25</td>
<td>18</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>100 nm</td>
<td>50</td>
<td>35</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>200 nm</td>
<td>100</td>
<td>70</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>500 nm</td>
<td>250</td>
<td>175</td>
<td>150</td>
<td>125</td>
</tr>
<tr>
<td>1 μm</td>
<td>500</td>
<td>350</td>
<td>300</td>
<td>250</td>
</tr>
<tr>
<td>2 μm</td>
<td>1000</td>
<td>700</td>
<td>600</td>
<td>500</td>
</tr>
</tbody>
</table>

The table shown above can be used in two ways:
A. If the desired alignment accuracy is known before the pattern is designed, the table will tell
the (approximate) maximum side length to use for square windows. For example, if the
alignment pixels are to be 100 nm in size and four square windows are to be designed,
then each window should be no more than 8.6 μm on a side. **The actual window side
length should be at least 10% to 30% smaller than the length listed to increase the speed
of the alignment and to avoid hitting the limit for the PC in use.** The maximum will vary
depending on the amount of low memory available on the PC when the alignment pattern
is used by AL.

B. If the windows have already been designed, the table can be used to determine a
reasonable pixel size (Center-to-Center distance) to enter in the alignment run file. For
example, if two square windows have been designed with side lengths of 10 μm, look
under the “2” column in the table to find the two numbers which bracket the side length. In
this case, the numbers are 7 μm and 18 μm, which correspond to pixel sizes of 20 and 50
nm, respectively. Therefore, the smallest pixel size for the two 10 μm square windows
should be around 50 nm, while 20 nm will be too small. In all cases, if a coarse alignment
is desired, a much larger spacing can always be used. (Note that if a size is entered which
is too small, when the alignment windows are calculated, NPGS will automatically increase
the size by 1.5x, 2x, 2.5x, …10x, until a size which is large enough is found. If a 10x
spacing is too small, an error will result.)

Note that the above tables are only for square windows, however, windows of any shape can be
designed. For windows of other shapes, the pixel size must be small enough so that no more than
~256k points are required to display all of the windows that will be open at once. From within
DesignCAD, the program "NPGS - WinCalc" can be used to suggest the pixel spacing for groups of
windows of any shape.

**Optional Duplicate Alignment Window Mode**

Normally, an alignment pattern will have a separate window/overlay pair for each registration mark.
However, a special mode allows multiple alignment marks to be used in a single window. This mode
may be useful in an application such as aligning to a randomly positioned carbon nanotube or similar
structure. In this example, two small crosshairs can be designed which will be positioned to match the
ends of the tube. To make use of this mode, simply design the window and one overlay in a drawing
layer and then design each additional overlay (up to 4 total) in a higher numbered drawing layer.
When AL encounters the alignment pattern, a message will be displayed indicating that the "Duplicate
Window Mode" is being used. (This mode duplicates the first window for use with the other overlays.)
If two overlays are used, a prompt will ask if only rotations are to be calculated, otherwise rotations
and an overall scaling will be calculated. For one, three, or four overlays, the calculations will be the
same as when using the normal window/overlay pairs. The "Duplicate Window Mode" can be used
with the Single Scan modes described below to reduce the total exposure to the alignment window.
This is especially important in the application with the nanotubes, because the subsequent pattern
writing is done inside of the area exposed by the alignment window.

**Optional Alignment Reference Point**

Each window/overlay combination may also include a "reference point" to be used in the alignment
correction calculations. One reference point may be included in each drawing layer to specify the
exact location in each window that is used for the alignment calculations, i.e., the offset, magnification,
and rotation calculations will be relative to the reference points. A reference point is set at the desired
location in each window layer by using the "Point Mark" command. (If more than one Point Mark is
found in a layer, the last point will be used as the reference point.) If no reference points are set by
the user, the average of the points defining each overlay will be used. For example, if an overlay is
symmetric in x and y, then the default reference point will be the center of the overlay. (If only one
window is open and the average of the overlay is the origin, the rms average of the overlay will be
used instead.) **In general, the default reference points will yield excellent results and custom
reference points will not be necessary.** However, if an overlay is used to match one or two edges of a
mark, then a reference point should be set by the user at the midpoint of the overlay. For example,
when alignment is done to two adjacent edges of a contact pad, a reference point should be set at the
corner where the two edges meet. When using multiple windows, the first window should not have a
reference point (default or user-defined) at the origin. When using reference points, be sure that each point is in the same drawing layer as the corresponding window/overlay pair.

**Defining Groups of Alignment Windows in the Run File Editor**

For alignment patterns, the "Start New Set" designation for layers in the Run File Editor is used to produce different groups of windows that will be displayed sequentially. For example, a set of large coarse alignment windows may be opened first and a set of smaller fine alignment windows afterwards by setting the "Start New Set" option on the drawing layer containing the first smaller window.

When an alignment pattern is processed, up to four alignment windows may be simultaneously displayed on the screen. If one window is opened, magnification and pattern x,y offsets will be calculated. If two windows are opened, magnification, xy offsets, and a total pattern rotation change will be calculated. If three or four windows are opened, a general 2x2 transformation matrix plus x,y offsets will be calculated.

**Creating Patterns for Fully Automatic Alignment**

**Automatic Alignment: Overview of Pattern Design**

An alignment pattern for Auto-Alignment can be identical to one used for semi-automatic alignment and the information in the previous section should be read before continuing.

Each "window" must be designed in a separate drawing layer, and an "overlay" must accompany each window.

The shape of the alignment windows is defined by the user just as they are for the semi-automatic alignment. The maximum window size is also the same as for the semi-automatic case, however, to maximize the speed of the Auto-Alignment feature, the number of points in the Auto-Alignment windows should be kept as small as possible.

When two or more sets of windows are used, the Auto-Alignment feature will automatically open and align to each set of windows, and the results from each set will be carried to the next. This flexibility allows the user design windows that will maximize the speed and accuracy of the alignment process for almost any circumstance.

Note that the default configuration for the NPGS Auto-Alignment is to use the previous alignment matrix for each new alignment. In NPGS v9 or higher, when a run file that contains alignment entities is processed in the Non-Stop mode by NPGS.exe, before any writing begins, the Pg_Align.sys file from any previous alignments will automatically be deleted to avoid starting with an invalid alignment. (To disable this feature, simply create a file in the current project called “pg_usealign.txt”. When this file is present, Pg_Align.sys will never be deleted by NPGS.exe.)

When the Pg_Align.sys file in the current project is deleted, the software will always start the first alignment using a unity matrix. For more information, see the “Prev. Matrix” parameter in Pg_AA[1,2,3].sys (Auto-Align Parameters) (page 181).

See also “AL.exe: Auto-Alignment Mode (page 124)”.  

**Automatic Alignment: Overlay Design**

While the window design is basically the same as for the semi-automatic case, the design of the overlays for Auto-Alignment is slightly more involved. Typically, an overlay will be drawn as one or more single-pass lines (i.e., lines of width = 0) that match the perimeter of the mark to be located. AL will calculate the pixels that define these lines and display them on the screen as the overlay. For Auto-Alignment purposes, additional calculations will be made using the designed overlays to define groups of pixels that will be used to test the fit between each overlay and the image of the alignment mark in the corresponding window. This set of points will be called the "fit overlay". Lines in the designed overlay that do not form closed polygons will generate identical pixels for the displayed
overlay and for the fit overlay. However, *lines that form closed polygons* will generate pixels along the lines for the displayed overlay, but *the fit overlay points will fill in the polygon*. When AL begins, the number of points calculated for Auto-Alignment testing will be displayed in the same manner as the points calculated for the alignment windows and overlays.

When thinking about how the Auto-Alignment feature calculates the fit to the mark, one should remember that there are two sets of pixels: one set is displayed as the overlay on the PC screen and the second set is used for the fit calculations. As described above, if an overlay consists of a closed polygon, the displayed pixels will show the perimeter of the polygon and the fit overlay pixels will fill in the polygon (but not be displayed). The fit overlay pixels are always exactly in sync with the displayed pixels, so that as the displayed overlay is moved, either automatically by the program or by the user, the two sets will correspond to the same location on the image. Note that circles and circular arcs may be designed as part of the displayed overlays, however, they will not be included when the points are calculated for the fit overlays.

*The fit calculation consists of a simple averaging of the intensities of the image pixels that match up with those in the fit overlay.* For example, if an overlay consists of a closed polygon, the intensities of the image pixels within the polygon will be averaged to obtain a value of the fit. One can easily see that if the overlay aligns properly with the registration mark, the fit value will be a maximum. As the overlay is moved away from the aligned position, less of the mark will lie under the overlay and the average will decrease.

This approach is very straightforward and provides the user with the maximum flexibility in controlling how the alignment process will work. For example, if a registration mark is known to have very bright edges, the overlay can be designed with extra lines around the edges in addition to the closed polygon that defines the shape of the mark. If the extra lines fall exactly on the closed polygon, they will not be displayed in the overlay, however, they will cause the pixels around the edges of the polygon to be counted twice in the fit calculation. This will effectively weight the average so that a mark with bright edges will produce a fit value that is significantly higher than an adjacent feature without bright edges.

**Automatic Alignment: Registration Marks**

There are two basic types of registration marks used for the alignment process:

**Small Isolated Marks**

These marks are ones that fit entirely within the alignment windows. Typically, the best overlay design will consist of a single-pass line that makes a closed polygon that matches the perimeter of the mark. *Note that this should be a line of line type = 0 and linewidth = 0 with multiple vertices; it should not be made with PolyFill.* The Auto-Alignment feature can produce very reasonable alignments to this type of mark even if the image is relatively noisy. Because the process of averaging pixels in the shape of the desired mark works on the overall size, shape, and intensity of the mark, this approach is quite insensitive to the image quality of the mark edges. Another advantage to this approach is that it is insensitive to variations in processing that may have made the overall size of the registration mark too big or too small, since the mark location will still be correct.
The figure above shows how a two-part alignment mark can be used for both coarse and fine alignment. The mark consists of the "L" shaped structure and a small box opposite to the corner of the "L". In this example, the box and width of the "L" are both 1 μm. Typically, two or four structures such as this might be located near the corners of the field of view, with the structures rotated so that the small boxes are all towards the center. *With this arrangement, any one of the marks is enough to indicate where the center of the field is located.*

On the left side of the figure, a 10 μm alignment window is shown drawn around the overlay, which consists of the outlines of both the "L" structure and the small box. This size of window should be sufficiently large so that at least some part of the mark will be seen when positioning is done with the typical SEM stage.

On the right side of the figure, a 3 μm alignment window is shown drawn just around the small box. Only the outline of the small box would be drawn in the same drawing layer as the window. This window is small enough to allow a very fast and accurate auto-alignment to be done. (Note that in the figure above, the small alignment window appears as a solid line, which indicates that the dashes are so small that they cannot be observed at the displayed magnification. In DesignCAD, small dashes will seem to merge into solid lines as the display size of the pattern is decreased, however, the actual size of the dashes or dots for filled polygons or alignment windows has no effect on NPGS.)

**A Limited Part of a Larger Structure**

For example, a small area near the corner of a large bonding pad could be viewed and the alignment would be done using just the bright edge of the pad near the corner. There are several different overlay designs that can result in good alignment accuracy for this type of mark, however, alignment to this type of mark will always be more sensitive to noise in the image than for the previous type of mark. *Typically, the best approach is to use a single-pass line to design a small box that is located in the corner of the large mark.* In addition to this box, also draw a single pass line in the shape of an "L" that matches the two edges of the mark near the corner. The "L" lines should extend to near the alignment window edges, and in some cases, it is advantageous to make them extend outside the alignment window. *Typically, when the entire alignment mark is not visible within the alignment window, the Auto-Alignment pre-align keystroke command option should be used to enhance the edges of the mark before the alignment is performed.* For more information, see *Pg_AA[1,2,3].sys* (Auto-Align Parameters) (page 181).

Three different overlays are shown above that might be used to align to a corner of a large bonding pad. In each case, the large square is the filled polygon that defines the window area and the other structures are single width lines that make up the overlay. In the second and third examples, the overlay consists of an "L" shaped line and a small box that has two sides on top of the "L" line.

**In NPGS v9 or higher, a special feature exists to optimize the auto alignment to inside or outside corners of large features.** In the *Pg_AA[1,2,3].sys* file being used, the "Fine: Weighting" factor can be set to a negative number. While the interior of any closed polygon that is part of the overlay (such as the pixels within the squares in the second two overlay examples shown above) will always give the best auto-alignment "fit" value when positioned on top of the large structure, when the negative weighting feature is used, the lines defining the overlay will be optimized when they are not on the mark. Specifically, the interior points of any closed polygon which is part of the overlay will always have a weighting factor of +1, while the user can specify the weighting factor for the lines of the overlay. When the lines have a negative weighting factor, the best position found by the auto-alignment routine will have all of the interior points on the feature, while as few lines of the overlay as
possible will be on the mark. Consequently, even a closed polygon defining a simple square will preferentially find the corner of a large feature, while without the negative weighting, the same square would find the same "fit" value at any position on the feature. In summary, when using NPGS v9 or higher, whenever a fit is done to a feature that extends outside of the alignment window, using a negative weighting factor with an overlay made up of a closed polygon will make the auto-alignment routine locate the edge of the feature.

**Converting from other CAD formats (GDSII, CIF, DXF,...)**

### File Import: GDSII

A conversion utility is included with NPGS to convert from the Calma GDSII stream format to the DesignCAD 2D ASCII (*.dc2) format. This utility can be called from within the NPGS Menu program by highlighting a file in the GDSII format with either a ".gds" or ".sf" filename extension and selecting "File - Pattern Import - GDSII". It will also be called automatically when a file in the GDSII format is selected when loading a pattern from within DesignCAD.

The GDSII conversion utility will read the GDSII file in two passes and will convert the "fileN.sf" file to a corresponding "fileN.dc2" file. (Note that ".sf" is a common extension for GDSII files, however, a GDSII file with any extension can be converted.) The first pass checks the syntax of the GDSII file and determines the relationships between nested structures within the file. The second pass follows the nested ordering of the GDSII file and generates the appropriate DesignCAD output.

The GDSII file should be created using a "NoLib" option so that all information on every referenced structure is included in the file. Up to 5000 unique structures may be included in the file and structure nesting may be up to 100 levels deep. Arrays may have up to 32,767 rows and up to 32,767 columns. The size of the file that may be converted is limited only by the amount of hard disk space available to store the output and temporary files. Note that the resulting DesignCAD file will be comparable in size to a "flat" GDSII file and both are typically much larger than a hierarchical GDSII file.

The options available for the conversion are displayed on the main window of the conversion program.

Layers in the GDSII format should be limited to 1 through 16. If GDSII layer zero is used, it will be converted to the DesignCAD layer 1, which may also contain GDSII layer one pattern elements as well, which is why GDSII layer zero is not recommended.

If to be converted to DesignCAD colors, GDSII datatypes and boxtypes should also be limited to 1 through 16.

In all cases, microns in a GDSII file will be converted to microns in the DesignCAD file.

The "DesignCAD Drawing Unit Size" parameter can be used to set the internal scaling factor (Drawing Unit Size) used to create the DesignCAD file. Normally, there will not be any reason to change the default.

The "DesignCAD Line Type Scale" parameter can be used to set the internal line type scaling factor used to create the DesignCAD file, which determines the size of the dashes for filled polygons. This parameter only affects the appearance of the filled polygons within DesignCAD and does not change how the pattern will be written.

The "Verbose" error-checking mode can be used when a file fails to convert properly. The verbose output can also be saved to a file.

Header information for the DesignCAD output file will be copied from a file named "gds_dc2.hdr", if it exists in the directory "\NPGS\Temp". If it does not exist, default information will be used for the output file and also will be copied to the file "gds_dc2.hdr" in the directory "\NPGS\Temp". The information in the "gds_dc2.hdr" file makes no difference to the Run File Editor, PG, or AL programs. This information is only used if the output file is viewed within DesignCAD. If desired, the file
"gds_dc2.hdr" may be modified using an ASCII editor as long as the format is not changed. (If the file is accidentally corrupted, simply delete it and a new file with default values will be created the next time a GDSII file is converted is run.) The "gds_dc2.hdr" file follows the format of lines 2 through 6 of the DesignCAD entity type 41 (see the DesignCAD manual for more information).

Temporary files named "gds_dc2.###" are created and deleted in the directory "\NPGS\Temp" during the conversion process. One file is created for each DesignCAD layer that contains pattern entities. For example, "gds_dc2.003" will be used for all information output to DesignCAD layer 3. However, if all pattern information is to be saved in one DesignCAD layer, commands will be stored directly to the final output file without using temporary files.

GDSII records supported:

- UNITS .................absolute scaling is preserved in the conversion
- STRNAME ............up to 5000 unique structures may be included in a single file
- BOUNDARY ...........polygons with up to 999 vertices will be converted
- PATH ..................wires with up to 999 vertices will be converted
  - wires may have Flush, Extended, or Custom ends
  - wires may have any width
- SREF ..................structure references are supported up to 100 levels deep
- AREF ..................array references are supported up to 100 levels deep
  - arrays may have up to 32,767 rows and/or columns
  - rotations, mirrors, and offsets are supported
- BOX ..................boxes are supported
- LAYER .................layer information is preserved
- DATATYPE ..........can be used for color, i.e., dose, information with /d mode
- BOXTYPE ............can be used for color, i.e., dose, information with /d mode

GDSII records not supported:

- REFLIBS ..............reference libraries are not allowed, i.e., all pattern information
  - must exist in the "fileN.sf" file
- TEXT ..................text is ignored
- NODE ..................nodes are ignored
- PROPATTR .........property attributes and property values are ignored
- MAG ..................structure magnification information is ignored

File Import: CIF

A conversion utility is included with NPGS to convert from the Caltech Intermediate Form Version 2.0 format to the DesignCAD 2D ASCI (*.dc2) format. This utility can be called from within the NPGS Menu program by highlighting a file in the CIF format with the ".cif" filename extension and selecting "File - Pattern Import - CIF". It will also be called automatically when a file in the CIF format is selected when loading a pattern from within DesignCAD.

The CIF conversion utility will read the CIF file in two passes and will convert the "fileN.cif" file to a corresponding "fileN.dc2" file. (Note that ".cif" is a common extension for CIF files, however, a CIF file with any extension can be converted.) The first pass checks the syntax of the CIF file. The second pass follows the nested ordering of the CIF file and generates the appropriate DesignCAD output.

Up to 2000 unique symbols may be defined in the file and nesting of symbol calls may be up to 50 levels deep. The size of the file that may be converted is limited only by the amount of hard disk space available to store the output and temporary files. Note that the resulting DesignCAD file will be comparable in size to a CIF file without symbol calls and both are typically much larger than a hierarchical CIF file.

The options available for the conversion are displayed on the main window of the conversion program.
If the first Color Mode option is selected, the CIF layer number will be used for both the DesignCAD layer and color for each pattern element. Since CIF layers are distinguished by name, rather than by number, the first layer name encountered will be #1, the second will be #2, etc. The actual CIF layer names will be stored as part of the DesignCAD file.

The second Color Mode option puts all pattern entities into DesignCAD layer #1 and uses the CIF layer information for the DesignCAD colors. Sixteen or fewer layers should be used in the CIF format.

The "CIF Units per Micron" option allows the user to specify a value for the CIF unit size. Normally, a CIF file will use the default size of 100 CIF units = 1 micron. This option can also be used to scale a CIF pattern up or down in size when converting to a DesignCAD file.

The "Verbose" error-checking mode can be used when a file fails to convert properly. The verbose output can also be saved to a file.

Header information for the DesignCAD output file will be copied from a file named "cif_dc2.hdr", if it exists in the directory "\NPGS\Temp". If it does not exist, default information will be used for the output file and to create the file "cif_dc2.hdr" in the directory "\NPGS\Temp". The information in the "cif_dc2.hdr" file makes no difference to the Run File Editor, PG, or AL programs. This information is only used if the output file is viewed within DesignCAD. If desired, the file "cif_dc2.hdr" may be modified using an ASCII editor as long as the format is not changed. (If the file is accidentally corrupted, simply delete it and a new file with default values will be created the next time a file is converted is run.) The "cif_dc2.hdr" file follows the format of lines 2 through 6 of the DesignCAD entity type 41 (see the DesignCAD manual for more information).

Temporary files named "cif_dc2.###" are created and deleted during the conversion process in the directory "\NPGS\Temp". One file is created for each DesignCAD layer that contains pattern entities. For example, "cif_dc2.003" will be used for all information output to DesignCAD layer 3. However, if all pattern information is to be saved in one DesignCAD layer, commands will be stored directly to the final output file without using temporary files.

**CIF commands supported:**

- **Polygon**..............polygons with up to 300 vertices will be converted
- **Wire**................wires with up to 300 vertices will be converted
  - wires may have any width
- **Round Flash**.........round flashes with \( \leq 0.1 \, \mu\text{m} \) diameter will be converted
  - to a single DesignCAD dot
  - round flashes with \( > 0.1 \, \mu\text{m} \) diameter will be converted
  - to a Filled Polygon with 8 or more sides; the number of sides
  - will increase as the square root of the diameter, up to a
  - maximum of 198 sides
- **Box**...................boxes may have length, width, center, and direction
- **Layer**................layer information is preserved
- **Symbols**............up to 2000 unique symbols may be defined
  - symbols may be internally scaled
- **Calls**................symbol calls are supported up to 50 levels deep
  - rotations, mirrors, and offsets are supported

**CIF commands not converted:**

- **User Ext**..............user extensions, i.e., any CIF command beginning with a digit, are allowed, but
  - will be ignored
- **Comments**.............comment commands, i.e., any CIF command beginning with a '(' and ending
  - with ')', are allowed, but will be ignored

**File Import: Other Supported Conversions**

DesignCAD includes file conversion utilities that can be used to convert to and from a variety of formats including: DWG, DXF, HPGL, IGES, and XYZ coordinates. These formats can be imported
Pattern Design

into DesignCAD using the “File – Import” function in DesignCAD. Once a file had been imported into
DesignCAD, the pattern should be saved to the DesignCAD 2D ASCII format using “NPGS – Save”.

Note that the DWG and DXF formats have changed over the years, so that the newer versions will not
be compatible with older programs. When saving files in the DWG or DXF formats for use with
DesignCAD, the files should be saved in a version no newer than 2012 for DesignCAD Express v21,
2005 for DesignCAD Express v16, and 2000 for DesignCAD 2000 LT.

For filled polygons to be interpreted correctly, they must be converted into multi-segmented lines that
enclose the area and the line type must be set to 1 for a serpentine fill or 5 for a one-sided fill. For
more information, see Filled Polygons (page 67).

File Import: Custom Defined Conversions
The DesignCAD DC2 file format is an ASCII (text) file format based on “entity” lines and “data” lines.
Typically, each entity line begins with a number that identifies the entity and the second number
indicates the number of data lines to follow.

An annotated example of a DC2 file that defines three pattern elements is shown below. The lines in
red italics are comments that are not part of the DC2 file format.

<Start of file>
The first line always has at least 5 numbers that define the extent of the pattern in drawing units.
NPGS does not use the numbers on this line, so anything can be entered.
0.0000 24.0000 8.0000 0 -0.0000 0.0000 DesignCAD 3D Ver. 9.0 in 2D Mode
The next entity is a required header entity (#42). Header entity numbers are 20, 40, 41, or 42. The
second number on a header entity line is always the number of data lines to follow, which is always 20
for a #42 header entity. The first data line is the conversion factor between drawing units and
microns. In this case, there are “8” drawing units per micron. The other 19 data lines are not used by
NPGS, but must be present.
42 20 0 0 0 0
8.000000
8.000000, 0.800000
8.000000
3
16.000000
0.000000
0.000000
1.000000
0
0
1
SIMPLEX2.VFN
0.00000000 0.00000000 0.00000000 0.00000000
0.00000000 0.00000000 0.00000000 0.00000000
0.00000000 0.00000000 0.00000000 0.00000000
0.00000000 0.00000000 0.00000000 0.00000000
1 0 0 0 0 0 0 0
1.00000000 1.00000000 1.00000000 1.00000000
1.00000000 1.00000000 1.00000000 1.00000000
; DesignCAD Ascii Drawing Comments (With ‘;’ as Leading Character
The next entity is an optional layer name entity line (#23). The second number always indicates how
many data lines will follow. In this case, the layer name for layer 0 is “Do Not Use”.
23 1 0 0 0
Do Not Use
The next entity is the new layer entity line (#21). This entity must precede any pattern entities. In this
case, the second number is the new layer for pattern elements and there are no data lines. All pattern
element entities, such as lines or circles/arcs, that follow this new layer entity will be in the drawing
layer 1 (one), until another new layer entity is encountered. Each new layer entity must always be
larger than the preceding layers.
21 1 0 0 0 0
The next entity is a line entity (#1). This line has 5 data points which define a 1 micron box that has the lower left corner at the origin. Note that the first and last data points, (0=x, 0=y, 0=z), are the same, which ‘closes’ the box. Starting with the third number, the values in the line entity define the: LineTypeScale, LineWidth, LineType, Color Number(old versions), x1, x2, x3, Red, Green, Blue, x4, and x5, where x1- x5 are not used in NPGS. When the LineType is set to “1” (one), the line entity will be interpreted by NPGS as defining a Filled Polygon with a serpentine sweep of the beam for the fill lines. Filled Polygons should have a LineWidth of zero.

1 5 0.8000 0 1 10 0 1 0 255 0 0 10 1
0 0 0
8 0 0
8 8 0
0 8 0
0 0 0

The next entity is a line entity (#1). This line has 5 data points which define a 1 micron box that has the lower left corner 2 microns to the right of the origin, i.e., at (2,0) in microns or (16,0) in these drawing units. Note that the first and last data points, (16=x, 0=y, 0=z), are the same, which ‘closes’ the box. When the LineType is set to “0” (zero), the line entity will be interpreted by NPGS as defining a line that may have a non-zero width. When the LineWidth is zero, as in this example, the line will always be written as a single pass of the beam. In effect, this entity defines the perimeter of a 1 micron box.

1 5 8 0 0 10 0 1 0 255 0 0 0 1
16 0 0
24 0 0
24 8 0
16 8 0
16 0 0

The next entity is a circle/arc entity (#16). This circle has a center at (2.5, 0.5) in microns or (20, 4) in these drawing units as shown on the first data line. The starting point of the circle is at (3, 0.5) in microns or (24, 4) in the file, as shown on the second data line. The ending point of the circle is on the third data line. If this entity defined an arc, the ending point would not match the starting point. The fourth data line is not used by NPGS, but must be present.

16 4 0.8000 0 0 10 0 1 0 255 0 0 10 1
20 4 0
24 4 0
24 4 0
20 8 0
<End of file>

When creating your own DC2 files that may use other entities, it is easy to make small sample patterns in DesignCAD and inspect the resulting output DC2 file.

If a translator from another CAD format to the DesignCAD 2D ASCII format is to be written, the following conditions must be met.

1. The first line of the pattern file must at least have 5 numbers, but they are not used by NPGS.
2. The second line must be a system parameter entity line (20, 40, 41, or 42).
3. If the system parameter entity is in the old format (20), there are two acceptable sequences. Either the system parameter entry must have a total of four lines, with the last line containing a single "***", or it must have at least thirteen lines followed by a "***". In the short sequence, the 2nd line after the entity line (20 0 0 0 0) must have the scaling parameter (i.e., # of DesignCAD storage units per micron). In the long sequence, the 12th line after the entity line must have the scaling parameter.
4. If the system parameter entity is in the new format (40, 41, or 42), the first number on the first line after the system parameter entity line must be the scaling parameter.
5. All entity lines are acceptable, however, only the following will be used (all others will be ignored): 1 (vector), 16 (circular arc), 20 (new level), 21, 40, 41, and 42.
6. The data lines for vectors and circle/arcs can be double precision values with either “x y” data or “x y z” data, where z will be ignored.
7. A filled polygon is designated by a dashed or dotted line (entity #1 with line type 1 or 5, respectively) with up to 1000 endpoints that form a closed polygon. Line type 1 will cause the area to be filled in a serpentine fashion (i.e., the beam is swept back and forth), while for line type 5 the beam always starts from the same side.

8. A "painted" area is designated by a vector of line type -1. The number of points given in the entity line is twice the number of lines that fill the area. Every two pairs of x-y points that follow the entity line are the starting and ending points of the vectors that fill the area. The vectors should always start from the same side of the painted area. In general, a Filled Polygon should be used instead of a "painted" area.

9. In NPGS v9, a "Dump Point" is designated by a dotted (line type 5) circle with RGB colors (0,0,0)=white on black background, (128,0,0)=red, and (0,128,0)=green and these elements should not be used in a pattern for any other purpose. The radius, width, and line type scale may be arbitrarily set. The dump location for the beam is always the center of the circle.
Using the Run File Editor

Run File Editor: Overview

Overview
The Run File Editor has been designed to allow even complex run files to be easily created. Basically, a run file is a sequential list of entities that are to be processed by NPGS.exe. The entities can include alignment patterns, individual patterns to be written, pattern arrays, fractured patterns, stage movement commands, comments, and groups of any other arbitrary commands. In NPGS v9, up to 5000 entities may be defined.

The display of the Run File Editor is split into two halves. The left hand side displays the list of entities that are to be sequentially processed and the right hand side dynamically displays the data for the entity that is highlighted on the left hand side.

The Run File Editor does not allow incomplete run files to be saved. Consequently, any entity that requires a pattern name must have a valid entry before the run file can be saved. When a pattern name is entered, the pattern file will be read and the parameters required for the exposure will be displayed on the right hand side. Note that the default values are not optimized for the pattern, but instead are taken from the "Pg_RFE.sys" system. In general, the defaults are set for typical patterns with narrow linewidths, but the user should select values for each run file that are appropriate for the structures to be written.

Templates
When the Run File Editor is launched and no run file is highlighted, a list of template run files will be presented, if they exist. The template run files are any run files that have a name starting with "_Template". The template run files can be created by the user to have standard entities such as Comments and Commands that are routinely used. See the note below on the File Save function.

Custom RFE Buttons
At the bottom of the Run File Editor are buttons that can be customized through the Pg_RFE.sys file. These buttons can be set to run any of the menu commands within the Run File Editor, however, the most useful commands have already been preset.

Status Bar
Information specific to the selected parameter will be displayed in the status bar at the bottom of the Run File Editor window.

What’s This Help
The "What’s This" icon is displayed in the lower right of the window.

Clicking it then clicking any prompt or data field will bring up help on the selected item. The information provided is quite detailed and should typically answer all common questions regarding the selected parameter.

Run File Editor: Menu Commands

Run File Editor: File Menu
Save
This command will save the run file to the current project directory. If the run file does not have a name, the "File Save" dialog box will be presented. If the run file is incomplete or it has not been changed since the last save or load, the "File - Save" command will be disabled.

Note: When “Save” is used with any run file that has a name starting with “_Template”, the “SaveAs” function will be called with the name set to blank. This allows template files to be used with user
defined preset entities and prevents the templates from accidentally being overwritten once they are modified for a normal writing session.

**SaveAs**
This command will save the run file to the current project directory using the "File Save" dialog box. If the run file is incomplete, the "File - Save" command will be disabled.

**Reread Current Pattern**
When a pattern name is entered in the Run File Editor, the pattern file will be read and the parameters required for the exposure will be displayed on the "Entity Data" side of the window. However, when an existing run file is loaded, the patterns are only read when a pattern file has a date newer than the run file and if specified by the user. Basically, if the pattern file is newer than the run file, there is a chance that the pattern has been modified such that it has different layers and/or colors than those contained in the older run file. When a pattern is newer, a prompt will be displayed during the loading of the run file and the user should agree to have the pattern reread. Once the run file is loaded, this command can be used if the user wishes to reread a specific pattern in the run file. To do so, simply highlight the pattern entity to be reread and select this command.

**Reread All Patterns**
This command is used in a similar fashion as the command above, however, it will cause the Run File Editor to reread all of the patterns listed.

When first using the sample patterns and run files provided with NPGS, you should always have the Run File Editor reread all of the patterns, otherwise, if the “mag scale” calibration factor for your SEM is smaller than the default value that was used when the sample run files were created, a run time error may be encountered.

**Show Run File**
This command can be used to open another run file in a Display Only Mode that does not allow any changes. This can be useful when comparing parameters in different run files or when you want to ensure that a run file is not accidentally changed during viewing. Note that entities from a run file shown in the Display Only Mode can be copied and subsequently pasted into a run file that is opened for editing.

**Printer Setup**
This command calls the standard Windows printer setup utility.

**Print Run File**
This command will produce a printed version of a run file similar to what is seen in the Run File Editor.

**Exit**
This command will terminate the Run File Editor. If the file has not been saved, a prompt will appear asking if it should be saved.

**Run File Editor: Edit Menu**

**Insert New Entity**
This command will insert a new entity into the entity list.

**Cut (Delete) Entity**
When a numbered entity is highlighted, this command will delete the entity from the run file. This command acts like the standard Windows "Cut" function, in that the deleted entity can be restored at a different location using the "Paste" command.

In addition to the "Cut" and "Paste" commands, the Run File Editor provides a "Drag and Drop" feature for rearranging entities. If the left mouse button is depressed and held down while over an entity, the entity can be moved to a new location in the run file by moving the mouse and releasing the button when the cursor is over the new location. Note that after the mouse button is depressed and the cursor is moved slightly, the cursor icon will change to a "hand", indicating that the "Drag and Drop" mode is active. When moving down (up) the list, the entity will be placed after (before) the entity onto which it is dropped.
Copy Entity
When a numbered entity is highlighted, this command will copy the entity to a temporary clipboard. This command acts like the standard Windows "Copy" function, in that the copied entity can be restored at a different location using the "Paste" command, even to a different run file.

Paste/Insert Entity
This command will restore an entity after it has been deleted or copied using the commands listed above.

Color Schemes
This command will bring up the dialog box for customizing the colors in the NPGS Menu program and the Run File Editor.

Set Doses
This command will be enabled only when an entity of the following types is highlighted and has a valid pattern name: Pattern, Array, and Fracture.

The dialog box that is presented will allow pattern exposures to be automatically stepped over selected ranges, as specified by the user. The stepping of the exposures can follow an exponential, linear, or polynomial function.

The two main uses of this dialog box are as follows:

1. Dose Testing using Colors in a Pattern - In this mode, the user will select a pattern layer to be modified. Typically, the pattern will have been designed using "NPGS - MakeArray" from within DesignCAD, so that the pattern has an array of different colors, that will each be exposed at a different dose. The desired exposure type, i.e., Area, Line, Point, or Time, and functional form will then be selected. Finally, any two of the following may be entered and the third will be calculated: Start Value, End Value, and Step. The calculated values for each exposure step (in this case the different colors/doses in the layer) will be displayed in the window on the right. When the desired values are displayed, hitting "Apply" or "OK" will make the changes to the specified layer. If "Apply" is used, a new layer can be selected and the process can be repeated.

2. Dose Testing using the Array Mode - In this mode, the initial parameter will be set to "Array Mode". This choice is only available when the highlighted entity is already in the Array mode. The end result is that each pattern written in the array will be at a different dose. In this case, the Start, End, and Step values will all be in percentages, where a value of 100% corresponds to the exposure times listed for the Array entity. This mode has the option to apply the dose steps to all layers of the pattern (default), to only one layer, or to all layers except the excluded layer. Note that if the exposure times listed for the entity are close to the hardware limits and the percentage would exceed the limits, a warning will be displayed when the pattern is processed by NPGS.exe and the actual exposure for any cases outside of the allowed range will be exposed at the limit.

Run File Editor: Help Menu
The items in the Help Menu for the Run File Editor are identical to those found in the main NPGS Menu program. For more information, see Menu Program: Help Menu (page 61).

Entity Entries and Highlighted Entity Data

Run File Editor: Allow Advanced Modes Entity
Number of Entities
This is the first prompt on the left hand side of the window. For NPGS v9, the maximum number of entities in a single run file is 5000. Since this parameter does not have any data on the right hand side, it has been grouped with the Allow Advanced Modes entity.
Allow Advanced Modes
If this prompt is set to "Yes", then the advanced modes listed on the right side can be individually enabled or disabled. If the prompt is set to "No", all of the listed advanced modes will be disabled.

Advanced Mode Entity Data (on right hand side)
The following items are all found under the "Highlighted Entity Data" when the "Allow Advanced Modes" prompt is highlighted:

Non-Stop Writing Mode
When set to "Yes", this mode causes NPGS, PG, and AL to write the patterns of the run file without stopping, except when a "Pause First" indicator is encountered for a specific layer. This option is intended for systems with an automated stage. This option can also affect the processing of the "Command" and "Comment" entities.

Disable Automated Stage Control
In each project, the system file "Pg_Stg.sys" can contain information that allows NPGS to control an automated stage. If an automated stage has been enabled in "Pg_Stg.sys", then this prompt will be active, and can disable the stage control for the run file being edited. If an automated stage is not enabled in "Pg_Stg.sys", then this prompt will not be active. For more information, see Pg_Stg.sys (Stage Interface Parameters) (page 196).

Disable Digital SEM Control
In each project, the system file "Pg_Cmdnd.sys" can contain information that allows NPGS to control a digital microscope. If a digital microscope has been enabled in "Pg_Cmdnd.sys", then this prompt will be active, and can disable the microscope control for the run file being edited. If a digital microscope is not enabled in "Pg_Cmdnd.sys", then this prompt will not be active. For more information, see Pg_Cmdnd.sys (External Program Names) (page 189).

Disable X-Y-Focus Mode
In each project, the system file "Pg_Cmdnd.sys" can contain information that allows NPGS to perform an X-Y-Focus correction as the stage is moved. If X-Y-Focus has been enabled in "Pg_Cmdnd.sys", then this prompt will be active, and can disable the X-Y-Focus for the run file being edited. If X-Y-Focus is not enabled in "Pg_Cmdnd.sys", then this prompt will not be active. For more information, see Pg_Cmdnd.sys (External Program Names) (page 189).

Disable Automated Beam Reading
In each project, the system file "Pg_Beam.sys" can contain information that allows NPGS to perform automated reading of the beam current. If beam reading has been enabled in "Pg_Beam.sys", then this prompt will be active, and can disable the beam reading for the run file being edited. If beam reading is not enabled in "Pg_Beam.sys", then this prompt will not be active. For more information, see Pg_Beam.sys (Auto-Beam Reading Parameters) (page 185).

The two sub prompts for the Automated Beam Reading option are discussed below:

Time Between Readings
When the Automated Beam Reading feature is in use, this parameter will define how long NPGS will wait between readings of the beam.

Check Beam Reading Before
When the Automated Beam Reading feature is in use, this parameter will indicate at which point in the pattern writing the beam check should take place:

1=Check before pattern.
2=Check before a layer.
3=Check before an entity.
4=Check before a dump point.
5=Check at the end of a pattern.

Enable Global Rotation Correction
This mode allows the user to locate known sites on a sample using the SEM so that NPGS can subsequently generate the correct stage commands that will position the sample using sample
coordinates, rather than along the stage axes. This mode is typically used with an automated stage, but if desired, can be used with a manual stage.

In general, consider a sample that is placed at an angle relative to the stage axes. If two positions known in sample coordinates are located on the sample, by acquiring the stage coordinates at each position NPGS can calculate the rotation angle between the stage axes and the sample coordinate axes. Subsequently, the positioning commands sent to the stage during the Array, Fracture, or Pattern modes will be properly modified to produce the desired motion along the sample coordinate axes. The Global Correction information will also be used during the coarse offset of the Auto-Alignment feature.

The two sub prompts for the Global Mode are discussed below:

**Offset for Stage Rotation Adjustment**
The first prompt of the Global Correction mode is for the X,Y offset between the two known positions on the sample. For example, if the two positions are 100 \( \mu \text{m} \) apart parallel to the \textit{X axis of the sample}, then the entry would be "100,0" or "-100,0", depending which point is to be located first. In other words, if the first point to be located were considered to be the origin, then the offset to the second point would be entered. \textit{Note that when the 2nd X,Y offset (discussed below) is not used, the values entered for the first offset can be changed by any scaling factor, i.e., if only the stage rotation is to be determined, the X,Y offset can be any vector in that is in the direction from the first located point to the second located point.} For example, an entry of "1,0" can be used when the two points to be located are parallel to the X-axis of the sample, no matter what the distance between them actually is.

2nd Offset for Stage Matrix
The next prompt is for a 2\textsuperscript{nd} X,Y offset that is relative to the very first point. By locating this third point, NPGS will be able to generate a 2x2 transformation matrix that relates the three points defined in sample coordinates to three locations read from the stage. In addition to correcting for a rotation between the stage and sample coordinate systems, this matrix can correct for independent X and Y scaling differences and non-orthogonality of the stage axes. When the 2\textsuperscript{nd} X,Y offset is used, both offsets must correspond to the actual distances between the located points. If the user only wants to correct for rotation by locating two points, simply leave this parameter empty.

If the X-Y-Focus mode is active and the Global mode is called for by a run file, the user will be prompted to collect data for the X-Y-Focus mode after the Global Correction data is collected.

Related Topics: see Direct Stage Control (page 159) and X-Y-Focus Mode (page 170)

**Run File Editor: Alignment Entity**
The Alignment Entity designates the pattern listed to be processed as an alignment pattern. (For specific details on how alignment patterns must be designed, see Creating Patterns for Semi-Automatic Alignment (page 81) and Creating Patterns for Fully Automatic Alignment (page 85).)

**Writing Sequences with Multiple Patterns**
\textit{Since the user will typically want the same alignment pattern to be used before each normal pattern is written, NPGS is programmed accordingly.} For example, when a run file is processed and NPGS encounters an Alignment entity in the run file, it will run AL using that pattern before each of the following patterns is written by PG, and PG will automatically be called with the alignment option enabled. If another Alignment entity is encountered, NPGS will repeat the scheme for the following patterns using the new alignment pattern, and so on. Specifically, if the run file has the following seven entities listed (where A# entities are marked as alignment patterns): A1, P1, P2, P3, A2, P4, P5; then NPGS would generate the following exposure sequence: A1, P1, A1, P2, A1, P3, A2, P4, A2, P5, where the A# patterns would be passed to the alignment program AL and the P# patterns to PG. Note that the alignment program AL will be called before each normal pattern is written by PG, even if a writing pattern has several identical repeats or is expanded into an array.
Example of Alignments Done Before Each Element of the Array Mode

An example of the left side of the Run File Editor display is shown below, where the run file is set up to repeat the alignment before each of the four elements of a 2x2 array entity.

<table>
<thead>
<tr>
<th>Entity Type</th>
<th>Alignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern Mode</td>
<td>Manual</td>
</tr>
<tr>
<td>Pattern Name</td>
<td>align</td>
</tr>
<tr>
<td>Number of times to repeat pattern</td>
<td>1</td>
</tr>
<tr>
<td>XY Move to Pattern Center (µm,µm)</td>
<td>0,0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Entity Type</th>
<th>Array</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern Name</td>
<td>sample0</td>
</tr>
<tr>
<td># of Rows in Pattern Array</td>
<td>2</td>
</tr>
<tr>
<td># of Columns in Pattern Array</td>
<td>2</td>
</tr>
<tr>
<td>Enable Exposure Steps for Array</td>
<td>No</td>
</tr>
<tr>
<td>Initial XY Move to Pattern Center (µm,µm)</td>
<td>2000,0</td>
</tr>
<tr>
<td>Array Spacing (Col,Row) (µm,µm)</td>
<td>2000,2000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Entity Type</th>
<th>MoveOnly</th>
</tr>
</thead>
<tbody>
<tr>
<td>XY Move to Writing Field Center (µm,µm)</td>
<td>-2000,0</td>
</tr>
</tbody>
</table>

In this example, the actual stage moves will be performed as indicated in the figure shown below. Note that the stage performs the moves defined within the Array entity, while the move entered for the Alignment entity is (0,0). This causes the alignment to be done at the same location as the writing, which is the best approach for most SEM stages, since the typical SEM stage has a positioning accuracy of ~0.5 to several microns.

Note that the "Initial XY Move to Pattern Center" listed in the run file for the Array entity defines the center of the array, however, the stage never actually makes that move. Instead, the first move of the stage is to the location of the first element of the array that is written, which in this case is in the lower left.

In this example, after the stage is moved to the position for each pattern, the alignment entity will be processed before each pattern is written.
After the last array element is aligned and written, the stage will then actually be moved to the center of the array. The final "MoveOnly" entity of the run file will then move the stage back to the starting position.

**Example of Offset Alignments with the Array Mode**
A second example of the left side of the Run File Editor display is shown below, where the run file is set up to repeat the alignment before each of the four elements of a 2x2 array entity. **However, in this case, an offset xy value is entered for the Alignment entity. Consequently, the patterns will be written in the same locations as the previous example, however, the alignment will be offset from the pattern exposure location.** Since this causes the stage to be moved between the alignment and the writing, it is only recommended when a very accurate stage is used or when the stage accuracy is known to be good enough for the desired alignment accuracy.

The actual stage moves performed when this run file is processed are shown below:

![Diagram showing stage moves for offset alignments](image)

This sequence is useful when there are no alignment marks within the writing field and the stage in use is accurate enough to allow movement between the alignment and the writing.
Note that both examples shown above will also apply when identical repeats of the Pattern entity are defined in the run file.

Also, whenever a run file contains complex stage sequences, it is recommended that a "dry run" be performed by processing the run file so that the commands will be sent to the stage, but the SEM should be left in imaging mode, so that the stage movements can easily be observed. In this way, any mistakes, oversights, or misunderstandings regarding the stage movement commands and sequences can be corrected before any real patterns are written.

Automatic Repeat of Comment/Command Between Alignment and Pattern Writing

Another advanced mode of the auto repeat of the alignment as described above is when the run file contains a Command or Comment entity between the Alignment entity and the Pattern entity. In this case, BOTH the Alignment and the Command or Comment will be repeated before each pattern. For example, if the sequence in the run file is as follows (where C# entities are either a Command or Comment):

A1, C1, P1, P2, P3, A2, C2, P4, P5;

the processing order would be:

A1, C1, P1, A1, C1, P2, A1, C1, P3, A2, C2, P4, A2, C2, P5.

Note that any Alignment entity will not be automatically repeated if it is followed by another Alignment entity or a MoveOnly entity, or by a Comment or Command entity that isn’t followed by a Pattern, Array, or Fracture entity.

When an automated stage is used, the "XY Move..." parameter for each writing pattern will be processed BEFORE the alignment is performed for the pattern. Consequently, the "XY Move..." parameter for the alignment pattern itself is not used. Also, the "Number of times to repeat pattern" parameter will normally be left at one for alignment patterns.

Alignment Mode Options

When the Alignment Entity type is selected, the "Alignment Mode" prompt is displayed, which can be used to select from the following options:

- **Manual**.................This is the manual alignment mode, where the user manually positions the alignment overlays to match up with the alignment marks.
- **AutoAlign1**............This is the first Auto-Alignment mode. Note that the three AutoAlign modes are identical to each other, except the default Auto-Alignment parameters will be read by AL.exe from "pg_aa1.sys", "pg_aa2.sys", or "pg_aa3.sys", respectively. The three Auto-Alignment system files make it easy to select Auto-Alignment configurations that are optimized for different sample/microscope conditions. For example, the first default file may be optimized for quick alignment to high contrast marks, the second for careful alignment to low contrast marks, and the third for edge detection of large bonding pads.
- **AutoAlign2**............See AutoAlign1.
- **AutoAlign3**............See AutoAlign1.
- **UsePrevious**..........In this mode, all patterns subsequently listed in the run file will be written by PG using the alignment parameters found in "Pg_Align.sys", without calling AL. In this mode the pattern name on the "PRV" line will be overwritten by "AlignSys" and no pattern parameter table will be generated. For example, if the run file has the following seven patterns listed (where A# patterns are marked as alignment patterns and the 5th entry is marked as "PRV...AlignSys"): A1, BB, CC, DD, PRV, EE, FF; then NPGS would generate the following sequence: A1, BB, A1, CC, A1, DD, EE, FF, where the A# patterns would be passed to AL and the others to PG with the alignment option enabled. The two patterns EE and FF would be written by PG using the alignment parameters determined before the writing of DD.
- **Disable**.................This mode is used to turn off all alignment for the writing patterns subsequently listed in the run file. For example, if the run file has the following seven entities listed (where A# entities are marked as alignment patterns and the A2 entry is marked as "Align: Disable"): A1, BB, CC, DD, A2, EE, FF; then NPGS would generate the following sequence: A1, BB, A1, CC, A1, DD, EE, FF, where the A1 patterns would be passed to AL and the others to PG. The three patterns BB, CC, and DD, would be written by PG with the alignment option enabled, while
the two patterns EE and FF would be written by PG without using any alignment parameters.

Alignment Entity Data (on right hand side)
The data on the right hand side for an Alignment entity is similar to Pattern entity data. The following topics discuss the specific changes for the Alignment entity.

Layer Prompt
For alignment patterns the "Start New Set" option is used to separate the layers into groups of windows. For example, if an alignment pattern is to have two groups of windows and the first group has three windows (drawn in layers 1, 2, and 3) and the second group has three windows (drawn in layers 4, 5, and 6) then layer 4 would be marked with the "Start New Set" option and the others would be designated as "Window". If any layer is to be skipped, it should be designated with the "Skip" option.

Within a group of windows defined by the "Start New Set" option, a value entered for the following parameters will be automatically copied to the other layers within the group: "Origin Offset", "Magnification", "Center-to-Center", "Line Spacing", "Configuration Parameter", "Measured Beam Current", and the "Color" parameter. In addition the "Center-to-Center" and "Line Spacing" values will be treated as only one parameter, i.e., changing one will automatically change the other.

Origin Offset Prompt
This prompt should have the same value in all layers in a group (this will be done automatically by the Run File Editor for alignment patterns). Note that when the magnification is changed between coarse and fine windows, the center of the field of view will typically shift. For example, if coarse windows are scanned at 200x and it is known that a shift of 4 μm in y occurs when the magnification is changed to 1000x for scanning the fine windows, then the first set of windows can be offset by 4 μm in y to compensate. This way, the coarse alignment windows will be offset relative to the fine windows to correct for the microscope error that is caused by changing the magnification. This sort of microscope error is easy to measure and has been observed to be fairly consistent, therefore, the "Origin Offset" provides a simple method for minimizing the problem.

Magnification Prompt
The "Magnification" entry is handled as usual except that the maximum limit is now based on the maximum pattern dimension in any of the layers within the group defined by the "Start New Set" option. In other words, when layers 1, 2, and 3 are defined as a group, the "Magnification" limit for all three layers is the same and is determined by the most distant structure from the origin in any of the three layers.

Point Spacing for Alignment Layers
Typically, the spacing value for the "Center-to-Center" and "Line Spacing" should be about one half of the desired accuracy for the alignment. From within DesignCAD, the BasicCAD program WinCalc can be used to determine appropriate alignment spacing values for sets of windows (For more information, see BasicCAD Programs Supplied with NPGS (page 76)). If large windows are required to initially find the alignment marks, then they should be given a relatively large point spacing so that they can be scanned efficiently by AL. A set of smaller alignment windows should be designed in the same DesignCAD file to follow the large alignment windows. The smaller windows can then be given the point spacing required to achieve the desired alignment accuracy. If the alignment windows require too many points using the "Center-to-Center" spacing specified in the run file, AL will issue a warning and increase the spacing such that the windows can be displayed. If the spacing has been increased 10x and there are still too many points, an error message will be displayed and the program will terminate. For more information, see error message AL(13) at Errors: Pattern Writing (NPGS, PG, AL) (page 230).

Configuration Parameter and Beam Current
For an alignment pattern, the following parameters may be entered, but are not used within the Run File Editor or by NPGS or AL: "Configuration Parameter" and "Measured Beam Current".

Dwell - Color Parameter
The dwell parameter that normally records the point exposure time now records the number of ADC (analog to digital conversion) counts to be averaged for each pixel displayed by AL. In NPGS v9,
each count takes ~2.7 μsec and a count value of ~10 to 30 will typically provide good signal averaging without significantly decreasing the speed of image acquisition. Note that each alignment layer, i.e., an alignment window, is only stepped using one rate, which is why the Run File Editor keeps all color/count values the same.

**Dose Parameter**  
The dose parameter line is completely omitted since it is meaningless in the alignment process. Also, the usual calculations to determine the exposure time are disabled.

**Run File Editor: Pattern Entity**  
*This is the entity type used for the normal mode pattern writing of the typical individual pattern.*

**Pattern Name**  
The pattern namemust specify a *.dc2 file located in the current project file. If the data field for the pattern name is double clicked, a list of available patterns will be displayed.

**Number of Repeats**  
In NPGS v9, each pattern may be repeated in an identically exposure up to 100 times. A different "XY Move..." may be entered for each repeat of the pattern. If more exposures are required, or if the exposures are to be in a regularly spaced array, use the "Array Entity".

**XY Move to Pattern Center**  
The "XY Move..." for each pattern is the initial stage offset (in microns) that may be passed to a driver for an automated stage before the pattern is written by PG or AL. *If alignment is being done before a normal writing pattern, the initial offset entered for the writing pattern will actually be passed to the stage before the alignment.*

**Pattern Entity Data (on right hand side)**  
The following items are all found under the "Highlighted Entity Data" when a Pattern entity is highlighted. Also note that the Entity Data is identical for Array patterns. When each pattern file is read, the appropriate prompts and parameters are displayed on the right hand side. The prompts initially are answered with defaults from the "Pg_RFE.sys" system file, or with the last entries of a previous pattern. The prompts are organized by pattern layer, then by color within each layer.

**Layer Prompt**  
This prompt provides the following five choices:

- **Normal Writing......** This mode is typically used for all pattern writing. In NPGS v9, the default is that the beam will be precisely turned on and off before and after each pattern element while the beam itself is stepped from exposure point to exposure point with the dwell time listed in the run file. Optional parameters in "Pg.sys" can also make this mode in NPGS v9 perform the same as in earlier versions, as explained below.

  For any NPGS version, when the run file is processed, the writing will only pause for the first layer of each pattern marked with this mode, unless the "Non-Stop Writing Mode" is active (See Advanced Modes).

- **Pause First...........** This mode will cause the pattern writing to always pause before writing the specified layer, even when the "Non-Stop Writing Mode" is active. After pausing, the writing will be done using the "Normal Writing" mode. This parameter is useful when a microscope parameter, such as magnification or beam current, is to be changed for different layers of the pattern. *Note that it is sometimes useful to insert a "Comment" entity in the run file in order to force a pause in the processing, rather than use the Pause First option.* The advantage of using the "Comment" entity is that a full description of the changes that are to be manually performed by the user can clearly be listed.
Continuous.......In NPGS v9, this mode should be used when there is no blanker installed. In that case, NPGS v9 will not pause between exposure points and will not pause between pattern entities.

Skip...............This mode will cause the specified layer to be skipped when the run file is processed by NPGS.

Pause/Cont.........The Pause/Continuous mode is the same as "Pause First", but after pausing, the writing will be done using the "Continuous" mode, as described above.

**Origin Offset Prompt**
The "Origin Offset" allows the origin of a single layer of a pattern to be offset from the origin of the total pattern, which is always at the center of the field of view of the microscope. This would be equivalent to moving all drawing elements in a layer relative to the pattern origin. This option allows one to correct for unwanted offset that occurs when the "Beam Current" or "Magnification" is changed between different layers of a single pattern or between different sets of alignment windows. The x and y values of the "Origin Offset" must be separated by a comma and have units of microns. Up to 13 characters may be entered. The "Origin Offset" limits are determined by the maximum pattern dimension (distance from the origin) and the current "Magnification" value that is displayed in the run file. Positive x offset will move the origin of the pattern to the right and positive y offset will move the origin up on the SEM display, which can typically be observed visually when using an analog microscope. In AL, any offset will be added to the window and overlay positions. When a pattern is written by PG, any offset entered here will be added to any offsets resulting from pattern alignment using AL.

*If there is more than one Origin Offset value in the run file, double clicking this prompt will allow all entries to be set to the same value.*

**Magnification Prompt**
The "Magnification" should be answered with the microscope magnification at which the pattern is to be written. The limits of the "Magnification" are set in the file "Pg_Rfe.sys", however, the upper limit may be lower than the default depending on the pattern size and the entry for the "Origin Offset" explained above. The maximum "Magnification" is adjusted so that the pattern to be written will always fit within the field of view. Whenever the "Magnification" is changed, the grid spacing of possible exposure point positions will change. To reflect this change, the "Center-to-Center" distance and the "Line Spacing" distance will be changed to the nearest multiple of the grid spacing. Also the exposure times of all colors in that layer will be recalculated to maintain the specified dose.

*If there is more than one Magnification value in the run file, double clicking this prompt will allow all entries to be set to the same value.*

*Hitting the “+” or “-” keys while the Magnification prompt is active will jump the value to either rounded values that are automatically generated or to user-defined values if enabled in Pg.Mag.sys.*

**Center-to-Center Prompt**
The "Center-to-Center" distance is the distance between adjacent exposure points as the beam is moved to write a line. When this value is changed, all of the exposure times in that drawing layer are changed to keep the specified dose. (The "Center-to-Center" distance does not affect Point Doses.) If the "Center-to-Center" distance along a line is larger than the exposed spot size, discrete points may result. The lower limit is the current grid spacing as determined by the "Magnification".

*If there is more than one Center-to-Center value in the run file, double clicking this prompt will allow all entries to be set to the same value.*

*Hitting the “+” or “-” keys while the Center-to-Center prompt is active will jump the value to 4, 8, 16 or 32 times the smallest possible step size. A value of 4xLSB is recommended when writing the finest linewidths.*
**Line Spacing Prompt**
The "Line Spacing" distance is the distance between adjacent lines when the beam makes multiple passes to fill in an area or to write a wide line. When this value is changed, all of the exposure times in the drawing layer that are calculated from Area Doses are changed to keep the specified dose. (The "Line Spacing" does not affect Line Doses or Point Doses.) If the exposed linewidth is less than the "Line Spacing", discrete lines may result when filling an area. The lower limit is the current grid spacing as determined by the "Magnification". Setting the "Line Spacing" equal to the "Center-to-Center" distance will result in a square grid of exposure points.

*If there is more than one Line Spacing value in the run file, double clicking this prompt will allow all entries to be set to the same value.*

*Hitting the “+” or “-“ keys while the Line Spacing prompt is active will jump the value to 4, 8, 16 or 32 times the smallest possible step size.*

**Configuration Parameter Prompt**
The "Configuration Parameter" is completely optional, but may be used for changing parameters on a digital microscope if the appropriate interface is available. For more information, see [Interfacing to the Microscope](page 162). When used with a digital microscope, the "Configuration Parameter" can be used to refer to a group of microscope parameters or it can refer to a single parameter, such as "Spot Size" or "Coarse Beam Current". Depending on how the parameter will be used, the run file prompt may be changed accordingly. For more information on modifying this parameter, see [Pg_RFE.sys (Run File Editor Defaults)](page 194). At run time, the entered value is displayed before the layer is written if it is the first layer of the pattern or if the "Start New Set" option is used to pause writing before that layer.

*If there is more than one Configuration Parameter value in the run file, double clicking this prompt will allow all entries to be set to the same value.*

**Measured Beam Current Prompt**
The "Measured Beam Current" is used to calculate the exposure/dose for each color in the layer. The value entered should be the value of the measured beam current to be used when the pattern is written. When this value is changed, all of the exposure times in that drawing layer are recalculated. If when the pattern is written, the measured beam current does not match the value entered in the run file, then the actual dose of the exposure will be incorrect. In such a case, the run file should be changed to match the measured beam current, or it is generally more convenient to use the "Exposure Scale" and/or "Beam Current" option that is displayed on the NPGS Menu program. These options will scale the exposure time by the amount specified and can correct for a difference between the actual and stored measured beam current values. Note that this approach will not always work, because there are hardware limits to the range of the exposure time per point. If the limit is reached a warning will be displayed before the pattern is written and it will also be entered into the LastRun.log file.

*If there is more than one Measured Beam Current value in the run file, double clicking this prompt will allow all entries to be set to the same value.*

**Multiple Pass Mode Prompt**
This prompt provides the following choices for the Multiple Pass Mode (available in NPGS v9 or higher only):

- Disable.................All writing is done in a single pass which will be the same as before this feature was available.

- Layer Repeat .......The entire layer will be written in N passes using the normal entity order and normal entity writing direction for each pass

- Layer Reverse .....The entire layer will be written in N passes using the normal entity order, but odd passes (1st, 3rd,...) will have the normal entity writing direction, while even passes (2nd, 4th,...) will have the writing direction reversed.

---

Entity Entries and Highlighted Entity Data ● Page 105
Entity Repeat ..... Each entity in the layer will be written in N passes using the normal entity writing direction for each pass.

Entity Reverse ..... Each entity in the layer will be written in N passes, but odd passes will use the normal entity writing direction for each pass, while even passes will have the writing direction reversed.

Note: Run files that are saved with the Multiple Pass Mode enabled can only be processed by NPGS software that supports the Multiple Pass Mode. Run files with this mode disabled are compatible with older versions of NPGS.

When the Multiple Pass Mode is active, prompts for the Number of Passes (N) and an optional Delay between Passes will also be displayed.

The Multiple Pass Mode will typically be used for either e-beam writing on substrates that charge where a delay between passes can allow the charge to dissipate or for FIB milling applications where alternating the direction of the passes can help produce a smooth, level bottom in milled areas. For more information on the milling applications, see “Multipass Modes for FIB Milling (page 163)”.

Dwell and Dose Parameter Prompts

For each color in a drawing layer a "Dwell" and "Dose" are recorded. If a dwell is entered, the corresponding dose is recalculated to match the time. Conversely, if a dose is entered, the dwell, which is the exposure time per point, is recalculated to match the dose. An "Area Dose" is given in units of μC/cm², a "Line Dose" is given in units of nC/cm, and a "Point Dose" is given in units of fC (10⁻¹⁵ C). The "Line Dose" is calculated for a single pass of the beam at an exposure point spacing given by the "Center-to-Center" distance, while the "Area Dose" is calculated based on the "Center-to-Center" and the "Line Spacing" distances:

\[
\text{Area Dose} = \frac{(\text{Beam Current}) \times (\text{Exposure Time})}{(\text{Center-to-Center}) \times (\text{Line Spacing})}
\]

\[
\text{Line Dose} = \frac{(\text{Beam Current}) \times (\text{Exposure Time})}{(\text{Center-to-Center})}
\]

\[
\text{Point Dose} = (\text{Beam Current}) \times (\text{Exposure Time})
\]

Ordering of Pattern Colors within the Run File

When using a Windows version of DesignCAD, patterns will be saved with RGB colors specified for each pattern element. Within the Run File Editor (RFE), the colors will be ordered by the following ranking: (256 * R) + (65536 * G) + B, where R, G, and B are the components of the RGB color value and each ranges from 0 to 255. These values can be viewed on the status bar in the RFE by selecting the corresponding Dwell prompt. Note that the “MakeArray” command in DesignCAD has been programmed to always produce a range of colors that vary from blue to red to yellow (where yellow = red + green). When processed by the color ranking scheme given above, the MakeArray color range will be ordered correctly within the run file, i.e., from blue (1st) to red to yellow (last).

(When using a DOS version of DesignCAD, each color will be assigned a DOS color number by DesignCAD, and the Run File Editor will order the colors accordingly.)

Exposure Time Limits

In NPGS v9, the limits for the dwell, i.e., exposure time per point, is set by the "max DAC rate" value in Pg.sys. (This value should not be changed by the user.) The exposure time will range from 1/(max DAC rate) in microseconds to one hour per point. In all cases, the accuracy of the exposure time can be 0.25% or better, as specified by the "percent error" parameter in Pg.sys.
Note that the limits encountered for values entered into the Run File Editor are set in the file *Pg_RFE.sys* (use "Options - System Files - Pg_RFE.sys to modify"). If the Run File Editor does not allow very large dwell times to be entered, the “Max” value on the Dwell data line in *Pg_RFE.sys* should be increased up to “4e9”, which will give just over one hour per point. For information on the format of the *Pg_RFE.sys* file, see *Pg_RFE.sys* (Run File Editor Defaults) (page 194).

Also, if an application always requires large dwell times or large doses, the units displayed in the Run File Editor can be changed for these parameters by making changes in *Pg_RFE.sys*. For example, if large point doses with long exposure times are routinely used, you can change the dwell times to seconds, instead of the default usec, and the Point Dose to nC, instead of the default fC. To do this, use “Options - System Files - Pg_RFE.sys” to make the following changes: 1) Change the “Mult” value on the Dwell line to “1e6”, which will make the units for the dwell time be seconds, instead of usec. Also, change the "Units" value from "(usec)" to "(sec)" on the same line. 2) Change the “Mult” value on the Point Dose line to “1e6”, which will make the units for the Point Dose be nC, instead of fC. 3) Also, you can change the "Max” value for the Point Dose line to a large value, such as “1e8”. Similar changes can be made to other data lines, as needed. Note that these changes will only affect the display in the Run File Editor and that the actual run files will always be saved using the native units so that they will be properly exposed in any NPGS Project.

If a dose is entered that results in a calculated exposure time that is outside the limits, then the closer limit will be returned for the calculated value and the value displayed will be highlighted. *In any case, the time listed in the run file will be used when the run file is read by PG or AL.*

If a time is entered that results in a calculated dose that is outside the limits set in "Pg_RFE.sys", then the closer limit will be returned for the calculated dose value. The time entered will be used when the run file is read by PG or AL. For NPGS v9 or higher, the exposure time limits will rarely be encountered.

*In all cases, a general rule is that for lines made by a single pass of the beam, the center-to-center distance should be about ¼ to ½ of the final linewidth.* This reduces the number of points to calculate and increases the exposure time per point, thus reducing or eliminating any calculation bottleneck. Use the "Time Test Mode" option when running PG to obtain calculation times for your patterns. For more information, see *PG.exe: Time Test Mode* (page 117).

**Run File Editor: Array Entity**

**Number of Rows and Columns**
The Array Entity will repeat the pattern in a rectangular array with up to 32,767 rows and columns. The first prompt is for the pattern to be repeated. The next two prompts are for the number of rows and columns to be in the array.

**Exposure Steps for Array Prompt**
This prompt can be used if each exposure of the pattern within the array is be given a different dose. Selecting "Yes" or "View" will bring up the "Edit - Set Doses" dialog box. For more information, see *Run File Editor: Edit Menu* (page 95). Selecting "No" will cause all patterns within the array to have the identical exposure, as defined in the pattern parameters on the right hand side. When the exposure steps are used, the different exposures will be applied in the order of the writing which follows a serpentine sequence as discussed below.

**Initial XY Move Prompt**
The next prompt is for the initial X,Y offset (in microns) which would position the stage at the center of the array. Note that the stage is not actually moved to the center, but instead it will move directly to the position of the first pattern of the array. *The first pattern will be in one of the corners of the array, as discussed below.* Subsequent patterns in the array will follow in a serpentine fashion along the first row, back on the next row, and so on. For example, if the stage is initially positioned at the edge of the sample 500 microns away in the +X direction from the location for the center of the array, the initial X,Y offset would be entered as "-500,0". If no automated stage motion is desired for the entire array, simply leave the prompt empty. *After the array is finished, the stage will be positioned at the array center, so that the move to any subsequent writing will be easy to determine.*
Array Spacing
The last prompt in the Array entity is for the column and row spacing (in microns). The sign of the entries will determine how the array is positioned relative to the first pattern. For example, an entry of "100,200" would create an array with 100 microns between columns and 200 microns between rows, and the first pattern would be in the lower left corner of the array. Similarly, entries with the signs of (-, +), (+,-), and (-,-), would have the first pattern in the lower-right, upper-left, and upper-right, respectively.  Note that this spacing is the stage step size between columns and rows, while the actual unexposed area between columns and rows will depend on the size of the patterns that are being written. If no automated stage motion is desired for the entire array, simply leave the prompt empty.

Array Entity Data (on right hand side)
The pattern data on the right hand side for the Array entity is identical to a Pattern entity. Please see the Run File Editor: Pattern Entity (page 103) for more information.

Run File Editor: Fracture Entity
The Fracture Entity allows a single large pattern to be "fractured" into smaller writing sub-fields. The Fracture entity is typically used with an automated stage. Normally, the pattern will be fractured when the run file is processed by NPGS.

Number of Fracture Fields
When a Fracture mode pattern is processed by NPGS, the entire pattern will be read and then fractured into individual *.dc2 files for each square sub-field. These temporary files will be named "%fr00001.dc2", "%fr00002.dc2", and so on, up to a maximum of 32,000 sub-fields. In the automatic fracturing mode, the maximum applies to the total number of possible sub-fields that is determined by the pattern dimensions and the sub-field size, even if some sub-fields do not contain any pattern elements. In the user defined mode, only the sub-fields defined by the user are counted when determining the maximum number allowed. For more information, also see the discussion on the NPGS Menu program command "Commands - Process Run File - Fracture test mode" at Menu Program: Commands Menu (page 57) and GetFract at BasicCAD Programs Supplied with NPGS (page 76) for how to generate and view the temporary files. These temporary files will either be automatically deleted after NPGS is finished with them or they will be left on the disk for future use, depending on the "delete tmps" parameter in "Pg.sys". For more information, see Pg.sys (General System Parameters) (page 172).

Using Previously Fractured Files
Some speed improvement can be achieved by using previously fractured files, rather than recalculating them. If the temporary files are left on the disk, the next time NPGS begins to process a pattern in the Fracture mode, it will prompt if the old files should be used or not. A file named "%fr_sum.dc2" is accessed when previously fractured files are reused. This summary file contains information on the fractured files, and it may be modified by the user, if desired. For each fractured file, the summary file contains the following information:

File#    Align    Pattern   X_center    Y_center
where File# is the number of the sub-field (%fr00001.dc2 = 00001); Align is 1 if the sub-field is to be processed by AL, otherwise it is zero; Pattern is 1 if the sub-field is to be processed by PG, otherwise it is zero; X_center and Y_center are the (x,y) coordinates in microns for the center of the sub-field, relative to the center of the entire pattern. When the fractured files are reused, NPGS will process them in the order listed in "%fr_sum.dc2". Consequently, if the user wishes to change the order or to delete specific sub-fields, the summary file can be modified accordingly. When deleting or rearranging the order, the entire line of the summary file should be deleted or moved as a single entity. Also, if alignment or pattern writing in a particular sub-field is to be skipped, the "Align" and/or "Pattern" entries can be changed from 1 to 0. However, it is generally not advisable to change these entries from 0 to 1.

Design Tips and Limitations
Lines, circles, and circular arcs that have a designed width greater than zero are converted to many filled polygons when fractured.  If a line or arc is to be written by only a single pass of the beam, it is
best to set the designed width to 0 (zero) within DesignCAD. Elements that are entirely within the sub-field will not be changed.

Filled areas (either a Filled Polygon, wide line, or wide arc) are not allowed to completely cover a sub-field.

Sub-Field Size Prompt
This prompt is for the width of the square sub-field in microns. The value entered will be used to calculate the maximum magnification allowed in the pattern parameters on the right hand side. (In contrast, for a normal pattern, the maximum pattern dimensions determine the maximum allowed magnification.)

Border Width Prompt
A special feature in the NPGS fracturing capability is the "Border Width" option. Consider writing a large pattern as a series of sub-fields where the actual writing field (which is defined by the microscope magnification) is the same size as the sub-fields. In this case, a pattern element that extends even 1 micron outside of one field would have to be broken and written in the adjacent field. The NPGS Border Option allows the user to define a border (in microns) around each sub-field where any pattern elements that extend only into the border area will not be broken. Instead, these elements will be written as if the current sub-field includes the border area. To accomplish this, the actual writing field must be large enough to include the sub-field plus the border. The Run File Editor will automatically set the limit on the maximum magnification depending on both the sub-field size and the border width. Any pattern element that extends outside of the border will be fractured at the edge of the original sub-field, as if the Border Option were inactive. To deactivate the Border Option, simply enter a value of 0 (zero) for the border width. In general, the border width should not be set to a value greater than the sub-field size.

If the automated stage in use with the microscope is extremely accurate and the writing field has been calibrated extremely well, then it would not matter if a pattern element is fractured or not. However, in practice, there is always the possibility of a gap or overlap wherever an element is fractured. By minimizing the number of fractured elements, the NPGS Border Option can reduce the need for a high precision stage and for perfect calibration of the writing field.

Initial XY Move Prompt
The next prompt is for the initial X,Y offset (in microns) which would move the stage to the center of the fractured pattern. (The center is the origin when the pattern is viewed in DesignCAD.) Note that the stage is not actually moved to the center, but instead it will move directly to the position of the first pattern. For example, if the stage is initially positioned such that the center of the microscope's field of view is at the edge of the sample a distance of 200 microns in the +Y direction from where the origin is to be for the pattern to be fractured, the entry should be "0,-200". The initial offset sent to the stage will then move the stage to the location of the first sub-field to be written. The first sub-field is determined by the user or automatically as described below. If no automated stage motion is desired for the writing of the entire fractured pattern, leave this prompt empty. After the last sub-field of the fractured pattern is finished writing, the stage will be positioned at the center of the entire pattern, so that the move to any subsequent writing will be easy to determine.

Field Position Prompt (for manual fracturing)
The next prompt is for a DesignCAD layer number that contains the ordering information for the sub-field centers, when the pattern is to be manually fractured. This prompt will be inactive when there is only one layer in the pattern. If 0 (zero) is entered for this parameter, the sub-fields will be automatically generated in a square grid uniformly centered on the maximum dimensions of the pattern. During automatic fracturing, the first sub-field to be written will be in the upper right corner of the pattern. Subsequent sub-fields will follow in a serpentine fashion along the first row of the grid and back on the next lower row, and so on. If one or more sub-fields do not include any pattern elements, they will be completely omitted, i.e., the stage will not even be positioned at those locations. For example, a large, sparse pattern may have hundreds or thousands of possible sub-fields, but if only 23 sub-fields contain pattern elements, the stage will only be positioned for those 23 fields. For more information, see "SAMPLE5" at Patterns for Exposure (page 36). If a value between 1 and 19, inclusive, is entered, it must be the layer number in the pattern file that contains information of the user-defined field centers. In the specified drawing layer, the first point of
any line element will be interpreted as the point for the center of a sub-field. If the line element has multiple segments, only the starting point of the first segment is used. The ordering of the line elements within the drawing layer determines the ordering for the writing of the sub-fields. For example, if a pattern is to be fractured into four 500 micron sub-fields that correspond to the four quadrants, then the first line element would begin at position (250,250), the second would begin at (-250,250), the third at (-250,-250), and the fourth at (250,-250). Each line element can have any number of subsequent segments.

The only restrictions on the placement of the sub-fields are that no sub-field should overlap another where a pattern element crosses from one sub-field to the next. When adjacent sub-fields do not form a square grid, the NPGS border option may need to be deactivated (set to zero) if a filled area crosses the corner of one sub-field into another.

Alignment Layers within the Fractured Pattern
The last two prompts are used when a pattern to be fractured includes "windows" and "overlays" for pattern alignment. (For more information on pattern alignment, see Alignment Tutorial: Step by Step Instructions (page 138).) Layer numbers that define a range of layers within the pattern should be entered for the prompts. For example, if the alignment information is on layers 11 through 15, inclusive, the value 11 should be entered for the 1st Alignment Layer and 15 should be entered for the Last Alignment Layer. Values for the alignment layer prompts can only be entered after a value has been entered for the Field Position Prompt, since manual fracturing is required when using alignment for individual sub-fields. (Also, setting the sub-field center layer to 0 will force the alignment layer entries to 0.) The software will keep the first layer value smaller than or equal to the last layer value. Also, the layer value for the sub-field centers cannot be within the range of values covered by the alignment layer values.

The Alignment Mode prompt can be used to change the mode between semi-automatic alignment and automatic alignment. This prompt will be inactive when the field position prompt or either alignment layer entry is set to zero.

The NPGS Fracture mode alignment option is both very flexible and very powerful. For example, if desired, alignment information can be included in only a few of the sub-fields. In this case, an automated stage would be positioned at the correct location, the alignment would be done (either the semi-automatic or fully automatic mode may be used), and then any pattern elements in that sub-field would be exposed using the corrections from the alignment procedure. Subsequent sub-fields would be exposed using the alignment corrections from the last alignment. If a high accuracy stage is used, it may be useful for a sub-field to contain only alignment information. In any case, each sub-field may contain multiple sets of windows/overlays and the windows/overlays may have unique shapes and locations within the sub-field.

Fracture Pattern Data (on right hand side)
The data on the right hand side for the Fracture mode is the same as the Pattern mode, with the following exceptions.

Layer Prompt
For fractured patterns that do not contain alignment layers and are automatically fractured, the layer prompt is the same as the Pattern mode.

If a Field Position Layer is specified that is between 1 and 19, then the layer prompt for that layer will be set to "Field Position" and will not have any other parameters displayed for that layer.

For fractured patterns that do contain alignment data, all layers between and including the first and last Alignment layers will be handled as if they were part of an Alignment Entity. The data entered for these layers will be used when they are processed as alignment windows/overlays by NPGS.

Magnification Prompt
The upper limit for the magnification will now depend on the "Sub-Field Size" plus twice the "Border Width", instead of the actual pattern dimensions.
**Run File Editor: MoveOnly Entity**

The MoveOnly Entity allows a stage movement command to be entered into the run file, without having any associated pattern writing or alignment. A typical use is to add a "MoveOnly" command at the end of the run file to move the stage to a known location after all pattern writing has been completed. The value to be entered is the relative (x,y) stage movement in microns.

There is no data on the right hand side for this entity.

**Run File Editor: Command Entity**

The Command Entity allows any Windows, DOS, or Script command(s) to be entered in the large text box on the right hand side of the Run File Editor window.

The "Command Mode" prompt can be used to select between a batch file format and a script format. For more information on using scripts within NPGS, see Script Commands (page 167).

The "Pause Mode" prompt can be used to select one of the following choices:

- **Before Only** ......... This option will always pause the processing of the run file before executing the command(s). An option to process or skip the command(s) will be presented.
- **Before Only*** ........ This option is processed as "Never" when the "Non-Stop" advanced mode is active.
- **After Only** .......... This option will always pause the processing of the run file after the execution of the command(s).
- **After Only*** ........... This option is processed as "Never" when the "Non-Stop" advanced mode is active.
- **Before/After** ........ This option combines the "Before Only" and "After Only" modes.
- **Before/After*** ........ This option is processed as "Never" when the "Non-Stop" advanced mode is active.
- **Never** ................ This option will prevent NPGS from pausing the run file processing when the command entity is encountered. However, commands within the command entity may still cause the processing to be paused.
- **Skip** .................. This option will cause the command entity to be skipped when the run file is processed. This allows the command to be "turned off", without having it be removed from the run file.

*These options are processed as "Never" when the "Non-Stop" advanced mode is active.

If entered, the "Command Name" will be displayed when the associated commands are executed by NPGS. Also, the command name is useful because it can summarize the purpose of the command entity, even when the entity is not highlighted, i.e., when the actual commands on the right hand side are not displayed.

When a command entity is highlighted, the right hand side of the window becomes a text entry box where any commands can be entered. Note that the standard Windows Copy/Cut/Paste commands (Ctrl C, Ctrl V, and Ctrl X, respectively) can be used within this text box. When the text entry box on the right hand side is active, the buttons at the bottom of the Run File Editor will be disabled. The command data can consist of Script commands or when the batch mode is selected any Windows or DOS commands as well as any of the elements of a batch file can be used.

*The working directory for Batch commands defaults to the current project.*

**Note that to call another batch file from within the Command Entity in the batch file mode, you must use the "Call" statement.** For example, the following line would be used within the Command Entity to run the batch program "MyProg.bat" in the directory \NPGS\Projects:

```
call \NPGS\Projects\myprog.bat
```

After ‘Batch’ commands have been entered, when the user clicks to another section of the Run File Editor, NPGS will run an "Integrity Check" on the commands. This will check if the
Using the Run File Editor

commands have valid paths and that the actual programs being called already exist* on the hard disk in the specified directories (*this check is skipped in the NPGS Office mode). Also, when a command does not have a path, the software will offer to add "\NPGS\Projects\" or "\NPGS\Program\" to the beginning of the command, as needed.

Suggested uses are to enter commands necessary to initialize an automated stage or a digital microscope.

**Run File Editor: Comment Entity**

The Comment Entity allows any comments to be entered in the large text box on the right hand side of the Run File Editor window.

The comments entered will be displayed when the run file is processed by NPGS, according to the "Display Mode" option shown below.

- **Always** ................. This option will always pause the processing of the run file after displaying the comment list.
- **Always** .................. This option is processed as "Never" when the "Non-Stop" advanced mode is active.
- **Never** .................. This option will prevent NPGS from displaying the comment list.

The "Comment Name" is useful because it can summarize the purpose of the comment entity, i.e., when the actual commands on the right hand side are not displayed.

When a comment entity is highlighted, the right hand side of the window becomes a text entry box where any comments can be entered. Note that the standard Windows Copy/Cut/Paste commands (Ctrl C, Ctrl V, and Ctrl X, respectively) can be used within this text box. When the text entry box on the right hand side is active, the buttons at the bottom of the Run File Editor will be disabled.

Suggested uses are to enter comments about how the run file has been organized, or comments on how the microscope is to be initialized before a particular.

**Run File Editor: Nested Run File Entity**

The Nested Run File Entity allows a run file to ‘call’ another run file. **When processed, only the Advanced Modes of the top level run file being processed will be used, while the Advanced Modes settings of any nested run files will be ignored.**

When a nested run file is processed, all of the entities in the nested run file will effectively be put into the calling run file at the position of the nested run file.

**Nested run files may themselves have other run files nested in them.** Up to a total of 100 nested run files may be in a single run file.

Double clicking on the ‘Nested Run File Name’ text box will present a list of the available run files in the current project. **Once the nested run file name is entered, selecting the name then hitting Enter will launch another Run File Editor for editing the nested run file.** Note that some care must be taken to avoid having an infinite loop of run files that call each other. **In the Menu program, when a run file is highlighted that has one or more nested run files, the entire sequence will be checked to see if any run file names are invalid and if an infinite calling loop exists.**

**When working with nested run files, it is highly recommended to use the ‘Estimate Total Time’ button in the NPGS Menu program to test the top level run file.** This test will expand all nested run files, calculate all of the points in all patterns, and give an estimate for the total writing time. When an automated stage is enabled (in the top level run file), a graphical overview of the positions of every pattern will be displayed.
Details on the Pattern Writing and Alignment Software

Writing and Aligning Patterns using NPGS.exe

NPGS.exe: Overview

The program NPGS.exe simplifies pattern writing and pattern alignment. Basically, NPGS sequentially reads a run file and makes the appropriate calls to PG.exe and AL.exe for pattern writing and alignment. Typically, NPGS.exe will be started from within the NPGS Menu program by selecting a run file and clicking the Custom Command "Process Run File" and the user will never run PG or AL directly.

Since the user will typically want the same alignment pattern to be used before each normal pattern is written by PG, NPGS is programmed accordingly. For example, when NPGS encounters an alignment pattern in the run file, it will run AL using that pattern before each of the following patterns is written by PG, and PG will automatically be called with the alignment option enabled. (For more information, see Run File Editor: Alignment Entity (page 98).) If another alignment pattern is encountered, NPGS will repeat the scheme for the following patterns using the new alignment pattern, and so on.

After each pattern is written, the user is given the option to rewrite the pattern, to continue, or to run any system command. The last option gives the user maximum flexibility in pattern writing, since any command, including NPGS itself, can be run without terminating the initial run file sequence.

The following mouse clicks can be used at any NPGS prompt: "double left click" = Space, "double right click" = Enter, and "left click then right click" = Esc.

For more information, see Writing Patterns with PG.exe (page 115) and Aligning Patterns with AL.exe (page 118).

DMA Transfer Size

One aspect of the pattern writing that occurs throughout this documentation is the use of Direct Memory Access (DMA). In NPGS v9, a burst mode DMA transfer across the PCI bus to the custom PC1516 board is used to send the calculated XY points to the board’s memory (which can hold up to 256k XY pairs). In addition, for each XY point, a dwell time and blanker control information is also passed. Note that the output from the PC1516 is asynchronous from the calculation and transfer of the XY points. This means that the CPU of the PC can calculate points well in advance of when they are actually written. In this fashion, the actual pattern writing will have no delays due to calculations, as long as the average writing speed is less than the average calculation speed per point. For a 1 GHz PC, the calculation speed should be faster than the writing in almost all cases.

NPGS.exe: Command Line Options

Typically, NPGS.exe will be started from within the NPGS Menu program by selecting a run file and clicking the Custom Command "Process Run File", however, it can also be called from a command prompt as described below:

From a command prompt, NPGS.exe is called by:

```
NPGS run_file [n or N] [ex] [s] [t] [!] [f]
```

or

```
NPGS ![CalCheck] (v9 or higher only)
```
where run_file.rf6 contains the pattern sequence and parameters to be used.

The option "!CalCheck" causes NPGS to check if the PCI516 board needs to be recalibrated based on the time value specified in Pg_Auto.sys. It is recommended to have this command in the "Pg_Menu_Start.bat" program in the "\NPGS\Projects" directory, so that each time the NPGS Menu program is started, it will check if the PCI516 board should be recalibrated.

The option "n" tells NPGS not to pause for the "Rewrite, continue, DOS command" prompt between patterns.

The option "N" tells NPGS, PG, and AL not to pause except for layers marked as "Pause First" in the run file.

The option "e" allows the user to scale all exposure times by the factor "x" (for example, "e0.123", "e1.05", or "e100"). This scaling factor is only passed to the writing pattern, PG, and does not have any effect on pattern alignment using AL.

The option "s" will cause NPGS to disable all calls to an automated stage. Note that the either the "e" or "s" option may follow the "n" or "N" option.

The option "t" allows the user to scale all exposure times by the factor "x" (for example, "e0.123", "e1.05", or "e100"). This scaling factor is only passed to the writing pattern, PG, and does not have any effect on pattern alignment using AL.

The option "t" enables the time test mode and does not actually write the patterns. This mode will call Pg as needed and will calculate all of the exposure points of every pattern in the run file. A display for the total estimated writing time for the run file will be displayed. When the run file includes stage moves, the estimated total time for all of the stage moves will be displayed. Since the actual stage speed is not known, the display will show two times for the stage moves where one assumes a 1 second per move speed and the other assumes 5 seconds per move. Usually, the actual stage time will be between these two values. In addition, when the run file includes stage moves, an interactive graphical overview of all pattern locations will be displayed. For each pattern, two squares can be displayed in the overview. The outer square marks the largest writing field for the lowest magnification used for that pattern (if the pattern has more than one layer, each layer may use a different magnification and only the largest field is shown). The inner square marks the largest area with pattern features based on the position of the pattern entities in the CAD file. When the pattern features are very close to the maximum writing field, only one square may be seen. The default is to display only the inner pattern size square.

The "t" option will normally be called by a Custom Command button labeled "Estimate Total Time".

The option "c" enables the error check mode and does not actually write the patterns. This option is best used to see the features of a single pattern displayed on the screen without actually writing the pattern with the microscope. (This option calls Pg using the ‘C’ command line option.) Stage control will be disabled when this mode is used.

The "c" option will normally be called by a Custom Command button labeled “Simulate Writing”.

The option "f" will activate the Stage Control mode for pattern viewing, which is most useful when an automated stage is installed. This mode is basically the same as used in the Global Rotation Correction mode, however, after the initialization, the user is repeatedly prompted for xy offsets relative to the sample axes. This mode makes it easy to move between exposures that are in known positions on the sample. For more information, see Run File Editor: Allow Advanced Modes Entity (page 96). This option also allows the user to initialize the X-Y-Focus mode. For more information, see X-Y-Focus Mode (page 170).

The option "f" is to be used only with the Fracture option. The "f" option will prevent NPGS from actually writing any of the generated sub-field patterns and the patterns will remain in the current directory as "fr00001.dc2", "fr00002.dc2", etc. The user may then load the patterns in DesignCAD using "NPGS - GetFract" to inspect the results of the fracturing process.

**NPGS.exe: Miscellaneous Tips**
Details on the Pattern Writing and Alignment Software

1. For alignment patterns to be interpreted properly by NPGS, they must be marked in the Run File Editor using the "Alignment Entity". Patterns marked for semi-automatic alignment (denoted by "Manual" in the Run File Editor) will pause for user input, while the Auto-Alignment patterns (denoted by "AutoAlign1", "AutoAlign2", or "AutoAlign3" in the Run File Editor) will align to the marks without waiting for the user. All pattern files after the "Use Previous" marker will be run by PG with the alignment option enabled, however, AL will not be called. This allows a previous alignment matrix to be used without calling AL. All pattern files after the "Disable" marker will be run by PG with the alignment option disabled.

2. When NPGS encounters a pattern using the Array or Fracture Entities, it will make as many calls to PG and AL as necessary to complete the structures. If using an automated stage, the appropriate stage motions will be automatically generated. For more information on the Array and Fracture modes, see Entity Entries and Highlighted Entity Data (page 96).

3. The "Process Run File – Time Test Mode" is very useful, since it will give a summary of the estimated time required to process the entire run file.

4. As NPGS processes a run file, it creates the following temporary run files for the calls to PG and AL: "%tmp_pg0.rf6", "%tmp_pg1.rf6", "%tmp_al0.rf6", and "%tmp_al1.rf6". If NPGS is terminated by the user, these files will be left in the current directory until the next time NPGS is run.

5. If PG or AL ends with an error message, an error file "NPGS.err" containing the message is created. While running, NPGS checks for this file to tell if an error has occurred during a call to PG or AL. If so, the error file is deleted and the user is asked if NPGS should terminate. If PG or AL is run directly from the command line, this file is still created if an error occurs, however, it can be ignored, since NPGS will delete it before any calls are made to PG or AL.

6. The DOS command option will run any DOS command or program that can execute within the available memory. The only other restriction is that the run file that is in use by NPGS should not be accessed by any other program.

7. At any NPGS prompt, hitting "q" will generate a prompt asking if the program should be terminated.

8. When called from NPGS, the program PG will not display the total number of patterns that have been written, however, it will display the pattern number and repeat number. Note that the pattern number is then the number of the pattern as it is encountered in the run file excluding any alignment patterns. For example, a typical run file might have an alignment pattern followed by six patterns to be written by PG. Whereas the six patterns will be listed as 2 through 7 in the Run File Editor, they will be patterns 1 through 6 as written by PG.

Writing Patterns with PG.exe

The following mouse clicks can be used at any prompt in PG or AL: "double left click" = Space, "double right click" = Enter, and "left click then right click" = Esc.

PG.exe: Overview

PG.exe is called by NPGS.exe to write patterns or it may be run by the user directly. When PG is run directly it must be supplied with a run file name on the command line. The run file, the pattern(s) to be written, and all PG*.sys files must be present in the current directory. Before each pattern is written, the program will wait for the user to tell it to: continue, stop, skip the current layer, or skip the current pattern. The write #, pattern #, repeat #, pattern name, pattern location, exposure scaling factor (if present), and alignment status are all displayed. The write # counts how many exposures there are; the pattern # refers to the pattern number in the run file; and the repeat # tells if the current pattern being written is an identical repeat. If pattern alignment is enabled, the transformation parameters will be displayed. Also displayed are the "Origin offset", "Magnification", "Configuration Parameter", and
"Measured Beam Current". The only other time the program will stop before completion is if a layer has a "Pause First" designation (specified in the Run File Editor) or if an error occurs. For more information, see Errors: Pattern Writing (NPGS, PG, AL) (page 230).

PG is normally called by NPGS.exe. It can also be called by the user from within the NPGS Menu program with the "Write Only" submenu under "Commands". Or, it can be run from a DOS command line prompt using the syntax: 

```
PG run_file [c or C] [a] [t] [s] [ex]
```

where run_file.rf6 contains the pattern information to be written, the "c" or "C" options causes PG to use error checking modes, where the "C" mode will graphically display the pattern on the NPGS screen exactly as it would be written to the sample, the "a" option causes PG to transform the pattern using the parameters stored in the alignment file "Pg_Align.sys", the "t" option causes PG to estimate the pattern writing time without calculating the actual exposure points, the "s" option causes PG to ignore any stage commands in the current run file, and the "e" option allows the user to scale all exposure times in by the factor "x" (for example, "e0.123", "e1.05", or "e100"). If the "e" option causes exposure times to larger or smaller than the allowed ranges, then the closer limit will be used. In this case, a warning message will be displayed stating that the exposure time limits have been reached.

**PG.exe: Error Checking Modes**

In the error checking modes, PG will calculate all exposure points in the pattern and display a summary of the program parameters for each pattern element, but will not actually expose the pattern. The exposure time and dose displayed will include any scaling by the "e" option, and both will be correct even if the exposure time was automatically restricted to the high or low limit. If "c" was specified, program execution will stop after each pattern element and give the user the opportunity to print out the calculated values. For each pattern element a complete listing of pattern and exposure parameter values are printed as well as timing information consisting of:

- Calculation Time (µsec/pt)
- Write Time (µsec/pt)
- Calculation Time (sec)
- Write Time (sec)

The calculation time will vary depending on the overhead associated with the specific pattern element and if a matrix alignment is being used. For example, a filled polygon that has a small number of points in the sweep side will have a longer calculation time per point than a filled polygon with a large number of points in the sweep side - even if the total area is the same. The write time per point is the exposure time plus the settling times for each point that are being used. If the calculation time per point is significantly longer than the write time per point, the actual pattern writing time may be reduced by changing the exposure parameters to increase the write time per point while keeping the dose the same. The write time in seconds includes the "vector delay" settling time.

If "C" was specified, the pattern will be displayed on the NPGS PC screen in exactly the same order as it would be written on the sample. In addition, the user has the option to watch the pattern writing in real time, 10x slower, 100x slower, or in a fast mode. The screen indicates that hitting the "+" or "-" keys will speed up or slow down the display, but double clicking the right or left mouse buttons will have the same effect, respectively. Note that while NPGS writes to the SEM with 16 bit resolution, the PC screen can only display images with ~10 bits of resolution, consequently, there may appear to be pixel size defects in the image displayed on the PC screen or the serpentine fill lines of a Filled Polygon may not appear to alternate as expected, however, in both cases, this is only an artifact of the comparatively low resolution of the monitor. During the display of the pattern element summaries of either mode, hitting "c" will switch to the other mode.

The following is only needed for advanced pattern debugging. When printed out, the exposure points are integers from 32,767 to -32,768 corresponding to the full deflection of the DAC output. The dwell value per point and the control bits per point will also be displayed when the XY data is printed to the screen. The "Command #" given during error checking is the number of the pattern element as it is encountered in the DesignCAD pattern file. The pattern element #1 is usually the first new layer command in the file. When error checking, PG displays the actual pattern file command line after each "Command #" is given.
**PG.exe: Time Test Mode**

When the time test option is used, the total writing time will be estimated using the number of points in each pattern element and the exposure and settling time, but the pattern(s) will not be exposed. The estimated writing time should be within ~30 seconds or ~5%, whichever is greater, of the actual writing time if the pattern is not limited by the calculation time of the exposure points.

**PG.exe: Continuous Mode**

When a blanker is installed, this mode will only be used when the Normal mode has been set to blank the beam between every exposure point. When a blanker is not installed, the Continuous mode will disable the extra settling time added at the beginning of each new pattern element. Note that when no blanker is used, if there is no settling time when the beam jumps a long distance, a "tail" may be exposed at the start of a new pattern entity, because the scan coils will not have had time to reach the starting point before the beam moves to the next location. Consequently, NPGS provides advanced settling parameters that can be optimized to minimize exposure "tails" at the start of pattern elements, while avoiding overexposed dots which will result from too long of an initial settling time.

**PG.exe: Optimizing the Exposure Time**

The drawing elements of a pattern are read sequentially as stored on the hard disk (the "NPGS - Save" command ensures that they are ordered by layer). Each pattern element will be calculated and the exposure data will be transferred to the NPGS PCI516 board, up to the limit of 256k XY points in the board’s memory. Once the memory on the PCI516 board is full, the calculated points will be saved in the PC’s memory until they can be sent to the board. Independent from the calculations, the board will output the points at the defined exposure time per point. Consequently, as long as the average exposure time per point (including all settling times) is slower than the calculation speed of the PC, the output will continue uninterrupted. For any fast PC, the calculations should almost always be faster than the output rate.

When the "show %done" parameter in Pg.sys is set to "2=graphical display", the pattern will be displayed on the NPGS PC screen as it is calculated, unless the dwell time of the pattern element is so short that the "show min dwell" limit is encountered. In that case, the pattern element will not be displayed in order to give the full CPU processing to the calculation of the exposure points, rather than using some processing speed to display the pattern. Whenever the calculations are fast enough to fill the memory on the PCI516 board, the "Displaying:…xx seconds" indicator will be updated as more points are calculated (and displayed to the NPGS PC screen, if that mode is enabled). If the "Displaying:…" indicator is not shown, then the PCI516 board memory is not completely filled. If this happens and the pattern is being graphically displayed, the "show min dwell" time in Pg.sys should be increased, so that the time will not be spent displaying the pattern image. The appropriate value for the "show min dwell" parameter will depend on the speed of the CPU and of the graphics board being used. For patterns written at such high speeds that they are never displayed, they can be viewed by using the "Commands - Process Run File - Error Check Mode".

When each pattern has been successfully written a pattern summary is printed. The summary consists of: the total number of points, the number of points in the largest and smallest single DMA transfers, the total writing time, the average microseconds per point, and a writing efficiency. In addition, the maximum timing error will be displayed. The total writing time does not include any time that the program paused waiting for a response from the user. The parameter "time pause" in the system file "Pg.sys" determines if the program will pause after the summary is displayed. The efficiency is given by 100% x (Ideal Writing Time)/(Actual Writing Time). The ideal writing time is the sum of the point exposure times plus any programmed settling times. Typically, patterns will have efficiencies ranging from 80% to 99%, although very short patterns may have a lower efficiency because then even fractions of a second of overhead will be significant. The two major factors that determine the pattern writing efficiency are the number of points in each pattern element (elements with more points are more efficient) and the ratio between the calculation time per point and the writing time per point. If needed, the pattern writing efficiency may be improved by increasing the exposure point spacing so that the exposure time per point is greater than the calculation time per point.
**PG.exe: Miscellaneous Tips**

1. When "Esc" is used to skip a pattern, the pattern elements are still read by PG, however, the exposure points are not calculated. If the pattern has a large number of elements, the hard disk access light may flash for several seconds as the pattern is read.

2. *The pattern writing may be terminated by hitting the “Esc” key (or by clicking left then right without moving the mouse).* The program will not stop until the current DMA transfer is completed.

3. When PG uses the file "Pg_Align.sys" for pattern alignment, the two alignment options (0 and 1) are written differently. Option 0 is the full transformation option. In this case, PG transforms each calculated point using the transformation below:

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}
\begin{bmatrix}
X \\
Y
\end{bmatrix}
+ \begin{bmatrix}
X_{\text{offset}} \\
Y_{\text{offset}}
\end{bmatrix} = \begin{bmatrix}
X' \\
Y'
\end{bmatrix}
\]

4. Since each point is transformed in an extra calculation step, this increases the calculation time, however, the total writing time is seldom affected. Option 1 uses only a total magnification and offset change. In this case, PG transforms the points that are read in from the pattern file before calculating the individual exposure points. Consequently, there is no effect on the calculation time.

5. Before, during, and after pattern writing the beam is positioned as follows:

   A. When PG is run, the beam position is not changed until the pattern writing starts.
   B. During pattern writing, the beam will be set to dump points whenever they are used in a pattern, even if a blanker is in use.
   C. After any pattern is finished writing, the beam will be positioned at the last dump location if a dump point was used in the pattern. If no dump point was used in a pattern and "blanker" = 1 or 2 in "Pg.sys", the beam will be positioned at (0,0). If no dump point was used and "blanker" is ≤0 in "Pg.sys", then the beam will be positioned at the default dump location (as specified in "Pg.sys"), unless the default location is "0 0". In that case, the beam is left at the final point in the pattern.

**Aligning Patterns with AL.exe**

The following mouse clicks can be used at any prompt in PG or AL: "double left click" = Space, "double right click" = Enter, and "left click then right click" = Esc.

**AL.exe: Overview**

**Overview**

Like PG, the alignment program interprets run files and DesignCAD patterns, however, at run time the patterns are written in a different way. Whereas PG calculates and writes each drawing element sequentially until all are written, AL calculates all of the points and then writes them repeatedly. In this mode filled polygons and wide lines become "windows" on selected parts of the screen (see figure). AL defaults to a semi-automatic mode or the Auto-Alignment mode may be activated as described later.

Up to four alignment windows may be simultaneously displayed on the screen. If one window is opened, magnification and pattern x,y offsets will be calculated. If two windows are opened, magnification, xy offsets, and a total pattern rotation change will be calculated. If three or four windows are opened, a general 2x2 transformation matrix plus x,y offsets will be calculated.

When using the semi-automatic alignment, the image within the alignment windows will be displayed on the PC screen, and the operator will use mouse and/or the PC arrow keys to move the overlay(s)
to match the registration mark(s). Once the overlays are positioned, hitting Space Bar will recalculate the alignment matrix and the results can be viewed after new image data is displayed on the screen.

**Terminating the Program**

Normally, to exit the AL program without saving any alignment results, simply hit ESC. *When the alignment results are to be saved for use during subsequent pattern writing, hit ENTER to terminate the AL program.*

**SEM Brightness and Contrast Settings**

Since the AL program will auto-scale the brightness of the image, the setting of the microscope CRT and detector brightness can usually be left at the same settings as used during normal imaging. However, if using an analog microscope, the CRT intensity should be low enough so that it will not be too bright when the beam is stationary at a single point. The contrast setting of the microscope detector will affect the performance of the AL program. Typically, the same contrast setting used for viewing with the microscope will be appropriate for use with the AL program.

*The best way to really understand the effect of the brightness and contrast settings is to watch the SEM output signal while making changes to the parameters.* (The SEM output signal is connected to the "Input" SMA connector on the PCI516 board.) If the sample is arranged such that right half of the SEM display is dark and left half is bright, then it should be easy to adjust the oscilloscope to get a waveform that basically looks like a square wave. If the noise on the signal is greater than the square shape or if the signal drifts in time, then AL will not be able to display a good image. Ideally, the voltage output from the SEM will change by at least 0.5 volts as the image brightness changes from black to white.

**AL.exe: Keystroke Commands**

The following is a list of single keystroke options designed to give the user the necessary control to optimize any alignment condition. Note that some of the common keystroke options will not be available during some operations. Consequently, the list of available keystrokes displayed within AL will be dynamically updated. (Keystrokes that are less commonly used but are always available are not displayed within AL, as noted below.)*


When the alignment program is running, a list of keystroke commands will be displayed across the top of the screen. If the mouse pointer is moved over one of the keystroke commands in the list, a summary statement will be displayed, and clicking the keystroke character will cause it to be performed. In cases where secondary keystrokes are listed below, for example, A/a, C/V, or J/K, left clicking will perform the primary character function and right clicking will perform the secondary character function.

Very few of these options will be used in a typical alignment, however, in certain circumstances, each provides a very useful function. A detailed description is given below to supplement the brief description of each that is available within the AL program (use "H" or "?"). The single keystroke commands are not case sensitive unless otherwise noted below:

**A (a)**

Auto contrast. The contrast limits will be set based on the maximum and minimum data intensities in the current window and the "Min and Max Auto Contrast" values set in "Pg_AL.sys". If ALL or MAG is selected, the intensities of points within all windows are used. The displayed data range will also be updated. This option is automatically executed after the first window in the first set is scanned. The image will be updated immediately if (a) is hit, otherwise, the image will be updated as new data is acquired. The width of the color bar on the right side of the screen will represent a histogram of the number of pixels of the displayed intensity, where the bottom of the bar represents the darkest pixel in the image and the top represents the brightest pixel. The contrast limits will be displayed on the color bar as horizontal yellow lines, which can be dragged using the mouse to change the contrast settings. Note that when the mouse is positioned at the midpoint between the contrast markers, the cursor will change which indicates that both contrast markers will be dragged together. This operation effectively changes just the brightness of the image, without changing the contrast.
Beam on/off. The beam is toggled on or off when in Normal, SEM, or Single Scan modes.

Center-to-Center spacing. The spacing of the scanned points is increased (decreased) from 1x to 9x of the value in the run file. The displayed scale remains the same, however, the appropriate number of points are skipped. When executed, the mode is changed to overwrite as needed. This option is intended to give the user direct control over the point spacing and the speed of the scanned windows (especially useful for large, coarse alignment windows). The change in speed will depend on the number of ADC acquisitions for each pixel. The overwrite modes have less of an increase in speed for the same change in spacing than the other modes.

Display/change system parameters. Most of the parameters set in "Pg_AL.sys" can be changed by using this option. Two state responses (i.e., 0 or 1) are automatically toggled if the user indicates that they are to be changed. Parameters changed using this option only affect the current operation of AL. To permanently change the defaults, the file "Pg_AL.sys" must be changed using the System File Editor found in the NPGS Menu program under "Options".

Enhance edges of alignment marks using 4 (8) nearest neighbors at each pixel location. This function uses a second derivative method, therefore, it is not recommended for noisy images. It is most useful when doing Auto-Alignment to a small portion of a large structure, such as to the corner of a large bonding pad or a mesa. When the edge is enhanced, the brightness of the mark interior will be preserved. This option is always available, but not displayed.

Average each pixel with 4 (8) nearest neighbors. This can be used to smooth noisy images before and/or after using the edge enhancement. This option is always available, but not displayed.

Generates an edges only display using 4 (8) nearest neighbors at each pixel location. This function uses a second derivative method, therefore, it is not recommended for noisy images. Generally, the 'e' command is recommended because it preserves the brightness of the mark, while this command only displays the edges. This option is always available, but not displayed.

Help. A brief help menu is displayed.

Jump to the next (previous) color palette of the four user-defined palettes in "Pg_AL.sys".

Matrix display. The current matrix will be displayed and optionally changed. (In one window mode, only the magnification and offsets will be displayed.) Hitting ESC while this option is prompting for new values will reset the offset, magnification, and/or matrix elements to default values. Only valid values will be accepted as input.

Normal mode. In this mode the beam is continuously scanned over the alignment windows and the running average of the acquired data is displayed.

Overwrite mode. In this mode any previous data will be overwritten by the current scan. After all windows have been updated the mode returns to what it was before the option was called.

Pixel size. The screen pixel size for the image display is stepped between 1, 2, 3, and 4, which effectively magnifies the alignment image. The upper limit depends on the resolution being used for Windows applications and is displayed in the top status bar within the AL program next to the "P" keystroke command. For example, if the screen resolution is set under Windows to a high resolution...
such as 1280 x 1024, the alignment pixels may be magnified by up to a factor of 4, while lower resolutions of the screen will be limited to 2 or 3. The sample pixel spacing is set by the “Center-to-Center” parameter in the alignment run file. Therefore, the screen size of a window will be determined by the designed size of the window, the “Center-to-Center” spacing, and the screen pixel size.

Q
Quick scan. All windows will be rewritten without acquiring new data. This is useful when the contrast limits are being changed manually or after changing the pixel size. Depending on the number of ADC acquisitions per pixel, this can be significantly faster than the normal scan.

R
Recalculate. (A "double left click" or Space Bar can also be used.) The transformation matrix is calculated using the current offsets of the alignment overlays. The displayed intermediate steps depend on the state of the "Matrix Display" option in "Pg_AL.sys". If it is 0, then no intermediate steps are displayed and scanning continues using the new transformation. If it is 1, then the new matrix (denoted by N>) will be displayed before it is applied to the previous matrix. The new total matrix (denoted by T>) will then be displayed before scanning continues. If the option is 2 and four windows are displayed, then all four intermediate matrices (denoted by 1>, 2>, 3>, and 4>) will be displayed. Matrix "1>" is calculated using windows 1,2,3, matrix "2>" uses windows 2,3,4, matrix "3>" uses windows 3,4,1, and matrix "4>" uses windows 4,1,2. Then the new matrix (denoted by N>) will be displayed. The new matrix is calculated by a weighted average of matrices 1> through 4>. The weighting scheme is described below - see the "W" option. The new total matrix (denoted by T>) will then be displayed before scanning continues. When any of the matrices are displayed they may be changed by the user or reset by hitting ESC. If transforming the current overlay positions would cause the alignment windows to fall outside of the allowed field of view or if the transformation would exceed the "tolerance" limits specified in the "Pg_AL.sys" system file, the "Invalid Matrix Calculation..." message will be displayed. The user will be able to hit any key to continue, which will cause the transformation to be aborted and the matrix will be reset to the previous values. If four windows are opened at once, position all four overlays before recalculating the matrix.

S
SEM mode. In this mode the beam is continuously scanned without averaging the scans and is similar to a slow analog SEM scan. This is particularly useful for coarse positioning of the sample using the stage motion, x and y image shift, or scan rotation. Note that the 's' key is case sensitive.

S
Single Scan mode. There are two different single scan modes: Overwrite and Averaging. In both, the beam is scanned once over the windows and is then turned off. When "B" or "S" is hit, the windows are scanned again. The SS Overwrite mode is selected when the original mode was Overwrite or SEM. The SS Averaging mode is selected when the original mode was Normal. In either Single Scan mode, if a fast blanker is in use ("blanker" > 0 in Pg.sys), the beam will be turned off while the beam position is changed from pixel to pixel in order to further minimize the exposure of the sample. However, depending on the speed of the computer, the actual time the beam is on can be significantly longer than the data acquisition time.

T
Time change. This option allows the # of ADC acquisitions per pixel (1=2.7 μs for NPGS v9) to be changed between 2 and 10,000. Typically, a value between 20 and 50 will provide good signal averaging without slowing down the data acquisition significantly.

W
Weights. This allows the weights for four window alignment to be changed. Hitting ESC within this option will reset all the weights to 1. The weights should reflect the user's confidence in the alignment of each window where W1 corresponds to window 1, W2 to 2, and so on. Any positive numbers may be entered and one weight may be zero (i.e., that window will not be used at all). In four window alignment there are four matrices that are calculated (as described in the description above for the "R" option) and must be averaged together. Since each intermediate matrix (1> to 4>) uses three windows, the weight for each matrix is the product of the weights of the individual windows. For example, the weight of matrix "1>" is just W1 x W2 x W3. The new matrix "N>" is the weighted sum of the four matrices divided by the sum of the matrix weights. If a window weight is set to zero, then
three of the four matrix weights are also zero and the calculation reduces to a three window transform. This option is only available during four window alignment.

Z
Zero level. This resets the ADC background level to zero. This is necessary when the electron detector brightness or contrast is changed during alignment.

! Run Coarse, then Fine Auto-Alignment functions. If used while in semi-automatic mode, the default parameters will be read from "Pg_AA1.sys". This option is always available, but not displayed.

~ Run Fine Auto-Alignment function only. If used while in semi-automatic mode, the default parameters will be read from "Pg_AA1.sys". The overlays will be aligned starting from their current positions. This option is always available, but not displayed.

= Display relative value for current overlay fit to mark. (If MAG or ALL is selected, value displayed will be for the overlay in window #1.) By using this function for different overlay positions, the data used by the Auto-Alignment feature can be observed. Note that the Auto-Alignment feature will calculate the best fit by averaging the highest of the values displayed this way. Therefore, the Auto-Aligned fit will not always correspond to the highest value displayed, but it should always provide a good match with the alignment mark. This option is always available, but not displayed.

@ Enable Auto-Alignment mode. This option is always available, but not displayed.

# Disable Auto-Alignment mode. This option is always available, but not displayed.

* Will pause all processing until any is hit. This generally used to pause the Auto-Alignment pre-align keystroke command sequence so that the results of each processing step can be evaluated. This option is always available, but not displayed.

[ ( ) ] Will "roll" the color scale up and down. This does not change how the colors are assigned to the data intensities. This can be used to maximize the contrast at the edge of the alignment mark. This option is always available, but not displayed.

Other keystroke options relating to the image brightness and contrast are described below. (The numeric keypad is to be used with the NumLock on.) These options are always available, but not displayed.

Up Arrow
Increase both contrast limits. This will effectively decrease the brightness of the image.

Down Arrow
Decrease both contrast limits. This will effectively increase the brightness of the image.

Right Arrow
Increase Contrast.

Left Arrow
Decrease Contrast.

Home
Increase upper contrast limit.

End
Decrease upper contrast limit.
PgUp
Increase lower contrast limit.

PgDn
Decrease lower contrast limit.

The color bar will show a histogram of the image data intensities, where the bottom of the bar corresponds to the darkest image pixel and the top of the bar corresponds to the brightest pixel. For each displayed color, the horizontal width of the bar corresponds to the number of image pixels with that color. The marker bars on the histogram indicate the current settings of the contrast limits and can be dragged using the mouse.

Additionally, the following keystroke commands can be used during the NPGS Calibration procedure, but are not used during normal alignment operations.

Ctl-E
Runs the Pg_Edit program for modifying Pg.sys in the current project.

Ctl-L
Runs the PCI516 Board Calibration.

Ctl-X
Allows the PCI516 X range to be dynamically adjusted*.

Ctl-Y
Allows the PCI516 Y range to be dynamically adjusted*.

*When using these functions, be sure not to exceed the maximum allowed voltage input to the SEM.

**AL.exe: Miscellaneous Tips**

**Blanker Use by AL**
When AL writes an alignment pattern, the beam is normally on continuously while the DACs are stepped through the points of the filled polygon(s) that make up a window. The beam is turned off when it is stepped between windows and when the program is prompting the user for a response to one of the options listed below. An exception is that the Single Scan modes will blank the beam between every step in order to further minimize the exposure to the sample.

**Exposure Point Spacing**
The "Center-to-Center" and "Line Spacing" distance in a run file must be the same for all windows in a group (this will be done automatically in the Run File Editor for patterns using the "Alignment Entity"). The spacing should be much larger than for a normal exposure to ensure that the exposure point limit is not exceeded and to minimize the time required to acquire the data in AL. When designing the pattern in DesignCAD, the program "NPGS - WinCalc" can be used to suggest an appropriate exposure point spacing to use for alignment window. Values will typically range from 20 nm to 1,000 nm (1 micron).

**System Files for AL**
The system file "Pg_AL.sys" contains the defaults and initial parameters for AL that allows it to be customized by the user. However, when the Auto-Alignment mode is activated, one of the three following files will also be read: "Pg_AA1.sys", "Pg_AA2.sys", or "Pg_AA3.sys". These files contain parameters that will override some of the entries in "Pg_AL.sys" and they contain parameters unique to the Auto-Alignment process.

**DMA Transfers**
The AL program does not use DMA transfers for the alignment window exposure points, however, it still must assign memory for the points. Up to ~256,000 points may be used in a single set of alignment windows.
Beam Positioning
Before, during, and after scanning alignment windows the beam is positioned as follows:

A. When AL is run, the beam position is not changed until scanning begins.

B. During scanning, when the user hits any key or when the program is waiting for user input, scanning stops and the beam is blanked if a blanker is in use. If dump points are set in the alignment window pattern, the beam will be positioned (independent of "blanker" status) at the dump point for the current window or at the last dump location if no point is defined for the current window. If "blanker" is ≤0, the beam will be positioned at the default dump location, unless the default location is "0 0". In that case, the beam is left at the current point in the pattern. If "blanker" = 1 or 2 and no dump points are in the pattern, the beam is blanked and the position is left at the current point in the pattern.

C. After any set of windows is finished scanning, the beam will be positioned at the last dump location if a dump point was used in the pattern. If no dump point was used in a pattern and "blanker" = 1 or 2 in "Pg.sys", then the beam will be positioned at 0,0. If no dump point was used and "blanker" is ≤0, then the beam will be positioned at the default dump location, unless the default location is "0 0". In that case, the beam is left at the final point in the pattern.

AL.exe: Auto-Alignment Mode

Auto-Alignment: Overview
The Auto-Alignment feature of AL provides all of the flexibility of the semi-automatic mode described previously and provides the ability to automatically align the overlays to the registration marks without user interaction after the initial setup. Before using the Auto-Alignment feature, the user should become familiar with the default, semi-automatic mode of AL. Basically, the Auto-Alignment feature works the same as the semi-automatic mode, except the placement of the overlays is automatically done by the coarse and fine Auto-Alignment functions.

There are three important topics that must be understood in order to obtain the best results with the Auto-Alignment feature. The first concerns the alignment pattern design and how AL will use the user-defined overlays when calculating the fit to the registration marks. For more information, see Automatic Alignment: Overlay Design (page 85). The second involves the use of the parameters that customize the operation of the Auto-Alignment feature. The third deals with obtaining the accuracy required for the initial sample positioning. The latter two topics are discussed below:

Auto-Alignment: Control Parameters
The Auto-Alignment feature of AL is designed to give the user full control over its operation so that its performance may be optimized over a wide variety of microscope and sample conditions. Since the Auto-Alignment feature is designed to run unattended, all of its operations are controlled by the parameters in the Auto-Alignment system files. The three versions of the Auto-Alignment system files are identical in format and provide the user with an easy way to keep three sets of parameters available for different alignment conditions. For more information, see Pg_AA[1,2,3].sys (Auto-Align Parameters) (page 181). An overview of the Auto-Alignment process will be given below.

1. The first step done by the Auto-Alignment routine is to calculate the locations of the pixels of the windows, the displayed overlays, and the fit overlays for the initial set of alignment windows.

2. The second step is to scan the beam over the alignment windows and acquire images of the sample. The quality of the images obtained will determine the accuracy of the alignment process. There are several parameters within NPGS that the user can set to control the image quality, however, the ultimate quality will depend on the type of mark being imaged, the accelerating voltage, the beam current, and the contrast setting of the electron detector. Typically, the electron detector will be set the same as it normally is for microscope viewing and the beam voltage and current will be set to the conditions required for the subsequent pattern writing. Ideally, the mark will be such that these conditions will yield a reasonable image with only a limited amount of signal
averaging. However, if the marks are made of a thin metal, the beam voltage is very high, and the beam current is very low, then the chances for any type of alignment are small. If the beam voltage must be high and the beam current must be low (fairly common settings for fine lithography) then thick gold registration marks may be necessary for good alignment.

3. The user can control the amount of signal averaging used in the image acquisition in two ways. In the Run File Editor for alignment patterns, the color of the pattern will be used to set the ADC acquisition time as each pixel is scanned. Each "Count" entered in the Run File Editor will cause the ADCs to signal average for ~2.7 µs. Typically, a value between 20 and 50 will provide good signal averaging without slowing down the data acquisition significantly. The second way to control the signal averaging is to set the number of scans that will be averaged before the Auto-Alignment is performed. This parameter is in the Auto-Alignment system files and may be set from 2 to 9 scans.

4. The final control the user has over the image quality is through the "Pre-Align Keystroke Commands" in the Auto-Alignment system files. In the semi-automatic mode, the user can use the following keystroke commands to process the displayed image: 'a' autoscales the brightness and contrast, 'f' does a spatial averaging of the pixels, 'e' enhances the edges in the image, and 'g' generates an edges only display of the image. In the Auto-Alignment mode, any combination of these commands that have been entered for the pre-align sequence in the Auto-Alignment system file will be executed before the alignment calculations are performed.

5. After the window images are acquired, AL will perform a coarse and fine alignment to each of the windows. The function of the coarse alignment routine is to perform a quick check of the images and to determine a coarse position for the marks. The fine alignment routine will then calculate a fit for every possible position for the overlay near the coarse position, and then obtain the final fit by averaging the best fits of those tested. The details on the coarse and fine alignment routines are given in the discussion on the Auto-Alignment system files.

6. After a fit has been obtained for each window in the current set, AL can optionally check if the calculated fit positions lie near or across the edges of the windows. If so, AL can use these fits to calculate a correction matrix and offset, and then automatically rescan to obtain more accurate fits. By rescanning with the new correction matrix, the windows will be changed such that the marks should then appear near the center of the windows.

7. The Auto-Alignment feature can send a correction command to an automated stage before doing the final alignment. For example, if the initial sample position is poorly aligned, a correction can be made by moving the stage. This feature can be very important if a series of many alignments are to be done automatically. By doing a coarse correction by moving the stage at each alignment site, problems due to systematic offsets can be eliminated. For example, if the sample is perfectly aligned to one set of registration marks, but the sample axes are rotated slightly with respect to the stage axes, the alignment sites would have an increasing offset as the stage is moved farther from the first site. By correcting the stage position at each site, this propagating offset would be eliminated. The Auto-Alignment coarse correction feature will make use of any Global Correction information in the current directory in the file "pg_angle.sys". An improved version of this feature can be implemented by setting the "stage offset" value in "Pg.sys" to one. In this case, the (x,y) offset that is determined from one alignment will be automatically added to the stage command for the next stage move. Consequently, any propagating offsets caused by a rotated sample will be eliminated, without requiring any additional stage moves.

8. If sets of coarse and fine windows are used at different magnifications, then it should be checked if the microscope has a significant shift in the field of view when the magnification is changed. If there is a significant shift, an "Origin Offset" should be entered in the run file for the coarse set of windows that will compensate for the microscope error. For example, if coarse windows are scanned at 200x and it is observed that a shift of 4 microns in y occurs when the magnification is changed to 1000x for scanning the fine windows, then the first set of windows can be offset by 4 microns in y to compensate. By making the correction for the known offset in the run file, the set of fine windows will be aligned better than if no correction was made. If the offset is larger than...
the size of the fine windows, a correction in the run file will be necessary for the Auto-Alignment to succeed.

9. **Before using the Auto-Alignment feature on an actual sample, the performance of AL should be tested with the alignment pattern, alignment run file, and the appropriate Auto-Alignment system file.** From within the NPGS Menu program, there are two modes available to use when testing AL.

A. "Commands - Align Only - Manually Test AutoAlignment Setup" will run AL in the Auto-Alignment manual-testing mode. Note that a run file used for this test should only contain the Alignment Entity. This mode will use the parameters in the run file and the Auto-Alignment system file selected by the run file, but will not automatically perform the alignment. This mode should be used to view the registration marks with the microscope in the same setup that will be used for the actual alignment in order to determine how much signal averaging will be necessary. This mode can also be used to see the effects of various image-filtering combinations.

B. "Commands - Align Only - See Results of AutoAlignment" will run AL in the Auto-Alignment preview mode. This mode will run the same as the normal Auto-Alignment mode, except it will pause after the alignment is finished for each set of windows. This mode is useful when evaluating the overall speed and accuracy for a given set of Auto-Alignment parameters.

10. **When an Auto-Alignment pattern is ready to use with exposure patterns, a single run file should be process using "NPGS.exe" which includes both the Auto-Alignment pattern and the exposure patterns.** If using an automated stage, in order to have non-stop operation, be sure to use the NPGS Menu program command: "Commands - Process Run File - Non Stop Writing Mode" or to enable the "Non Stop Writing Mode" option in the Run File Editor, so that the program will not wait for any user input.

Related topic: Pg_AA[1,2,3].sys (Auto-Align Parameters) (page 181)

**Auto-Alignment: Sample Setup**

There are two concerns for the sample setup before alignment. The first is simply that the registration marks must be at least partially visible when the alignment windows are initially scanned. The second is that if multiple sites are to be aligned to, then the axes that define the exposure locations must be reasonably well aligned to the stage axes or the Global Correction mode must be used. For more information, see Run File Editor: Allow Advanced Modes Entity (page 96). If an automated stage will be used to move over a large area of the sample, the X-Y-Focus mode may also be useful. For more information, see X-Y-Focus Mode (page 170).

A useful technique is to have two extra sets of marks that are positioned on the sample in sync with the actual exposure sites. Then, after loading the sample, the first set of extra marks can be located without worrying about exposing any sensitive areas. It should then be possible to adjust the sample rotation such that the stage can be moved back and forth between the locations of the extra marks to a reasonable degree of accuracy. Once the stage rotation is accurate enough to move between these two sets of marks, then it should also be good enough for any number of subsequent marks if the "stage offset" option in Pg.sys is used as described above.

*Remember that when the alignment windows are scanned, the resist will be exposed, however, if the alignment is done quickly, the applied dose may be low enough that the resist will not be fully developed.* If the initial sample position is poorly aligned, the alignment windows may overlap part of the sample that was not intended to be exposed. Ideally, the registration marks should be far enough away from the areas of interest, such that no damage will be done even when the initial sample position is in the worst case.

**Auto Alignment: Custom Processing**

If using the Custom option for the Auto-Alignment, the user must write a program that can be called from the command line that will read binary files containing the window, overlay, and image data. The
only limitation on the user program is that it must run under the Windows version on the NPGS PC. The user program will be passed command line arguments as shown below:

```
aa_user (center) (width) (window_threshold) (average_threshold)
```

where, the four parameters will be the "Fine:" values in the Auto-Alignment system file being used. The four parameters do not need to be used, however, they provide an easy way to customize the operation of the custom program by changing the values in the Auto-Alignment system files.

AA_USER will be called for each window separately. Before it is called, four binary data files will be created that contain the information for the window to be processed. The binary data files are:

**al_win.dat**
This file contains xy pairs of integers that define the pixel locations of the current window. The integers range from -32,768 to 32,767 and correspond to full-scale display at the magnification listed in the run file. For example, if the run file magnification is 1000x and the mag_scale parameter in "Pg.sys" is 90,000, then the field of view is ±45 microns. A location of (3641,728) would be 5 microns in x and 1 microns in y from the center of the field of view.

**al_ovl.dat**
This file contains xy pairs of integers that define the pixel locations for the displayed overlay in the current window. The scaling is the same as above.

**al_fit.dat**
This file contains xy pairs of integers that define the pixel locations for the fit overlay in the current window. The scaling is the same as above. The fit overlay is the same as the display overlay, but pixels within closed polygons are also included. (These points define the pixels that AL uses in its Auto-Alignment calculations to determine the fit between the overlay and the image.)

**al_scr.dat**
This file contains integers that represent the image intensity at each pixel in the current window. The order of the pixel intensities is the same as the pixel locations defined in al_win.dat. The integers range from -32,768 to 32,767 and correspond to full-scale input range of the 16-bit ADC used to read the image intensity data.

The format for the above files is as follows. The first 2 bytes of each file will contain the number of integers, N, that follow. (Note that this will be twice the number of xy pairs in the first three files.) The next N bytes will contain the data as described above. The two overlay files will have 3 additional integers (6 bytes) of information after the xy data. The first integer gives the pixel separation, S, in the same units as the xy data. The next two integers define the reference point (X,Y) for the overlay position. For example, when the overlay is unchanged from the xy locations defined in al_ovl.dat, then it is considered to be at the reference location (X,Y). If the overlay is moved 3 pixels to the right, then its location would be (X+3S,Y), if the "xy mirror" parameter in "Pg.sys" is set to 1 (one).

After evaluating the window, overlay, and image data, the custom program aa_user must create a 4 byte, binary file named "AA_USER.sys" that contains the integer offset between the calculated fit location and the original reference location (X,Y). The first integer is the x offset and the second is the y offset.
Detailed Tutorial on Pattern Writing

The following is a step-by-step procedure for writing sub-50 nm lines* on a silicon sample using a gold on carbon SEM standard for correct stigmator adjustment (*the actual linewidth obtained will depend on the resist thickness, the optimization of the SEM, the kV, and the filament type, i.e., field emission vs. W or LaB6; a thermal FE SEM should routinely produce ~20 nm lines with this procedure). Typical parameters and specific comments are given for both analog and digital microscopes. (Other resist/exposure/developer combinations will also work, however, the following procedure has been extensively tested.) Special instructions for first time users are marked in the same way as this sentence. A general reference on lithography is Microlithography Process Technology for IC Fabrication by David J. Elliott. If this book is not available, most technical libraries will have many other books on all aspects of lithography. Other titles are also listed on the NPGS web site.

Writing Tutorial: Sample Preparation

1. Spin PMMA, poly(methyl-methacrylate), resist onto a Si wafer to a thickness of ~50 nm to 150 nm thickness and bake* ≥ 2 hours at 160°C. The final thickness will depend on the concentration of the PMMA, the solvent, and the spin speed. One recipe uses 3% by weight of 950,000 MW (molecular weight) PMMA in chlorobenzene spun at 500 rpm for 3 sec then 4000 rpm for 20 sec. The bake time and temperature are not critical. *Other prebake recipes for PMMA range from 170°C for 30 minutes in an oven to ~15 seconds on a hot plate at 180°C.

If your ultimate goal is to write on a substrate other than silicon, it is still strongly recommended that the initial exposures be preformed on silicon. By writing on silicon, any results can easily be compared to other results, including the Diagnostic Images found on the "Sample Pictures" page of the NPGS web site.

2. Cleave the wafer to obtain pieces ~1 cm square. To cleave, make a ~1 mm long scratch on the top surface perpendicular to the edge of the wafer and pulling it apart* using two pair of tweezers with wide ends (*slightly bending the wafer may be necessary). Scribing a line across the entire surface and breaking along the line is not recommended, since this will typically cause fragments of the substrate to be scattered across the entire surface and it will not follow the cleavage planes. After cleaving, blow off the sample with dry nitrogen.

3. Choose a sample with a clean surface and a square upper-right corner (reference corner). A reference corner in the upper right is convenient when using a manual stage that has coordinates which increase when the area viewed in the SEM moves down and to the left.

4. Using a diamond scribe mark an ID # in the lower-left corner. (This is where the sample may be handled in subsequent processing.) If the sample is marked after the PMMA is spun, the number of silicon fragments that result from the scratching will be reduced by the coating of PMMA.

5. On the surface of the sample on the right side, use one of following techniques. Make ~1 mm long scratches perpendicular to the edge of the sample. Subsequently, these will be used for initial focusing and for relocating the patterned areas after processing. If a diamond scribe is used, the scratches will be into the substrate and will be very obvious when imaged in the microscope. The point of sharp tweezers can also be used, which will only scratch the resist and not into the substrate. Before writing, the stage will be moved to put the end of a scratch in view and the test patterns will be written only a short distance from the end of the scratch. This allows the final focus to be done at the end of the scratch, which will be very close to the pattern writing locations and will consequently minimize the effect of any tilt in the sample. A convenient combination is to use ~1 mm scratches, focus on the smallest particle near the end of the scratch away from the edge, and then make a contamination spot for the final fine focus. Making a contamination spot is very useful, since it gives a real time check of the focus and astigmatism of the beam. Typically, when using a field emission SEM, a contamination spot with a diameter from 10 to 30 nm can be made and the resulting lithography linewidths may be 20 nm
or less. See the “Contamination Spot Diagnostic” section in Common Exposure Problems (page 44) for more information on creating contamination spots. A second technique is to use a pencil to mark the edge to provide some graphite particles to focus on before writing. The graphite left on the surface should be as little as possible to prevent contamination of the writing area on the sample area. Using a clean dry gas, blow off excess graphite from the surface. Another technique is to skip the scratches and graphite and just use the electron beam in "Spot Mode" to make a contamination mark for focusing. This technique only works well in a microscope where there is sufficient pump oil to make large contamination spots.

6. Mount the sample onto a holder using water based conducting carbon paste, carbon putty, PMMA, or spring clips. Spring clips are recommended, because they will keep the sample clean and make it easy to ensure that the sample is flat against the sample holder. (The "Other Resources" page of the NPGS web site contains a link to a supplier of sample mounts with spring clips.) After mounting, always look at the sample from the side to check that it is flat against the holder.

7. Load the sample into the chamber according to the SEM instruction manual. Ideally, the sample should be loaded with the top edge approximately parallel to the X stage motion. (When viewed, the reference corner will typically be in the upper-right of the SEM display.) If the beam is on during loading it must be prevented from exposing the sample by blanking it with the beam blanker or simply by setting the stage position such that the beam will not hit the sample.

**Writing Tutorial: Microscope Optimization**

Different microscope manuals will often use different terminology for the various SEM parameters. In this documentation, the term "emission current" will be used to mean the current coming off of the filament and "beam current" or "probe current" will mean the current that reaches the sample.

1. Set the basic microscope parameters as shown below or to similar settings for the model in use. In general, the microscope will be set to the highest possible kV, the smallest aperture, a working distance between 5 and 10 mm, and a beam current of 5 to 15 pA for W, 10 to 25 pA for LaB6, and 20 to 50 pA for field emission. Note that low currents are recommended for the smallest linewidths, but the highest currents available from the microscope may often be useful when writing large features.

Set **FEI XL30/Sirion/Quanta or Nova** to the following configuration:
- Voltage: 30 kV
- Spot Size: 1 (this will give ~25 pA of beam current)
- Aperture: 30 micron (this is the standard small size)
- Working Distance*: 5 to 10 mm
- Stage Backlash Correction: On
- Scan Rotation: Set to align sample/stage XY with screen
- Scanservice Blanker: Set switch to EXT (blue light), 90 volts (actual blanking voltage will vary)

(* be sure to ‘unlink’ the stage when focusing using the Z position)

Set **LEO/Leica S440 SEM** to the following configuration:
- Voltage (EHT): 40 kV
- Beam Current: 20 µA (emission current in this manual)
- Aperture: 10 micron (this is smaller than the normal size)
- I Probe: 10 pA (beam current in this manual)
- Working Distance: 5 to 10 mm
- Optibeam: On
- Optibeam Conjugate: Off (this is contrary to the LEO recommendation)
- Stage Backlash Correction: On
- Scan Rotation: Set to align sample/stage XY with screen
- LEO Blanker: Set switches to “On” and “Run”

Set **JEOL 840 or 6400 SEM** to the following configuration:
- Voltage: 40 kV
Gun Bias ................................................. 7
Coarse Probe Current ............................. 6e-12 to 3e-11 to give ~5 to 10 pA
Aperture .................................................. 4 (smallest)
Working Distance .................................... 8 or 15'
Image Select ........................................... SEI
EOS Mode .............................................. SEM
Screen bright/contrast ............................. 12:00
Scan Speed ............................................ SLOW**
Scan Mode .............................................. PIC
Character ................................................ WHITE
Scan Rotation ......................................... Set to align sample/stage XY with screen
Scanservice Blanker ................................ Set switch to EXT (blue light), 90 volts (actual blanking
voltage will vary)
Deben Blanker ........................................ Set to “Beam blanking” and “ON 200V” (actual blanking
voltage will vary)
JEOL Magnetic Blanker: ......................... Set switch to EXT (bottom LED on)
(* such that the sample distance is 5 to 10 mm)
(** for a JEOL 840, 845, or 848, any scan mode can be used)

Set JEOL 6500F/7000F/7001F/7600F SEM to the following configuration:
Voltage.................................................... 30 kV
Probe Current ......................................... 3 (Small) to 6 (Medium) to give ~25 pA
Aperture .................................................. 4 (smallest)
Working Distance .................................... 5 to 10 mm
Scan Speed ............................................ Slow
Wobble.................................................... Use Focus Wobble for lithography
Scan Rotation ......................................... Set to align sample/stage XY with screen
Deben Blanker ........................................ Set to “Beam blanking” and “ON 200V” (actual blanking
voltage will vary)
Diagnostics ............................................. Image quality should not change when blanker is
retracted/inserted.

Set Zeiss/LEO Gemini column SEM to the following configuration:
Voltage.................................................... 30 kV
Aperture .................................................. 7.5 to 20 um to give ~25 pA
Working Distance .................................... 5 to 10 mm
Scan Speed ............................................ 15 (slowest)
Scan Rotation ......................................... Set to align sample/stage XY with screen
Raith Blanker .......................................... Power On, Beam On/Off LEDs should agree with NPGS
Diagnostics ............................................. Beam current measured on sample should scale nearly
linearly with size of selected aperture.

2. Properly Saturate the Filament. This should be done at the kV to be used for lithography. Note the
for lithography, you should not simply use the previous setting for the filament saturation, even
though that is often the procedure for SEM microscopy. Setting the filament at too low of a current
will make it sensitive to small changes, while too high of a current will significantly reduce the
filament life. For field emission models, the user will typically not change the filament current.

3. Set the Gun (filament) Shift/Tilt Controls. The tilt setting will normally be adjusted to maximize the
current on the sample. Note that the shift setting may be adjusted during a physical column
alignment procedure or by a procedure that changes the beam current over a wide range of
values. Some people will simply adjust it to maximize the sample current, just like the tilt. Please
consult your SEM manual or SEM service representative for the recommended procedure
(although don’t be surprised if you get different recommendations). Note that on lower cost
models, the SEM may not have electronic gun shift/tilt controls and may only have knobs at the
top of the column to physically shift and/or tilt the gun, which will be used to maximize the beam
current. (In this discussion, "beam current" means the current actually hitting the sample, while
some SEM brands may use the term with a different meaning.) For field emission models, the
user will typically not change the gun/shift controls.
4. Adjust the "Fine Beam Current", "Spot Size", or "I Probe" to obtain 20 pA to 50 pA when using a field emission SEM. Note that on many SEM models, the beam current will be selected from a very limited number of "spot" sizes and the user will not be able to adjust the current to a predefined value, but must instead use the current value produced by the microscope. (The emission current should typically be < 100 µA.) If using W (tungsten) or LaB₆, a lower current should be used to achieve the same pattern linewidths. For example, with W, the smallest linewidths may be achieved with 5 to 15 pA. In every case, the "Measured Beam Current" in the run file must match the actual current, in order to have accurate doses.

5. Move the Au standard into view at the lowest available magnification without exposing the sample. (The Au standard should be mounted on the sample holder, therefore its approximate position should be known.)

6. Bring the Au standard into focus using the coarse and fine focus adjustments. A recommended alternate approach is to set the focus (=WD=working distance) of the microscope to a standard value such as 6 mm, then focus using the Z position of the stage (if present, ‘unlink’ the Z and focus control in the microscope software). Before each of the steps below, use the normal electronic focus of the microscope to set the best focus.

Whenever adjusting the electronic focus or stigmator settings, the recommended approach is to find the setting that gives an equally bad image (on each side of the ‘good’ image) when an equal offset is made to each side of the good setting. The recommended way to implement this is to do a normal adjustment to get a ‘good’ image, then to make equal adjustments to either side of the ‘good’ image (the adjustments may be the clockwise/counterclockwise adjustments to a knob or the right/left or up/down position of the mouse). If the images at equal offsets on each side of the ‘good’ image are equally bad, then return to the good (=center) position. If one side is better than the other, return to a position near the center, but with a small offset in the direction of the ‘better’ image. Then repeat this process until equal adjustments to either side of the ‘good’ image are equally bad. Note that when the ‘better’ of the two ‘bad’ images switches from one side to the other, reduce the small offset in the good direction by half. This will cause the procedure to converge to the ideal position.

7. If available, reset (or ‘clear’ or ‘degauSS’) the objective and/or condenser lenses to remove hysteresis.

Hysteresis is caused when a ferromagnetic material will stay magnetized after an external magnetic field is removed. In an SEM, this effect will produce an unwanted contribution to the magnetic field related to the magnetic lenses (typically the objective and condenser lenses) whenever the current through the lenses is reduced from a significantly larger value. The net effect is that the beam will experience both the field from the current through the lens as well as the unwanted contribution from the magnetization of the ferromagnetic material. Nearly all microscopes with magnetic lenses will have an option to ‘clear’ the hysteresis, which will leave the beam with only the intended magnetic field created by the current through the lens.

When carefully optimizing the beam, it is recommended that the lenses be cleared after the beam current is set and the initial focusing has been done. The best approach is to have the Au standard in focus, then clear the hysteresis. After this first clearing, the image will almost always degrade, where the amount of change in the image will indicate the relative magnitude of the unwanted magnetic field that was eliminated. The two steps of clearing the hysteresis, then refocusing, can be repeated until the clearing step produces no obvious changes in the image quality. This will usually take 2 or 3 repeats of the clear/focus steps.

8. Adjust the aperture centering. Most SEMs will have a “wobble” or “lens modulation” mode that automatically changes the focus back and forth. While this mode is active, the image will swing back and forth on the screen if the aperture is poorly centered. It is recommended to find a small, bright, nominally round, speck of something that fills about 1/3 of the imaging screen when the magnification is set to give an image area of about 1 to 3 microns. This speck should be in reasonably good focus before centering the aperture. With the “wobble” mode active, the X and Y
positions for the aperture should be moved to make the image motion change from "bad" to "good" to "bad" and back again. This ensures that you can fully observe the middle "good" position, which produces the minimum motion on the imaging screen. Then, independently set the X and Y positions for minimal oscillation of the image while in the "wobble" mode of the SEM. Note that if there is significant astigmatism, it may be difficult to set the aperture centering correctly. In that case, you should jump ahead to the astigmatism correction step, come back to center the aperture, and then repeat the astigmatism step. Also, a few SEM models will have significant interplay between the X and Y adjustments, which will make them very difficult to optimize, while the better models will have no noticeable interplay and will be relatively easy to optimize.

9. Adjust the stigmators. The astigmatism correction should be done on a SEM gold calibration standard as seen above. For a microscope with a W or LaB6 filament, initially, simply move the stage to the smallest speck of anything you can see on the sample. Then, adjust the focus and astigmatism. Repeat this process of moving to the smallest speck of dust or whatever, then adjusting the focus and astigmatism, until the microscope is at a field size of 1 micron or smaller. Note that sometimes you may want to go to a lower magnification and search around to find a better small speck to use for the next step. Also, adjusting the astigmatism may be skipped at the lower magnifications. For field emission models, it should be possible to go almost directly to high magnification and optimize the focus and stigmators. Once the microscope is at a field size of 1 micron or smaller, the imaging field may need to be moved frequently, since contamination will often quickly degrade the image over such a small field.

10. Increase magnification until the image is blurred.

11. Repeat the last three steps until a magnification is obtained that has a field size of 1 micron or smaller. (The image quality will degrade at the higher magnifications. To get a better image use the reduced screen option to change the viewing area to ~2" x 2" on the display screen or use a slow scan on the full frame. Also the image will degrade in time if the same area is continuously viewed, so for best results slightly shift the viewing area very often by changing the electronic image shift or the stage position. For diffusion pumped systems with no cold trap, changing the view area often is essential.) The characteristics of the microscope being used and the operator's personal preference will play a large role in determining the actual details used for this procedure. The objective is to adjust the stigmator corrections such that the beam astigmatism is minimal.

12. Check the probe current with the Faraday cup and picoammeter. If available, adjust with the fine current control to obtain the value to be used for the subsequent lithography.

13. Double check aperture centering, focus, and stigmators, then move the stage slightly and take a picture at a standard magnification (perhaps 100,000x or 150,000x) and scan speed. Having a record of the microscope optimization will be very useful for reference by new users and also for comparing the image quality over time.

14. Repeat the last step until an optimum picture is achieved. With practice one or two tries should be sufficient.

When learning to do lithography, the SEM Setup should be repeated until good pictures of the gold standard can consistently be achieved at a low beam current and a field size of 1 micron or smaller. When practicing, all parameters should be changed randomly before each setup to fully test the user's ability to find the optimum conditions when starting from arbitrary SEM configurations. Patterns should be written only after the user has demonstrated mastery of the microscope setup by consistently obtaining good pictures of the gold standard.

Once you have mastered the operation of the SEM for taking pictures, you can move on to learning how to optimize it better when doing fine lithography. Being able to get a good picture of the resolution standard should allow you to do reasonable lithography
on the order of 50 to 100 nm. To be able to do the finest lithography typically requires a more careful setup of the SEM than is required just to get a good picture! Fortunately, with practice, most people will be able to consistently optimize the SEM well enough to obtain fine lithography.

Note that all references to magnification values in this manual assume that the SEM magnification is calibrated to the approximate size of a Polaroid. If the SEM is calibrated so that the magnification value corresponds to the displayed image on the SEM screen, the values referenced in this manual should be approximately doubled.

After this procedure is completed, a focus plane with minimum astigmatism will be established and the focus and stigmators should not be changed!

Writing Tutorial: Sample Positioning

1. Reduce magnification to the lowest value.

2. Move the stage to approach the sample from above until the top edge of the sample just comes into view, then increase the magnification.

3. Repeat the last step until a magnification giving a field size of ~20 microns is achieved. (Once the magnification is above 200x the fine Z may be used to focus after each step, if necessary.)

4. With an image field size of ~20 microns, move the sample in the X direction and adjust the stage rotation until the entire top edge (~10 mm) can be viewed with the vertical position changing less than 10 microns. This alignment is necessary so that patterns can be found after they are written! When an automated stage is available, the Global Correction mode will be much easier than using this manual alignment procedure. Alternately, when first learning to do lithography, by writing at the end of a scratch, the location of the written patterns can be very easy to find.

5. If available, use the scan rotation to level the image of the edge so that the writing axes will be parallel to the edge of the sample. Note that on some microscopes, the scan rotation will introduce distortions into the pattern writing. If using the scan rotation just changes the aspect ratio on the order of a few percent, then the error is probably within spec, which means that the distortion must be tolerated. If the error is worse than a few percent, it is recommended to have the scan rotation fixed or avoid using it for any precise writing.

6. If using the approach with graphite marks on a level sample, move the reference corner (upper-right) to the middle of the screen (at a magnification with a field size of ~20 microns) and record the x and y stage positions. Then, move the y position by ~1 mm such that the right edge of the sample is moving up the screen. Finally, find some graphite to focus on (reduce the magnification if needed). Using the mechanical fine Z*, focus on the smallest piece (<<1 micron) that appears to be directly on the surface. Increase the magnification to give a field size of 5 microns or smaller and adjust the fine focus. (Use a reduced screen to improve image quality.)

7. If using the SEM to make a mark on the surface of the resist, record the coordinates of the reference corner, move to a location near the writing area, and change to the "Spot Mode" of the SEM or hit "DAC (0,0) on the NPGS Menu then set the SEM to external control. This will stop the raster scanning of the beam and after several seconds will typically contaminate a small spot on the PMMA. This small spot can then be used for focusing on the PMMA surface using the mechanical fine Z* and/or find focus. The obvious advantage of this method is that no graphite is needed and the spot can be made almost anywhere on the sample. Depending on the SEM in use, you may or may not be able to successfully use this type of spot for astigmatism adjustments. Often, for non field emission SEMs, the spot will appear too blurry to allow fine adjustments to the astigmatism correction settings and in nearly all cases, imaging of the contamination spot at high magnification will make the spot bigger and less clear.
8. If using the scratch technique, find the scratch closest to the reference corner and follow it out to the end. Just past the end of the scratch, using the fine mechanical Z*, focus on the smallest particle (<<1 micron) that appears to be directly on the surface of the resist. Increase the magnification to give a field size of 5 microns or smaller and adjust the fine focus. (Use a reduced screen to improve image quality.) *It is often useful to make a contamination spot as discussed in the previous step after focusing on a particle near the end of the scratch.*

*Most microscopes will have the ability to move the stage vertically with enough control so that the Z motion can be used to bring the sample to the height of the focal plane of the beam (actually, it is a focal hemisphere, not a plane). Note that on many microscopes, as the height of the sample is changed, the stage will also move in X and/or Y. If the XY movement is significant, it becomes very difficult to carefully focus at the higher magnifications. In any case, after the microscope is focused as well as possible using the Z control of the stage, the final focus should be performed using the electronic focus of the microscope. If the microscope has an option to “Link” the Z stage position (commonly found on FEI microscopes) and the focus, be sure to “unlink” before changing the Z height, otherwise, the microscope may automatically adjust the electronic focus as the user changes the Z height. Manually adjusting the Z using a knob on the chamber will usually avoid any changes to the focus setting, even when the microscope focus value is linked to the Z height.*

The benefit of this approach is that the surface of the PMMA can be brought nominally into focus without having any effect on the optimization of the microscope that was achieved using a gold resolution standard, as discussed in the previous section. The final change in the electronic focus is then less likely to introduce any astigmatism into the beam.

**Writing Tutorial: Writing a Pattern**

1. Turn on the PC and run the NPGS Menu program. Select the project directory "\NPGS\Projects\Samples".

2. If used, turn the Beam Blanker to external control. (The default of the NPGS hardware is to blank the beam so the image on the microscope will typically go black on a digital SEM or disappear on an analog SEM.)

3. If using an analog microscope: **Turn down SEM brightness!** (The SEM brightness refers to the control for the photomultiplier tube [PMT], which is different than the CRT brightness on an analog SEM or the PC screen brightness on a digital SEM.)

4. Set the SEM Enable for NPGS control of the beam. (This disconnects the SEM raster scan generator and will burn a spot in the CRT if the brightness is too high on an analog microscope. On a digital microscope the image will freeze and no spot will be displayed on the CRT.) **Typically, the SEM will be changed into external control by lifting and flipping the locking switch on the blue NPGS/SEM switch that is provided with NPGS for such models (this applies to most JEOL, Hitachi, and Amray models). On most LEO/Zeiss models, the SEM software must also be set to external control, while on FEI models, only the software needs to be changed to enter external control.**

5. If using an analog microscope, turn up the SEM brightness until a flickering spot is barely visible in the center of the SEM CRT.

6. Move the stage to 1 mm from the reference corner in both the x and y directions (the y position should be almost correct from the last move) or just move a short distance from the final focus location if using the scratch or spot technique. **Actually, when first learning, it can be useful to write a pattern at the very edge of the sample or right at the focus location near the scratch or spot, since this will be easy to find, even though it might not come out well.**
7. From within the NPGS Menu program, highlight "SAMPLE0.rf6" (or any other run file name) and click the Custom Command "Process Run File".

Sample0 is very good when first learning to do lithography, because it consists of circles filled with radial spokes. These structures will make the effect of any astigmatism in the beam during pattern writing very obvious once the pattern is developed. Patterns with no astigmatism will appear uniform around the circle and in all of the spokes, while patterns with astigmatism will have lines in a some particular direction that are well defined and lines at 90 degrees will be wide, underexposed, or non-existent. It is recommended to include circles or radial spokes in any test pattern in order to easily identify astigmatism in the developed patterns. Also see the "Diagnostic Images" on the "Sample Pictures" page of the NPGS web site.

8. Set the magnification to the correct value for the pattern to be written. (Most digital microscopes can be set up so that NPGS automatically sets the magnification.)

9. Hit Space Bar at the prompt and pattern writing will start.

10. If using an analog microscope, adjust the brightness when the pattern begins to write. While the pattern writing is independent of the CRT brightness, there are several advantages to watching the pattern trace on the CRT:

- A. If the beam is hitting the sample the spot should have a slightly flicker as it is swept across the sample and should disappear when the beam is blanked. If the spot on the CRT is steady and does not blank properly, then it may indicate that the beam is not hitting the sample. For example, if the SEM has a Faraday cup in the column or if the filament has broken, a steady spot can still be observed if the brightness is set high enough.
- B. If the sample is dirty, then the contamination will often show up as bright flashes as the beam is swept across it. In some cases it will be worth knowing immediately that a critical part of the pattern has hit a piece of dust.
- C. If the filament breaks during a series of exposures it will be immediately obvious if the pattern writing was previously visible on the CRT. Note that if the filament does break, turning up the brightness will then produce the same effect as described in A above.

On a digital microscope, the pattern will not appear on the SEM screen. However, for any SEM, NPGS can be set to display the pattern on the NPGS PC screen as it is written. See "show %done" in Pg.sys for more information.

11. Move the stage and write as many patterns as desired. When first learning, it is recommended that the patterns be placed just far enough apart so that they don’t overlap. This will keep them near to the final focus location, and also make them easier to find after the processing. Be sure to keep a record of how the patterns were positioned on the sample so that they can be found later. Alternately, when an automated stage has been interfaced to NPGS, a single run file can be created that includes all stage moves can write any series of patterns.

12. After all of the exposures in a set have been completed, it is strongly recommended that the beam current be measured again and compared to the initial value. This simple check will alert the user to any changes in the beam current, which will be useful to know when evaluating the resulting exposures. In addition, it can also be a good idea to check that the microscope focus is still correct by moving back to the location used for the final focus of the beam before writing.

When learning to do lithography, the SEM Setup and Pattern Writing should be repeated after randomly changing all microscope parameters. In order to make finding the patterns as easy as possible, do not repeat the alignment to the edge of the sample when using the graphite approach. After writing several rows of patterns (written after retuning the microscope between each row), proceed to the next section. By following this procedure, a single sample will contain several practice runs and consistency can
A perfect exposure after a single optimization of the microscope may happen due to chance, but a series of very good exposures when the microscope has been fully reoptimized each time proves that you know what you are doing!

**Writing Tutorial: Developing the Sample**

1. If carbon paste was used in mounting, it should be cleaned off before developing. If water based, simply wipe the back of the sample on a wet cloth.

2. Develop the sample in 3:1 IPA (Isopropyl Alcohol = 2 Propanol) : MIBK (Methyl Isobutyl Ketone = 2-Pentanone,4-methyl) at 25°C Celsius for 60 seconds. *Tips: 1) The optimum development time will depend on the temperature, so ideally, the developer temperature will be carefully regulated. 2) Doing multiple short development steps is not recommended, since it will simply increase the timing error in the complete process. 3) A small amount of agitation of the sample is recommended. This may be done by gently moving the sample back and forth by hand a few mm’s during the development.*

3. Immediately rinse in IPA for ~20 seconds, followed by DI water for ~20 seconds (optional), and then blow dry with a clean gas. *Tips: 1) PMMA can be developed in IPA without the use of MIBK, so be sure to use a constant amount of time in the IPA in all cases. 2) The DI water rinse step can be omitted, but do not omit the IPA step before the DI water rinse.*

4. Sputter or evaporate ~2 to 20 nm AuPd onto the sample before viewing. (If the metal is to be lifted off after viewing, it should be evaporated and not sputtered.) *Tips: If AuPd is not available, most any other metal can be used, however, if the metal deposition produces a grain size comparable to the feature size, it may obstruct the viewing of fine features. Besides AuPd, Ti and Cr typically will produce a coating with a small grain size, while Au or Al will have larger grain sizes. Note that the grain size will also depend on the deposition rate, the deposition technique, and the substrate temperature.*

When exposing test pieces while learning the basics of lithography, do NOT lift-off the metal before viewing. Observation of the developed PMMA (after coating with a metal) will give the most information about the exposure parameters and the microscope setup. The most difficult aspect of SEM lithography for new users is to be able to consistently minimize the astigmatism in the beam before writing the patterns.

**Writing Tutorial: View in SEM**

1. Mount the sample in the same orientation as when it was exposed.

2. Align to the edge of the sample as was done before writing, or use the "Commands - Direct Stage Control", if an automated stage is interfaced to NPGS.

3. Find the reference corner of the sample and move relative to that position to where the pattern was exposed or follow a scratch, as appropriate.

4. Locate the first pattern using the slow scan mode at 100 to 5000x. If the pattern is very small, this can step can be extremely difficult if the sample has not been consistently aligned!

*When looking for a small pattern, be sure that the microscope is properly focused on the surface and do not use too high or too low of a magnification. When looking at the surface of a relatively featureless sample, it may not be obvious when the focus is not adjusted properly (you can adjust the focus on the graphite placed previously at the edge of the sample or use the spot mode trick). If the focus is just a little off, you could...*
be looking directly at a fine pattern and not be able to see it! Also, when viewing a relatively featureless sample, you may not notice a difference between 100x and 100,000x! Since 100,000x will typically view an area about 1 micron square, it is not very useful for finding patterns. At very low magnifications and often even at the same magnification used to write the pattern, the microscope display will not have enough resolution to make fine patterns visible.

Once you have located a fine pattern, it is instructive to lower the magnification to see when the structure disappears on the screen. You can also change the focus to see how carefully it must be set to be able to see the pattern.

For Diagnostic Images showing common exposure problems, please visit the "Sample Pictures" page on the NPGS web site.

Writing Tutorial: Lift-Off & Etching

When first learning to do lithography, doing lift-off or etching is NOT recommended. Quite simply, if the lift-off step fails, the written patterns may be completely lost, while if the sample is just developed, coated, and viewed, even underexposed patterns can be evaluated.

Once good patterns are achieved in the developed resist, it is reasonable to start doing lift-off or etching. For lift-off when using PMMA, the typical approach is to soak the sample in acetone (dimethyl ketone) until the PMMA dissolves and the evaporated metal that was on top of the PMMA floats away. After about 10 to 20 minutes of soaking an acetone at room temperature, the surface of the metal should look wrinkled. If the sample has good undercutting, squirting acetone onto the metal should then make it float away.

For large features in thick resist, this step is usually very straightforward, however, for small features where the resist undercutting may be marginal, lift-off can be more difficult. Variations on the lift-off process include squirting the acetone onto the surface of the sample (a syringe can be used to generate a more forceful stream), using an ultrasonic cleaner, or using hot acetone (acetone is very flammable, so this technique is not recommended). A simple, but aggressive technique can be to physically scrub the sample surface after lift-off to remove any remaining metal edges on the metal features. Obviously, care must be taken so that the entire pattern does not get removed. One group has reported success with this approach using a soft toothbrush.

An etching step may also be used on the developed PMMA in order to transfer the pattern to the underlying structure. The specifics of the etching step will vary widely between applications, so no general information will be presented here.
Detailed Tutorial on Pattern Alignment

This tutorial assumes that you are familiar with the design and writing procedures for normal patterns and the design of alignment patterns.

Related Topics: Creating Patterns for Semi-Automatic Alignment (page 81), Creating Patterns for Fully Automatic Alignment (page 85), and Aligning Patterns with AL.exe (page 118).

Alignment Tutorial: Step by Step Instructions

1. Ideally, the location of the structure on the sample to be aligned to will be known so that it may be moved into the field of view using the microscope stage while the beam is blanked. This can be accomplished by having some reference feature, such as an extra set of registration marks, on the sample that is a known distance from the first pattern to be aligned to. After finding the reference feature while viewing in the microscope, the beam would then be blanked and the stage would be moved the known distance to the location where the alignment and pattern writing will take place. Using this procedure, the reference feature will get some exposure while it is viewed, but the actual pattern writing area will not. With a good stage, the initial positioning accuracy using this method can be on the order of a micron. In all cases, the stage accuracy should be characterized before attempting any lithography, so that the accuracy of the typical stage move will be known.

2. If the location of the structure on the sample to be aligned to is not known, then the area to be exposed must be viewed to roughly set the coarse alignment. An alignment pattern consisting of a single large filled box and overlay may be useful in this case or the area can simply be viewed on the microscope display. This is usually OK as long as the viewing time is kept to a minimum. The actual allowable viewing time will depend on the beam current, resist sensitivity, etc. Note that the typical SEM raster scan will expose a vertical line down the left side of the viewing area with a much larger dose than the rest of the viewing area. This results because the beam is paused before each horizontal line is scanned. Remember that when the alignment windows are scanned, the resist will typically be exposed. If the initial sample position is poorly aligned, the alignment windows may overlap part of the sample that was not intended to be exposed. Ideally, the registration marks should be far enough away from the areas of interest, such that no damage will be done even when the initial sample position is in the worst case.

3. Once the area to be written is roughly positioned using either procedure described above, the NPGS alignment program will be used to image the registration marks, so that corrections for the pattern writing can be calculated. The beam should already be set up for the subsequent pattern writing: i.e., the alignment should be done at the same microscope conditions to be used for the pattern writing. Typically, a single run file will be used that contains both the alignment patterns and the normal writing patterns. From within the NPGS Menu program, this run file should be highlighted and the "Process Run File" command should be selected from the Custom Commands.

4. When the NPGS alignment program AL.exe starts, it displays the maximum number of points allowed, the "Origin Offset" and "Magnification" listed in the run file, the total number of points calculated to generate the alignment windows, displayed overlays, and fit overlays, and the number of points in each window and overlay. If the alignment windows or overlays require too many points using the "Center-to-Center" spacing specified in the run file, AL will issue a warning and increase the spacing such that the windows can be displayed. If the spacing has been increased 10x and there are still too many points, an error message will be displayed and the program will terminate. See error message AL(13).

5. The maximum number of points for the fit overlay is equal to the maximum number of points available for alignment windows and the maximum number of points for the displayed overlay is ~8,000. The spacing will be increased if any of these limits is exceeded. If the Auto-Alignment
feature is not being used and if the fit overlay size is causing the spacing to be increased, simply edit the pattern and change any closed polygons so that they will have a small gap at some point or draw them in two parts instead of one. This will reduce the number of points required for the fit overlay, since the closed polygons which have their interior points calculated will be eliminated.

6. When the user signals the program to continue by hitting the Space Bar, the first set of alignment windows are scanned using the "Initial" parameters in the system file "Pg_AL.sys". Subsequent sets of windows in the alignment pattern will be scanned using the "Secondary" parameters of the same system file. Hitting ESC instead of Space Bar will cause the program to skip the current set of alignment windows.

7. When AL begins, an option to use the previous alignment matrix will appear if the file "Pg_Align.sys" exists in the current directory and it contains a full alignment matrix. (The option will be selected by hitting ENTER to continue instead of Space Bar.) This option is useful when aligning a series of patterns. Typically, each pattern in a series will require the same matrix and a different offset. This option is especially useful if one or more of the patterns in a series are missing some of the alignment marks. If the alignment matrix is determined on a full set of marks, then a reasonable alignment may still be obtained on the other patterns, even if only one of the alignment marks is available. In the case when the current alignment pattern only has 1 window, the transformation matrix in "Pg_Align.sys" will still be used. This capability can increase the speed of alignment by allowing the user to generate the transformation matrix by aligning to a test pattern with 3 or 4 registration marks and then aligning to only 1 mark for each exposure site. Basically, the rotation of the sample will be determined on the test structure and will be used at each subsequent exposure site.

8. **If coarse positioning is required to get the alignment marks to be within the windows, the stage position, image shift, and scan rotation may all be used.** If any of these functions is used to position the sample, the AL keyboard command "o" (the letter 'O' for Overwrite mode) must be used to overwrite the old image data or the AL "s" command should be used to enter the "SEM" mode, which overwrites the old image data on every new scan. Since the transformation matrix can only be used by PG to transform the subsequent pattern within the field of view of the microscope, manually positioning of the sample may be necessary depending on the initial accuracy of the sample alignment. For example, if the pattern to be subsequently written has elements 10 microns away from the edge of the field of view, then the matrix transformation cannot be used to correct for more than a 10 micron offset of the sample. A transformation that results in exposure points outside of the field of view of the microscope will generate error PG(-1) at run time. To reduce the likelihood of such an effect, the x and y border parameters may be used to create a buffer region around the alignment field of view. Also see the parameters "X and Y field..." in the description of the system file "Pg_AL.sys". For more information, see Pg_AL.sys (Alignment Parameters) (page 178).

9. During alignment, at the right of the screen is a color bar showing the shades of the current palette as defined in "Pg_AL.sys". Hitting "J" ("K") will jump forward (back) through the four user-defined colors schemes listed in "Pg_AL.sys". The width of the color bar will display a histogram representing the number of pixels of each intensity value.

10. The status line at the top of the screen displays the primary keystroke commands, the increment size, the selected window(s) for alignment, the range of acquired data intensities (0=value with beam off), and the current contrast limits. The "DATA" values are integers that correspond to the reading of the analog to digital converter (ADC) used for image acquisition. The highest data value corresponds to the top of the color bar and the lowest data value corresponds to the bottom of the color bar. Since the ADC is 16-bits and accepts a ±10v input range, each integer corresponds to a ~0.3 mV change in the input signal. For example, if the voltage of the image signal has a range of 0.5 volts from the lowest value to the highest value, the difference between the two DATA numbers would be ~1700 (0.5/0.0003). For good image display, the range of the DATA numbers should be 1000 or more. If the image is good on the microscope, but the DATA range is very small in AL, the image signal should be checked and increased, if possible. If the DATA range is
very large (>20,000), a resistive voltage divider may be added where the BNC attaches to the NPGS "Input" connector.

11. The contrast limits determine how the data intensities will be partitioned into the shades of the color scale. **The displayed upper and lower "CONT" values that are displayed on the AL screen indicate the intensity values that will be displayed as the brightest and darkest pixels, respectively.** Horizontal yellow lines on the color bar show how the contrast limits are positioned relative to the maximum and minimum data values. **The user may change the contrast limits by dragging the yellow lines with the mouse.** Any data value above the upper contrast limit will be displayed in the highest color and any data values below the lower contrast limit will be displayed in the lowest color. The data between the limits is linearly divided between the other shades of the color scale. Consequently, making the contrast limits closer together will increase the image contrast and making the limits farther apart will decrease contrast. Also, increasing both contrast limits will decrease the image brightness, etc. The cursor will change when it is positioned at the midpoint of the two yellow lines, which indicates that both lines can be dragged together, effectively changing only the brightness of the image.

12. At the bottom of the screen is displayed the offset (in microns) of the overlay in the currently selected window. If ALL is selected, the average of all of the window offsets will be displayed as X0 and Y0. This average is only meaningful if the windows have not been individually positioned. If MAG is selected and only one window is open, the current magnification of the overlay will be displayed, otherwise no information is displayed. **The smallest step size for the overlays is equal to the "Center-to-Center" distance in the run file for the alignment pattern.**

13. **Once a set of windows is being scanned on the sample, the basic goal is to align the overlays with the alignment marks.** This is accomplished by dragging each overlay to align with its corresponding registration mark. The arrow keys can also be used for fine alignment of the overlay in the currently selected window. In all cases, the screen will display the currently selected window(s) as "Ins=ALL, 1, 2, 3, 4, or MAG".

14. The increment size is the number of pixels that the overlays will move in response to the arrow keys. It also affects the changes in the contrast settings that result from the number pad keys, i.e., the larger the increment size, the larger the change in the contrast settings. The keys "+" and "+" increase and decrease the increment size through the values of 1, 2, 4, and 8, however, for current versions of NPGS, the increment is typically unused.

15. **The ESC key is the cancel/reset/abort key.** When an option is waiting for a "y,[n],Esc" response, the ESC key will cancel the option without changing any values. If the current option was waiting for new values for the magnification, offset, or matrix, then hitting ESC will reset the values to the defaults, i.e., offsets to zero and the matrix or magnification to unity. If the program is not waiting for a value to be entered, then ESC will abort the current set of alignment windows and the program will continue to the next set or quit if there are no more windows. **Quitting the program this way will not store any alignment parameters for use by PG during the subsequent pattern writing.**

16. **Once the alignment is satisfactory, the ENTER key should be used to continue to the next set of windows or quit if there are no more alignment windows.** When ENTER is used after the last set of windows, it will cause the current alignment matrix to be saved to the hard disk for use by PG. A prompt then asks if the alignment matrix should be recalculated before saving. Typically, the best response is to hit enter, which will select the default choice and cause the alignment matrix to be recalculated.

17. **When the pattern writing begins, if the manual mode is being used, the alignment parameters will be displayed.** If the display shows "Alignment:None", it indicates that the Alignment program was terminated without saving any alignment parameters, which is typically caused by using ESC to quit, rather than ENTER.
18. The system file "Pg_AL.sys" contains the default parameters for manual alignment and "Pg_AA1.sys", "Pg_AA2.sys", and "Pg_AA3.sys" contain the parameters for Auto Alignment. If the Auto-Alignment feature is manually enabled while using a pattern marked for semi-automatic alignment (denoted by "Manual" in the Run File Editor), the Auto-Alignment defaults will be used from "Pg_AA1.sys". The values in these system files can be changed to optimize the alignment for different applications. For complete details, see "Pg_AL.sys (Alignment Parameters) (page 178)" and "Pg_AA[1,2,3].sys (Auto-Align Parameters) (page 181)".
Advanced Features of NPGS

Auto Logging Mode

The NPGS Auto Logging mode makes it easy to document every exposure made by NPGS. When this mode is active, before any pattern writing is started by NPGS, the user will be presented with a log file that can be easily modified to document the parameters associated with the current writing session. After the log file is modified and saved, it will be appended to the files called "Project.log" and "LastRun.log" in the current project. The "Project.log" file is never deleted by NPGS, so it can contain the documentation for all exposures made with NPGS in the associated project. By periodically renaming the "Project.log" file, the user can easily create archives of the patterning history for each project.

The "LastRun.log" file will automatically be overwritten by NPGS whenever a run file is processed. Also, the programs NPGS.exe, PG.exe, and AL.exe will automatically add descriptive comments to "LastRun.log" as a run is a file is processed, so that a detailed summary will be available once the processing is finished. More concise comments and any error messages will also be automatically appended to "Project.log".

From within the NPGS Menu program, the menu "File - Log Files..." can be used to view (and optionally search and/or print) the "NPGS_Master.log" file, which contains summary information for all exposures made by NPGS. The "Project.log" file for the current project will contain detailed information when the Auto Logging mode is used, in addition to any error messages generated during the pattern writing. The "LastRun.log" file will contain the detailed information for the last run file that was processed.

The powerful aspect to the NPGS Auto Logging mode is that the parameters that are displayed before a run file is processed can be completely customized for each project by the users. The default log file that is displayed before patterns are written is called "Pg_Log_Pre.sys", which is defined in "Pg_Edit_Log.def" in each project. Also defined is the file "Pg_Log_Post.sys", which can be used to enter post writing notes into the "Project.log" file. Note that if the definition file is changed, the corresponding system file must also be changed to match the definition file. The user is encouraged to customize the logging definition file so that all desired parameters can be easily documented.

Auto Logging: Mode/Entity Command List

To customize the "Pg_Log_Pre.sys" file, the user will need to understand the format of a definition file as described below. A definition file tells the display software what to expect in the corresponding system files and also what editing options are available. For example, if an entry in the "Pg_Log_Pre.sys" file is to have 4 choices, then the four possible choices for the entry must be entered into the corresponding definition file. By looking at the table below and the default definition file, it is expected that the format will quickly become obvious.

A definition file may contain definitions for any number of files. For each file, every line in the file must be described by the appropriate entity (E*) and mode (M*) commands. The commands that can be used to describe the "Pg_Edit_Log.def" file are listed below. The M* commands apply to the entire file or to multiple lines, while the E* commands apply only to entities on a single lines. Note that multiple E* commands can be used to define a single line of the file. Also, for the "#characters" parameter, "-1" will mean to end of current line for the E* commands, otherwise it will be the number of characters to allow for that entity.

<table>
<thead>
<tr>
<th>M/E</th>
<th>Description</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>File Name</td>
<td>&quot;filename.ext&quot;,&quot;description&quot;</td>
</tr>
<tr>
<td>M2</td>
<td>Line Numbers</td>
<td>&quot;1=on,0=off (default)&quot;,&quot;first number&quot;,&quot;separator&quot;</td>
</tr>
<tr>
<td>M3</td>
<td>File Format</td>
<td>&quot;1=file parameters in quotes, 0=no quotes (default)&quot;</td>
</tr>
<tr>
<td>M4</td>
<td>Help File Name</td>
<td>&quot;helpname.hlp&quot; (each line can have What's This&quot; help through the E10 entity below; the helpname.hlp file can be specified with a full path)</td>
</tr>
<tr>
<td>M5</td>
<td>File Length Check</td>
<td>(no parameters; if M5 is not specified, an error)</td>
</tr>
</tbody>
</table>
message will be generated if the length of the file does not match the definition

"number of lines to read in and save out, but not to display (-1=end of file)"

(no parameters; must mark end of file definition)

"format string (0=integer,0.0=1 decimal place, etc.),"lower limit","upper limit","# characters"

"format string (0=integer,0.0=1 decimal place, etc.),"lower limit","upper limit","# characters"

"#choices","choice1","choice2",..."choiceN","# characters" (if choiceN = "???", any text up to #chars long may also be entered in addition to the list of choices)

"a=allowed characters, e=excluded character","characters to allow/exclude","#characters" (the ‘A’ version must have characters on the line in the file)

"a=allowed characters, e=excluded character", "characters to allow/exclude","#characters" (same as E4, however, a blank line is accepted)

"a=allowed characters, e=excluded character", "characters to allow/exclude","#characters" (same as E4, however, the text in the file is ignored)

"1=display, 0=do not display","#characters" (the text in the file will be read and saved, but can not be edited)

"any text" (this will be displayed on the screen, but is not read from or saved to the file)

"id#" (each line can have a What’s This help ID that links to the help file defined by M4)

"any text" (each line can have text that will appear on the status bar when the line is selected)

(no parameters; every line of the definition file with E* commands must be terminated by E0)

(no parameters, however, all text after the ‘>’ will be interpreted as a comment and will be ignored)

Auto Logging: Default Definition File

The default logging definition file is shown below:

"M1","Pg_Log_Post.sys","Logging: Post-Write Parameters"

">>>The next two lines are not needed, since the defaults are zero anyway."

"M2","0","0",""

"M3","0"

">>>Now, begin the definition for each line in the file...

"E7","1","-1","E11","Post-Writing Comments...","E0"

"E3","2","Yea","No","15","E7","1","-1","E11","Succeful Completion","E0"

"E3","6","<1%","2-3%","3-5%","5-10%","10-20%",">20%","15","E7","1","-1","E11","Total Beam Drift","E0"

"E3","4","None","Slight","Moderate","Extreme","15","E7","1","-1","E11","Focus Change After Exposure","E0"

"E6","e","","80","E11","Comment Line 1","E0"
Advanced Features of NPGS

Auto Text Mode

There are two types of AutoText, which can be generated by NPGS. The first generates text within a pattern during the design phase, while the second generates the text when the pattern is actually written.

MakeArray AutoText

When a pattern is being created in DesignCAD, the NPGS - MakeArray function can automatically number the elements of an array. To use this feature, a text entity containing the characters “##” or
“###” (that is, 2 or 3 “#” characters without any quotes) should be placed within the area to be copied for the array. To activate the AutoText function, the individual elements of the array must be set to different colors and/or different layers when prompted by MakeArray. Consequently, the AutoText function is limited to arrays with 256 elements or less.

When the AutoText mode is activated within the MakeArray function, the text characters of “##” or “###” will be replaced by the vector text starting with “1”, “2”, “3”, and so on. The size and position of the original “##” or “###” text strings will determine the size and position of the vector text which is generated. In all cases, the text must be aligned horizontally. Note that the vectors for each number will be in a “group”, and the “Explode” command must be used to individually edit the vectors.

The default text will be “Simplex2”, which has very narrow characters, which effectively produces two passes of the beam along the perimeter of each number. If this font is not available, the currently selected font will be used. The recommended alternate font is “Simplex”.

Runtime AutoText
This mode generates the actual vectors when the pattern is written within a run file being processed by NPGS. To use this mode, simply include any of the following text entities in the pattern (without any quotes):

```
#T00..................... - exposure number for total run file
#E00.................... - exposure number for current entity
#X00.................... - column number in an Array entity
#Y00.................... - row number in an Array entity
MM/DD/YYYY...... - date
MM/DD/YY......... - date
DD/MM/YYYY...... - date
DD/MM/YY......... - date
HH:MM:SS........... - time (24 hr format)
HH:MM............... - time (24 hr format)
```

The text strings containing zeros may have from 2 to 6 zeros. For example, if the user enters the string “#T0000”, the first pattern written in the run file would have the number “#T0001” written in place of the text string. If the text string is “#T00” and the pattern is the 100th pattern in the run file, the number written would be “#T100”, but it would be compressed to fit within the space occupied by the original “#T00” string in the pattern file.

When the pattern is written, the text string will be replaced by vector text, where the number strings, date strings, and time strings, will be replaced as listed above. Note that these strings can be positioned within the file at any size and angle, and they will be written at the designed size and position by NPGS.

The font used is defined by the file “NPGS_Auto_Text_CHARS.dc2”. The default file exists in the “NPGS\Projects” directory and uses the Simplex2 font. If the user wants to use a different font, the “NPGS_Auto_Text_CHARS.dc2” file can be copied to their NPGS Project directory and modified. The file consists of a text entity, which defines the characters that are supported. This string should not be changed. Each character of the string is defined as vectors in a unique layer in the pattern. For example, for the character set of “1234567890#-/:TEXY”, the character “1” must be defined as vectors in layer 1, character “2” in layer 2, and so on, up to character “Y” in layer 18. Note that the relative positions of the vectors in different layers do not matter, however, all vector characters are scaled relative to the size of the largest character when used by NPGS. Each character must be defined with no more than 10 vector entities, and each vector can have no more than 300 vertices.

Automated Beam Current Reading
Overview
NPGS has the ability to make automated readings of the beam current periodically during the pattern writing and to adjust the exposure times to compensate for drift. The user defined parameters that control the operation of this option are contained in the system file “Pg_Beam.sys”, which can be modified using the System File Editor from within the NPGS Menu program. For more information, see Pg_Beam.sys  (Auto-Beam Reading Parameters) (page 185). The discussion on "Pg_Beam.sys"
Advanced Features of NPGS

An optional mode for this feature is to just enter the name of an external program on line #2 in Pg_Beam.sys that can take an absolute reading of the beam current (in pA or Amps) and save the value in "%pg_io.tmp" in the current project directory. Once this program name is entered, the Get Beam Current button on the main menu will be active when a run file with a single beam current is highlighted. For additional information, see the section Menu Program: Main Window (page 52). This button is intended to make it easy for the user to have NPGS read the beam current before a run file is processed, but it does not activate the full automated beam current readings, as described in the rest of this section.

Absolute vs. Relative Readings

The NPGS beam current reading mode has several options. The first option relates to the reading mode, which is either absolute or relative. In the absolute mode, the measurement must return the actual beam current in pA, and the exposure time will be modified to correct for the difference between the measured beam current and the beam current listed in the run file. For example, if the run file specifies 10 pA and only 8 pA are measured, the exposure times will be multiplied by 1.25 in order to provide the dose listed in the run file. When in the relative mode, the software will assume that the first reading corresponds to the beam current listed in the run file and subsequent readings will be compared to the first. In this mode, the measured units do not matter, but the reading must be proportional to the actual current. For example, if the first reading is 100 (arbitrary units) and a subsequent reading is 80, the exposure times would be multiplied by 1.25. The relative mode assumes that the beam current is initially set at the first current listed in the run file.

Faraday Cup Modes

Several modes are also available regarding the Faraday cup. If the Faraday cup can be inserted into the beam path under remote control, TTL pins on the parallel port or an external program can be used to insert and retract the cup. Parameters in the system file allow the user to specify which parallel port to use and if a delay should be used after each change in the cup. If the Faraday cup can be controlled through software, an external program can activate it while using the internal beam reading mode (discussed below) or the external program can activate the cup and make the reading. If the Faraday cup is mounted on an automated stage, the software can automatically move to the correct location before reading the current. Also, control is provided to specify if a beam blanker needs to be deactivated before the current is read. When a blanker is deactivated, a delay is typically needed for the picoammeter to adjust to the new value, before the meter is read.

External vs. Internal Readings

The actual reading of the beam current can be done using an external program that accesses specific hardware, or the internal mode can be used to read an analog voltage from the NPGS hardware. A typical use of the external mode would be to access a picoammeter through a GPIB interface in order to make an absolute measurement of the current. For example, a Keithley 485 with GPIB interface can autoscale and then make one or more readings of the current. Any external hardware may be accessed by providing the appropriate program that can be called by NPGS.

Typical Configurations

Since there are so many options for the beam reading function, the user must be careful to set the parameters in "Pg_Beam.sys" to match the available hardware. The typical configurations are:

1. A Faraday cup on an automated stage that is attached to a picoammeter with GPIB interface.

2. A Faraday cup that can be inserted into the beam path that is attached to a picoammeter with an analog interface.

3. A field emission SEM that has an output voltage that is proportional to the beam current that hits one of the SEM apertures.

A list showing the execution sequence for the various options follows. The first three steps have actions that are enabled or disabled in pairs, i.e., step B and B* are both always performed or
skipped, while the data reading step either uses the external program specified by the user or the analog to digital converter in the NPGS hardware. Note that the Faraday cup may be inserted using the external program or a pin on the parallel port of the PC, as defined in Pg_Beam.sys.

A) Move to Faraday Cup using Automated Stage
B) Insert Faraday Cup
C) BCC Output: Beam On
D) Read Current: External Program or Analog Voltage w/ NPGS Hardware
C*) BCC Output: Beam Off
B*) Retract Faraday Cup
A*) Move Back to Original Location

Each step can be controlled by setting the appropriate parameters in "Pg_Beam.sys". For more information, see Pg_Beam.sys (Auto-Beam Reading Parameters) (page 185). Note that each time NPGS makes a beam reading, the value will be saved to the "LastRun.log" file.

Miscellaneous
Normally, when using the beam current reading option, run files should be processed by NPGS. Since the actual current reading is done by PG.exe, a temporary file is created so that each time PG.exe is called by NPGS, it can know the results of the last reading of the current. The temporary file is named "%pg_beam.tmp". Each time NPGS is run, the temporary file will be deleted so that old data is not accessed. However, if PG is used to process a run file directly, an old temporary file may exist that will be accessed. Consequently, if PG is used directly, it is recommended to first delete the temporary file, if it exists. When processing run files with NPGS, no extra actions are required. A typical example of "%pg_beam.tmp" follows (comments have been added at the right):

304974.2700  a parameter that stores the time of the last reading
8.838830     beam current from the initial reading (for relative mode)
8.435891     beam current from the most recent reading
10.000000    run file value for the current at the initial reading
10.000000    run file value for the current at the most recent reading

When in the 'absolute' mode, the beam currents will be recorded in pA. When in the 'relative' mode, the beam current units may be arbitrary. However, when using the 'internal' mode and the 'offset' is zero and the 'scaling' is 1.0, the values will be the voltage read on the A/D of the input to the NPGS hardware.

**Beam Optimization with Pg_Optimize (Beta)**
This feature is being provided as a beta release.

**Overview**
The Pg_Optimize.exe program can be used with most digital microscopes to provide an easy to use interface for carefully optimizing the focus and stigmator settings.
The fundamental idea behind Pg_Optimize is that when optimizing the focus or stigmator settings on a microscope, the best setting is centered between two values which are equally bad. Before using Pg_Optimize, the user should first manually optimize the focus and stigmators, so that the image quality is reasonably good. When Pg_Optimize is started, it will read the initial Focus, X Stigmator, and Y Stigmator values from the microscope which become the initial “Center” positions. The operator can then use Pg_Optimize to easily check if the image quality is equally bad on each side of the starting value using the “+1” and “-1” buttons (or optionally the “+2” and “-2” buttons). These buttons will send new values to the microscope based on the value of the step size. For the best results, the step size should be just large enough that the images on each side of Center are obviously degraded. If the images are equally degraded on each side of the starting position, it means that the manual optimization was very good and the “Center” button should be clicked to return to the original value. However, it will typically be seen that one of the test images will be better than the other. In this case, the user simply clicks the “Click if Better” button below the button which gives the better image. Pg_Optimize will then make an adjustment to the Center position to shift it in the direction of the better image using the “Fine Step Size” and the operator can again compare the “+1” and “-1” images. This process is continued until the two test images are both equally degraded which will typically appear as defocused images, even when the stigmators are being adjusted. The key to having the procedure converge is that whenever the ‘better’ image changes sides, the software automatically reduces the “Fine Step Size”. Once the “Focus” is optimized this way, the “X Stig”, and then “Y Stig” values should be optimized using the identical procedure. Depending on how good the original manual optimization was, it may be necessary to cycle through the three values multiple times.

A unique aspect of Pg_Optimize is that the ideal setting is determined by comparing the two images on either side of the “Center” value, while the actual image quality at the Center position itself is never used during the adjustment procedure. With this in mind, the “Left-Right” button can be used where the left mouse button will step the test value by the negative step size and the right mouse button will step in the positive direction. Note that there is an optional check box on the display which causes this mode to skip the Center position and another to cause the center mouse click (usually the mouse wheel) to select the current setting as the better image. With both check boxes marked, the process is simplified to using a right click and a left click without moving the mouse to jump between the “+1” and “-1” images and clicking the mouse wheel when the better image is being displayed. This mode allows the user to hold the mouse over the “Left-Right” button the entire time and just watch the microscope display as the three mouse buttons are clicked.
Details
1. The Pg_Optimize program can be added to a ‘Custom Command’ in the NPGS Menu program (use “Options - Custom Commands”) by creating a button which uses a minimized Batch file to launch “NPGS\Program\Pg_Optimize.exe”. The button should be set to be ‘Always’ enabled.

2. Pg_Optimize requires that the commands listed in Pg_Optimize.sys must be able to communicate with the microscope. Be sure to set up the serial or Ethernet communication between NPGS and the microscope before using Pg_Optimize.

3. In the typical use of Pg_Optimize, the “-Fine” and “+Fine” buttons will not be used. These buttons allow the “Center” position to be stepped manually by the operator.

4. The “Fine Step Size” is automatically used for the offsets to the “Center” value when the “Click if Better” button is clicked. In most cases, the “Fine Step Size” should start about half as large as the main “Step Size”, and it will automatically be reduced as the procedure approaches the best value.

5. If needed, the “1/2” and “2x” buttons can be used to adjust the step size values. In general, it is best if the default values in Pg_Optimize.sys are set so that the operator does not need to manually change the step sizes.

6. The “Configure” button will launch the NPGS System File Editor for the Pg_Optimize.sys file. The parameters in the file should be self-explanatory, but see Pg_Optimize.sys (Beam Optimization Parameters) (page 192) for additional details.

7. The “Set Scan” button can be used to issue multiple commands which will typically be used to set the microscope scan speed to the desired value for use with Pg_Optimize. One approach is to use a fast scan, so that the microscope display instantly updates when the “+1” and “-1” buttons are clicked. However, a better approach is to set the microscope scan speed such that one full scan on the display takes from about 20 to 30 seconds. Using this approach, the “+1” image can be displayed on the upper half of the screen and the “-1” image can be displayed on the lower half of the screen. This approach gives the best signal to noise and makes it easy to compare the image quality for the two settings since both are on the microscope display at the same time.

8. The “Degauss” button can be used to send commands to the microscope to degauss the lenses. Note that this function in the microscope software may be called “lens clear” or “hysteresis removal” depending on the microscope in use. It is best to degauss the lenses two or more times before a careful optimization is performed.

Bitmap File Exposures (Beta)
This feature is being provided as a beta release.

Overview
A new mode to allow bitmap files to be exposed has been added to NPGS. This mode is primarily for use when milling 3D structures with a FIB, but may also be useful in 3D exposures of resist or metal deposition applications. In any case, this feature is intended to be used with a fast beam blanker. The bitmap writing mode is intended only for use with an e-beam or ion beam column which has a fast beam blanker controlled by NPGS.

The bitmap files are loaded into a DesignCAD file, which is then treated as a normal pattern file. Supported bitmap formats include 16 color, 256 color, and 24 bit RGB files with 256 or fewer unique colors. The bitmap may be up to 8,000x8,000 pixels. The bitmap itself must be created outside of NPGS.

Pattern Design with a Bitmap File
To include a bitmap file in a DesignCAD pattern file, do the following:

1. Use “File - Image - Load Image File” in DesignCAD to load a bitmap into a layer that has no other pattern elements. The bitmap file should be located in the current NPGS Project. Only one bitmap should be loaded into a single pattern layer. Normal pattern entities can be used in non-bitmap layers.
2. Hit the ‘u’ key to run the Units command, right click near two corners of the bitmap to snap to the corners, then enter the desired distance in microns for this dimension of the bitmap. Alternately, the Units command can be used to set the desired size of a feature in the image.

3. Optionally, normal vector pattern elements can be included in other drawing layers.

4. Run ‘NPGS - MaxMag’ and hit ‘o’ to set the origin to the center of the pattern.

5. Save the file as normal.

**Run File Editor Settings with a Bitmap File**

When creating a run file that has a pattern which includes a bitmap, do the following:

1. Make a new run file and load the DC2 file with the bitmap into a ‘Pattern’ or ‘Array’ entity. *You should see that the layer with the bitmap has a label of "BMP_rowxcol" where 'row' and 'col' are the number of pixels in each direction.*

2. The Center-to-Center and Line Spacing should automatically both be set to the size of the pixel. When you select one of these prompts, the status bar at the bottom will show the limits and also "(+/- BITMAP Mode = P/1)" where 'P' is the size of the pixel in the bitmap. If you hit the +/- keys, the spacing will jump between P/1, P/2, P/4, ...P/16. However, there will be some limits on how small the value may be. For example, if both CC and LS are P/4, then each original bitmap pixel will be exposed with a 4x4 array of smaller sub-pixel steps of the beam. During the writing, the pixels of each row of the bitmap will be written, using whatever number of sub-pixels are defined in the run file. For any bitmap, the smallest spacings are limited so that the number of sub-pixels times the number of pixels in a single row of the bitmap must be less than about 32,000.

3. To use the new RGB component mode to set the doses, run Set Doses, select the Layer and the Area/Line/Point/Time mode you want, then select the "RGB Mode" which is a new choice in the Exponential/Linear/Polynomial pull-down list. See below for additional details.

4. You can use the 'Multiple Pass Mode' with bitmaps to expose with multiple passes. *Only the 'Entity Repeat' and 'Entity Reverse' modes should be used.*

5. Save the file as normal.

**Details on RGB Dose Mode**

The RGB Dose mode allows the color components in the bitmap to be used to define the dose. Normally in NPGS, the color components of the pattern entities are used to distinguish doses, but only in that each RGB color gets a unique dose and the RGB color determines the ordering of the doses as displayed in the Run File Editor. This new RGB color mode allows the color components themselves to be used in a mathematical calculation of the dose. For example, in a grayscale bitmap, the pixels with RGB color (32,32,32) can have one half the dose of the pixels with color (64,64,64). This allows the relative dose information to be encoded into the bitmap itself.

When the RGB Mode is selected, the following choices appear:

- Dose Max.............the maximum value for the dose range in the selected units
- Red Mult ..............the multiplier for the Red component of the RGB values
- Green Mult...........the multiplier for the Green component of the RGB values
- Blue Mult..............the multiplier for the Blue component of the RGB values

In general, the dose for each color of the pattern will be calculated as follows:

\[
Dose(R,G,B) = \text{DoseMax} \times (\text{Rm} \times R + \text{Gm} \times G + \text{Bm} \times B) / \text{RGBmax}
\]

where RGBmax = \([255 \times (\text{Rm} + \text{Gm} + \text{Bm})]\)

In the case where you just want to set the dose based on the G value, set Rm=0, Gm=1, and Bm=0. *This approach will provide a maximum of 256 doses.* The calculation will then be:
Dose(G) = DoseMax * (G) / (255)

Also, if any of the multipliers are set negative, then all will be changed negative to indicate that you have selected the inverse mode *where the largest RGB values will produce the smallest doses*. In this case, the calculation is as follows, where each multiplier below and RGBmax are the absolute values:

Dose(R,G,B) = DoseMax * [RGBmax - (Rm*R + Gm*G + Bm*B) / RGBmax

or in the simple case of Rm=0, Gm=-1, and Bm=0:

Dose(G) = DoseMax * (255 - G) / (255)

In the case where you want to set the dose based on both the G and R values, you can set Rm=1, Gm=256, and Bm=0. *This approach will provide a maximum of 65,536 doses*. The calculation will then be:

Dose(R,G) = DoseMax * (R + 256*G) / RGmax

where RGmax = [255 * (1 + 256)]

**Other Notes for Bitmap Exposures**

Miscellaneous notes regarding the exposure of bitmaps follow

1. When a bitmap is added to a DC2 file, only a reference to the bitmap is saved in the DC2 file. This means that the DC2 file will contain the full path to the bitmap, but not the actual data from the bitmap. *Consequently, care must be taken if a DC2 file which references a bitmap file is moved to another directory after it is created*. In this case, the DC2 file will still reference the bitmap in the original directory. If that bitmap is not found, DesignCAD will prompt for the new location.

2. The 'Simulate Writing' mode will display the bitmap and will show multiple passes in increasingly bright colors when the Multiple Pass mode is active. *For bitmaps exposed with a very large number of exposure points, the 'Fast' display modes may not respond promptly.*

3. Processing the run file for normal writing will display the entire bitmap in a single pass as it is calculated, even if it is written in multiple passes. This is the same as non-bitmap pattern elements.

4. When NPGS is moving the beam to expose a bitmap, the default mode will follow a serpentine path along each row from top to bottom. When each pixel of the bitmap is exposed with ‘sub-pixels’ made of smaller steps of the beam, all ‘sub-pixels’ at each pixel location will be exposed before the beam moves to the next pixel.

5. The multiple pass ‘Reverse’ mode will raster a bitmap from top to bottom on odd passes and from bottom to top on even passes.

6. *For bitmaps, any dwell times that are entered into the run file editor as less than 1.05 times the smallest allowed dwell time will be treated as zero dose*. In this case, the beam will still step to the pixel, but the beam blanker will be used to blank the beam. For blanked pixels, the default dwell time will be 5 usec. When an exposed pixel follows a blanked pixel, the blanked pixel will have a default dwell time of 500 usec, which is intended to ensure that the beam position is accurate before stepping to the exposed pixel which follows. The fast and slow blanked pixel dwell times will be adjusted by the program as needed to optimize the writing for extremely fast or slow patterns.

**Custom Commands and Command Entities**

The Custom Commands on the NPGS Menu Program allow the user to make any button activate one of the options from the pull down menus, to launch external batch programs, or even to run VisualBasic or JavaScripts. Similarly, the Command Entity in a run file can be used to launch external batch programs, or even to run VisualBasic or JavaScripts.
Programmning a Custom Command or Command Entity as a Batch File:
These modes can be used to run any executable on the NPGS PC. This provides incredible flexibility regarding the possibilities for remote control of external devices through NPGS.

Useful commands include:

\NPGS\Program\BCC On ....................... This sets the Blanker Control from NPGS to the Beam On condition. Note that the blanker must be in external control.

\NPGS\Program\BCC Off ....................... This sets the Blanker Control from NPGS to the Beam Off condition.

More information on the next set of commands can be found at “Miscellaneous Files (page 205)".

\NPGS\Projects\Tune 2.4 ....................... This plays a short tune. Choices are 1 through 5, where the fractional part will indicate the speed.

\NPGS\Projects\Tune 2 20 .................... This plays tune #2 every 20 seconds until the user hits a key.

\NPGS\Projects\Wav  Song.wav ............. This plays any wav file. The full path for the song may be necessary.

\NPGS\Projects\Pg_Pause ..................... This gives advanced control within batch files for selecting different choices and to have default selections after a defined delay.

The following commands and arguments will depend on the microscope being used (** represents an arbitrary argument which would be passed to the executable). In each case, see the section in the printed NPGS Installation Guide regarding the interface program for your microscope. These commands are very powerful, since any feature that can be controlled through the microscope’s digital interface can be controlled through a button on the NPGS Menu program or can be automatically executed when a run file is process by NPGS.

\NPGS\Projects\Pg_FEI ** ...................... Used to communicate with FEI XL30 and Sirion SEMs through a serial interface.

\NPGS\Projects\Pg_QXT ** .................... Used to communicate with FEI Quanta and Nova SEMs through an Ethernet DCOM interface.

\NPGS\Projects\Pg_H232 ** ................... Used to communicate with Hitachi 4300, 4700, 4800, SU70, SU6600, and similar SEMs through a serial interface.

\NPGS\Projects\Pg_HDCOM ** .............. Used to communicate with Hitachi 3400, and similar SEMs through a Ethernet DCOM interface.

\NPGS\Projects\Pg_6500 ** ................... Used to communicate with JEOL 6500F, 7000F, and similar SEMs through an Ethernet interface.

\NPGS\Projects\Pg_JEIK ** .................... Used to communicate with JEOL 7001F, 7500F, 7600F, and similar SEMs through an Ethernet interface.

\NPGS\Projects\Pg_EDSI ** ................... Used to communicate with JEOL SEMs with the EDSI Ethernet interface; models 6060 through 6490, and similar.

\NPGS\Projects\Pg_LEO32 ** .............. Used to communicate with LEO/Zeiss SEMs through the RemCon32 serial interface; models 440, 1400 series, 1500 series, Supra, Ultra, and similar.
Advanced Features of NPGS

Digital Image Acquisition

Overview
NPGS includes the program "Pg_Image.exe" which allows digital images to be acquired using the microscope and the NPGS hardware through a Windows user interface. The images can be saved in common graphics formats including JPG, TIF, and BMP. While most newer microscopes can already save digital images, older microscopes typically require accessories that cost from $3k to $10k US to add the features found in Pg_Image.

To start Pg_Image, use "Commands - Digital Imaging" from within the NPGS Menu program.

Alternately, shortcuts can be placed on the Windows desktop that link directly to the "NPGS\Program\Pg_Image.exe" file for use with unique image directories. In this case, the "Target" on the "Properties" for the shortcut, should be set to something similar to the following:

C:\NPGS\Program\Pg_Image.exe -PAc:\NPGS\Projects\Samples -TPc:\NPGS\Projects\Temp

Where the "-PA" parameter lists the full path for where the images will be saved and the "-TP" parameter lists the full path to the NPGS temporary directory.

Known limitations in Pg_Image:

- Under Win95, right clicking on an image does not open the popup menu.

- The "Print Setup" command in Pg_Image does not recognize if the selected printer is changed. Instead, you must use the Windows functions to define the default printer, i.e., "Start - Settings - Printers".

- The "wheel zoom" mode may become non-functional.
Acquiring an Image

Before an image can be acquired by NPGS, the microscope must be put under NPGS control. On most microscopes, this is done through the microscope software, or using an 'NPGS Mode' button in NPGS, or through a dedicated manual NPGS/SEM switch (for older SEMs).

If the microscope can be put under external control through a program on the NPGS PC, the appropriate command(s) can be put into the batch files named “Ext_Scan_On.bat” and “Ext_Scan_Off.bat”. When Pg_Image is started, it will first look for “Ext_Scan_On.bat” in the current user’s Project directory. If not found there, it will look in \NPGS\Projects. If found, the batch file will be executed and the command(s) in the file should put the microscope into external control. When Pg_Image completes a scan, it will run “Ext_Scan_Off.bat”, which can be in either the user’s Project or in \NPGS\Projects and should put the microscope back to normal scanning mode.

Once the microscope is under NPGS control, to acquire a new image, select "File - New Scan" from the pull down menu, or click the blank paper icon on the Icon Toolbar. The "Image Data Input" dialog box will appear, which as the following inputs:

SEM Magnification
This value must match the SEM magnification value if the scale bar on the image is to have the correct length. If the SEM can be controlled externally, the "Get" and "Set" can be used to retrieve the SEM magnification or set the SEM magnification, respectively, once they have been properly initialized. To enable the Get/Set functions, the appropriate external commands must be entered in the "Commands - Configure Mag Get/Set" menu. For more information, see Pg_Image: Commands Menu (page 158).

Scale Factor
This value will reduce the image area so that it is smaller than the maximum possible scan field. Since the maximum scan area is typically larger than the normal SEM display area, a value of about 0.9 will make the Pg_Image scan field be similar to the size of the SEM scan field. The maximum allowed value is 0.99.

Center of Scan (x,y)
The center of the scan area is defined by this entry. Presently, the center is restricted to (0,0).

Scan Points (x,y)
The number of X and Y scan points can be entered at this data prompt. The values can range from 16 to 4096. If only one value is entered, it will automatically be duplicated to produce a square image area.

Data Reads per Point
This is the number of ADC data readings for each pixel in the image. The allowed range is from 2 to 10,000. Each reading takes ~2.7 microseconds.

Settle per Point
This is the amount of settling per pixel, where this value defines the number of initial ADC readings which are taken, but not included in the average for the pixel.

Settle per Line
This is the settling time before each horizontal scan line is acquired in milliseconds.

JPG Quality Factor
This value determines the amount of compression that will be used when saving the image as a JPG file, where, a quality factor of 100 gives the least compression.

Image Resolution (dpi)
This value determines the default print size.

Display Scale Bar
When a checkmark is present, the scale bar will be displayed on the image.
Save 16-bit Raw Data
When a checkmark is present, the 16 bit data acquired from the DACs will be saved in a file with the same name as the image, but with the extension of "dat".

New Group Name
If a custom set of parameters is entered for the data entries listed above, they can be saved and recalled for later use by typing a "New Group Name" and clicking "Save".

Get Group Data
Once a data group has been saved as described above, it can be selected from the pull down list of the "Get Group Data" parameter. Once a group is selected, clicking "Delete" will remove the group from the list.

Acquire
This button will initiate the image acquisition.

Continuous
This button will initiate the image acquisition in the continuous mode. In this mode, the image will autocontrast after the first full scan, and will then continue acquiring new scans until the user clicks the "X" in the upper right of the scan window. When the "X" is clicked, the scan will return to a normal scan and will stop at the end of the current scan. After the first full scan, the Histogram option can be used to adjust the brightness and contrast of the displayed image. The Set Crosshair option can be used at any time during the Continuous mode.

Cancel
This will cancel the image acquisition, as well as any changes to the saved data groups.

Typical Image Operations
Adjusting Brightness/Contrast
After an image is acquired, the software automatically* adjusts the brightness and contrast, however, for some images, you may need to make manual adjustments. The first step should be to use the "Edit - Image Data Histogram" command. This command will display a histogram showing the distribution of the brightness of the pixels. The best image will typically be displayed when the palette range markers exclude any pixels that are at the right or left extremes in the histogram, i.e., very bright or very dark, respectively. Note that you can adjust the palette range markers by "clicking and dragging" the red markers to the position you want.

In the Data Histogram mode, the "Typical" button will run the automatic* adjustment of the brightness/contrast settings. The "Maximize" button will set the values to the extremes of the image data range. The "Palette Range" entry box can be used to manually set the contrast limits. Normally, a good image will result when the "Typical" button is used, if the values in Pg_Al.sys are properly set as described below. If desired, the "Palette Range" box can be used to set the limits to values beyond the data range which will result in a low contrast image. This option is useful only in special cases.

*The automatic adjustment uses the "Auto contrast Min and Max" values in the Pg_Ai.sys file in the current project. For example, if the ‘Min’ value is 0.1, the lower contrast limit on the histogram will be set so that 10% of the pixels are below the marker, and if the ‘Max’ value is 0.2, the upper contrast limit will be set so that 20% of the pixels are above the marker. This dynamic autocontrast will prevent a few extremely bright or extremely dark pixels from affecting the resulting image. This is the same scheme used by the NPGS Alignment program (AL.exe), which also uses the Min/Max values in Pg_Ai.sys.

If the range of the data shown by the "Edit - Image Data Histogram" command is limited, i.e., less than about 1000, it means that the voltage output from the SEM is not very large and the image quality may be compromised. Note that each unit in the image data range represents a voltage of about 0.3 mV when the ADC input range is ±10 volts.

Measuring Distances
If NPGS has been calibrated for the SEM in use and the correct magnification has been entered when the image was acquired, the "Image - Crosshairs" command can be used to set dynamic crosshairs...
and the distance between the crosshairs will be displayed. The crosshairs and the distance text can be moved after they have been placed by "clicking and dragging" with the mouse. Note that the standard scale bar can also be moved in this fashion and the color of the crosshairs can be toggled by using the right mouse button or a menu command.

**Cropping the Image**
Cropping the image is a three step process.

1. First, use the "Edit - Select Area to Copy" command to drag a rectangle around the area for the cropped image.
2. Next, use the "Edit - Copy" command to copy the selected area to the Windows clipboard.
3. Finally, use the "Edit - Paste to New Image" command to create a new image from the selected area.

Note that to include the scale bar, annotations, and/or crosshairs in the new image, the file should first be saved in the TIFF format with the "Save Annotations on Image" box checked and then reloaded into Pg_Image.

**Left Mouse Button**
The default function of the left mouse button is that by clicking and dragging, you can reposition the crosshairs, text, and scale bar to any location on the image. However, if the "Edit - Select Area to Copy" function is enabled, a rectangle will be displayed showing the selected area for copying.

**Right Mouse Button**
The right mouse button provides pop up menus that will vary depending if the mouse pointer was over the image, a text annotation, or a crosshair marker.

**Saving and Retrieving an Image**
The NPGS Pg_Image program has a unique option for naming files. When the "File - Save" command is called, the "Auto Name" option will automatically create a long file name based on the name components that you have selected. When opening an image, Pg_Image will be able to display a file list based on any of the name components that you have previously used in the current project. Alternately, the "Auto Name" function can be turned off and then any long filename can be manually typed in.

**Pg_Image: Menu Commands**

**Pg_Image: File Menu**

**New Scan**
This command will display the dialog box used to set the parameters for a new scan. The blank paper icon on the Icon Toolbar will do the same thing.

**Open**
This command will allow you to retrieve an image that has been previously saved in the current project.

**Save / SaveAs**
These commands will allow you to save an image by entering a file name or using the unique "AutoName" function of Pg_Image. All files will be saved to the current project.

**Print Setup**
This command will allow a printer that is currently installed under Windows to be selected. Note that this option will only be available when an image is being viewed.

**Print**
This command will print an image to a printer that is currently installed under Windows. Note that this option will only be available when an image is being viewed. A print preview window will show the image as it will appear on the paper.
Previous Files List
A list of files that have been previously opened will be displayed. Clicking on a file in the list will immediately open the file.

Exit
This command will terminate the Pg_Image program.

Pg_Image: Edit Menu
Undo
This command will reverse the last processing that was applied to the image. For example, if you have just used the “Image - Rotate” command and do not like the results, the “Edit - Undo” command will return the image to the previous state.

Select Area to Copy
This command will allow you to click and drag the mouse to define a rectangle for copying.

Copy
This command will copy the selected part of the image to the Windows clipboard. Note that an area must be currently selected for this command to be operational. Once copied, any graphics enabled Windows program can access the data from the Windows clipboard.

Paste to New Image
This command will paste the copied image area to a new image. Note that part of an image must be copied for this function to be operational. Pg_Image does not allow multiple images to be pasted into a composite image. For advanced image processing, please use one of the many powerful image editing programs that are available through other vendors.

Pg_Image: Image Menu
Image Data Histogram
This command displays a histogram of the brightness of the original 16-bit data. The palette range markers indicate how the pixels fall across the displayed color palette. In other words, all pixels below the left hand marker will be displayed as the darkest color and all pixels above the right hand marker will be displayed as the brightest color. Often, in SEM images, there will be a few very bright pixels that can confuse the typical auto contrast feature in SEM imaging systems. By using this command, you can easily set the range for the data to ignore any such bright pixels.

This group of commands provides basic image optimization features.

Rotate
Brightness
Contrast
Despeckle
Gamma
Smooth/Sharpen

The next two commands are only active when the original 16 bit data is available, which is either when a new image has been acquired or when a "dat" file has been opened.

Set Crosshairs
This command allows crosshairs to be displayed on the image. Note that after crosshairs have been placed, the crosshairs and the distance text can be moved using the mouse. Also, the right mouse button will allow the crosshair color to be toggled.

Toggle All Crosshair Colors
This command will step the colors of the crosshairs between white, black, and a variable color that depends on the underlying image brightness.
Add Text
This command allows text annotation to be placed anywhere on the image. Note that after the annotation has been added, it can be moved using the mouse. Also, right clicking on existing text will allow it to be changed or deleted.

**Pg_Image: Zoom Menu**

25% to 500%
These commands will set the display zoom value as indicated. Note that if the image becomes too large to fit within the display window, slider bars will appear to allow you to scroll the image.

Wheel Zoom Mode
This command will enable a zoom mode for a wheel mouse that allows the wheel to adjust the zoom value up or down. (Note that the wheel support through the Microsoft software used to create Pg_Image may not work with some mice.)

Zoom to Window
This command sets the display zoom value so that the entire image will fit within the display window. Note that the display window can first be dragged to the desired size and then this command will either shrink or expand the image to fit in the window.

**Pg_Image: View Menu**

Tool Bar
This command causes the Icon Toolbar to be displayed or hidden. Note that the Icon Toolbar may be moved with the mouse to any position on the screen.

Status Bar
This command causes the status line at the bottom of the window to be displayed or hidden.

Image Info
This command will redisplay the original information that was set when the image was acquired. Note that this command is only active when the original 16 bit data is available, which is either when a new image has been acquired or when a "dat" file has been opened.

Hide All Crosshairs
These commands will hide or display the crosshairs. Note that up to 4 pairs of crosshairs can be displayed. Also, individual crosshair pairs can be hidden by right clicking on one of the crosshairs or its label and selecting the "Hide" command.

Hide All Text
These commands will hide or display the text annotations. Note that an individual text annotation can be hidden, changed, or deleted by right clicking on the annotation and selecting the appropriate option from the popup menu.

Hide Scale Bar
This command will hide or display the scale bar.

**Pg_Image: Commands Menu**

Beam On/Off
These commands will run the external program BCC to turn the beam on and off. Note that the NPGS Blanking Control Circuit must be controlling the SEM blanker for these commands to work.

DAC 0,0
This command will set the DACs on the NPGS hardware to (0,0).

DAC 10,10
This command will set the DACs on the NPGS hardware to (10,10). This command is typically used when there is no blanker on the SEM and the beam is to be positioned at the corner of the imaging area, rather than at the center. *Note that the beam should not be left positioned at a large deflection when the SEM is at low magnifications, otherwise the scan coils could overheat.*
Direct Stage Control

This command will call the external program NPGS.exe in the Direct Stage Control mode.

Configure Mag Get/Set

This command displays a dialog box where the external commands for getting and setting the SEM magnification can be entered. For the "Get" command to function, an external program must be called that creates a text file called "%pg_io.tmp" in the current project directory that contains the current SEM magnification on the first line. For the "Set" command to function, the external program must accept the magnification value on the command line and then communicate with the SEM to change its magnification accordingly. In the command that is entered, the characters "<>" are used to indicate where Pg_Image will insert the SEM magnification that is to be set. For example, if the external program "Scope" (found in c:\NPGS\Projects) requires the command line argument of "MAG1000;" to change the magnification to 1000 (and 1000 can be replaced by any number), the entry would be "c:\NPGS\Projects\Scope MAG<>;".

Direct Stage Control

Overview

The Direct Stage Control Mode can be activated within the NPGS Menu program by selecting "Commands - Direct Stage Control". This feature is most useful when the microscope has an automated stage interfaced to NPGS.

Sample Viewing

This mode allows the user to make stage movements along the sample axes when viewing the sample. The user is first prompted for a unit vector defining the relative positions of the two positions that will be identified, as discussed above. For example, if any two points will be located that are parallel to the x-axis of the sample, the entry can be "1,0". If a second vector is entered as well, then both will be interpreted as the two vectors used in the Global mode as previously discussed. The program will then allow the user to enter X,Y offsets in microns or to use the arrow keys to change the values as desired. (Left Arrow decreases X, Right Arrow increases X, Up Arrow increases Y, and Down Arrow decreases Y). Once the desired relative offset is displayed, hitting ENTER will calculate the rotated command that can be sent to the stage, if an automated stage controller is interfaced to NPGS. The Direct Stage Control mode will make use of the Global Correction and the X-Y-Focus data, as appropriate.

Measuring Stage Backlash

The Direct Stage Control can be used to measure the backlash of the stage by following these steps:

1. Optimize the beam and find an obvious feature (or edge of a feature) which can be used to determine positions to less than 1 um.
2. Adjust the SEM magnification to show an area about 10 um wide with the feature from (1) near the center.
3. In NPGS, run "Commands - Direct Stage Control", hit 'Enter' to skip the first prompt, then hit 'i' to set the increment to the desired step distance, such as 100 um.
4. In Direct Stage Control, hit the right arrow key to set the XY move to (100,0) and hit 'Enter'. The feature should move out of view to the left. After all moves, wait until the Direct Stage Control software indicates that the stage move has finished.
5. In Direct Stage Control, hit the left arrow key twice to set the XY move to (-100,0) and hit 'Enter'. The feature should return to near the center of the image. Mark this position on the screen. You may want to use one side of the SEM distance measuring marker.
6. In Direct Stage Control, hit the right arrow key twice to set the XY move to (100,0) and hit 'Enter'. The feature should return to near the center of the image. Measure the difference between this position of the feature and the position in (5). This difference is the uncorrected stage backlash in X. Also, observe any shift in Y, if present.
7. As needed, repeat steps 4-6 to confirm repeatability and adjust the image field size as needed to get a good measurement of the backlash offset.
8. Now, repeat 4-7, but use the up/down arrow keys to measure the Y backlash.

9. The steps above can also be repeated with a larger increment, if desired. The fundamental backlash in the stage will typically be independent of the increment, but other stage errors may get worse with longer moves.

The steps above can be performed with ‘Backlash Correction’ turned on and off. When the backlash correction is turned off, the measurements will indicate the fundamental backlash in the stage mechanism. When backlash correction is enabled, the measured offsets will usually be less than 1 micron, but in some cases the correction may make the performance worse.

*Backlash Correction will typically be enabled either through the microscope or 3rd party stage control software or through the NPGS software which controls the stage. For more information, see the documentation in the NPGS Installation Guide regarding the NPGS software which controls the microscope and/or stage.

Related Topic: X-Y-Focus Mode (page 170)

**Interfacing to an Automated Stage**

**Available/Custom Stage Drivers**

*Interface programs for automated stages from Deben Research, FEI/Philips, Hitachi, JEOL-Japan, JEOL-USA, LEO/Zeiss, Oxford Instruments, Kleinkdiek, and Tescan are available at no charge.* Separate documentation that is provided with each driver describes how it is to be used to interface NPGS to the specific stage controller. If an unsupported automated stage is used, a custom driver is relatively easy to design. Source code in C that uses serial communication is available that can be used as a starting point for writing your own driver. Before writing a custom driver, it is helpful to understand how NPGS interacts with an automated stage.

The name of the program that communicates with the stage should be entered on the first line of "Pg_Stg.sys" (use "Options - System Files - Pg_Stg.sys") in each project directory that will use stage control. *The stage control program file itself should be located in the “\NPGS\Projects” directory.* It is best to first test the communications from a command prompt in the “\NPGS\Projects” directory to make sure that the driver is properly sending and receiving information to and from the stage. Once the driver is operating correctly, it can be tested from within NPGS by using the "Direct Stage Control" command. Any system file that the driver may need to access should be copied to "\NPGS\Projects” and to each project directory.

For serial stage interface programs supplied with NPGS, the system file used by the driver can be edited from within the NPGS Menu program using the command "Options - System Files… - System File Editor”.

When a run file is processed by NPGS, the "XY Move..." parameter entered in the Run File Editor can be passed to a program named on line #1 of the "Pg_Stg.sys" file. This program is either one of the drivers mentioned above, or a custom driver written by the user. For more information on the other parameters in the system file, see Pg_Stg.sys (Stage Interface Parameters) (page 196).

**NPGS/Stage Interface Modes**

NPGS has two modes for using the "XY Move..." parameter as defined by the "stage cmnds" parameter in "Pg.sys". If the "stage cmnds" parameter is 0 (zero), any ASCII character, except a space, is allowed in the "XY Move..." string, and the exact string will be passed to the stage driver program. This was the only mode available with early versions of NPGS and is provided now only for backwards compatibility. Normally, this mode should not be used. For more information, see Pg.sys (General System Parameters) (page 172).

The "stage cmnds" parameter in "Pg.sys" should be "1" (one), which causes only numeric entries (in microns) separated by a comma or an empty field to be accepted by the Run File Editor.

**Numeric Entries for the XY Move Data Field**
Numeric values will be processed before being passed to the stage driver program, while an empty character field indicates that all stage commands are to be bypassed for the current pattern. If you wish to skip a single move, simply enter "0,0".

The first step of the processing of numeric values is to transform the values by any rotation or matrix generated by the Global Correction mode. If the Global Correction mode is not used, the values will not be changed. The second step is to create the final string as defined by the parameters in the "Pg_Stg.sys" file. If the relative move is "0,0", it will not be passed to the stage driver at all.

**Automatic "Stage Offset" Corrections**
The parameter "stage offset" in "Pg.sys" also affects the operation of an automated stage. When numeric entries are used for the XY Move and alignment has been performed in a run file processed by NPGS, the final electronic offset calculated during the alignment will be included in the next movement command to the stage if "stage offset" is set to 1. For example, if the final alignment has a 10 micron offset in the +Y direction, it means that the SEM field of view should actually be moved 10 microns in the +Y direction on the sample. Consequently, 10 microns would be added to Y value of the next stage command, so that the next stage movement would effectively be from the actual position of the previous alignment. This capability allows NPGS to correct for systematic offsets that can occur. For example, if the sample rotation is slightly off and the stage is being moved between many exposure sites along a row, then if left uncorrected, each location would be more and more misaligned as the stage is moved. By correcting each stage command based on the results of the previous alignment, the increasing offset can be eliminated.

**Custom Stage Interface Program Requirements**
The interface program called by NPGS for stage control must:

1. Accept the processed "XY Move..." string as a single command line argument. (The output format for the processed command is defined by the parameters in Pg_Stg.sys.)
2. Perform the requested communication with the stage driver.
3. Terminate after the stage motion has been completed. (The driver should wait until the stage is properly positioned, otherwise NPGS will not know when the motion has stopped. It is also a good idea to include a delay for the stage to settle before the pattern writing is resumed.)
4. Return the stage position to the file "%pg_io.tmp" when given '?' on the command line (see Pg_Stg.sys). The first entry on the first line should be the X position in microns and the first entry on the second line should be the Y position in microns. Any other entries are allowed and will simply be ignored by NPGS.

A custom driver can be written in any language, as long as it can be called as a command line program. In addition to the passing of commands through the command line, NPGS can communicate to an external program through a temporary file called "%pg_io.tmp" that will be created in the current project directory. For more information, see Files for NPGS (page 199).

**Stage Driver Feedback**
Whenever a call is made to the "stage_driver" specified in Pg_Stg.sys, NPGS.exe, Pg.exe, and Al.exe will check if the stage_driver has created the text file "NPGS\Projects\%pg_stg.err". If this file exists when the stage driver terminates, the first line of the file will be displayed as the "error_message", and the file will be deleted. In this way, any stage driver called by NPGS can return an error message if the stage move is unsuccessful.

**Other Information**
When a run file is processed directly by PG or AL, only the ASCII mode for the "XY Move..." parameter or the character "/" is supported. In almost all cases, run files should be processed by NPGS, rather than by the individual programs PG and AL.

When an automated stage is interfaced to NPGS, the Direct Stage Control (page 159) mode makes it very easy to find exposures that are in known positions on the sample.
If the Global Correction mode is not used, the software will assume that the writing axes are parallel to the stage axes. When the Global Correction mode is used, the writing axes may be arbitrarily oriented with respect to the stage axes.

In all cases, it is assumed that the writing axes will be parallel to the sample coordinates.

Typical Serial Cable Connections

**PC to PC Serial Cable**

```
G  1  G
TD 2  3  TD
RD 3  2  RD
RTS 4  7  RTS
CTS 6  8  CTS
DSR 5  6  DSR
G  7  5  G
DCC 8  1  DCC
DTR 20  4  DTR
```

- Pin numbers for 25-pin connector
- Pin numbers for 9-pin connector

**Interfacing to the Microscope**

**Overview**

NPGS can pass parameters to an SEM interface program in a similar manner as to a stage driver described above. (For some SEMs, the same driver may control both SEM parameters and stage positioning.)

Before writing each layer of a pattern, PG can pass the following parameters (entered in the Run File Editor) to a program named on line #9 of the "Pg_Cmdm.sys" file: "Magnification", "Configuration Parameter", and "Measured Beam Current". AL can pass the same parameters before each group of alignment windows. In addition to the passing of commands through the command line, PG and AL can communicate to an external program through a temporary file called "$pg_io.tmp" that will be created in the current project directory. For more information, see Files for NPGS (page 199). If the user's microscope can be computer controlled, then a program that will interface to the microscope may be created and the appropriate name entered on line #9 of "Pg_Cmdm.sys". Any program that is listed in "Pg_Cmdm.sys" should be located in "\NPGS\Projects". In patterns with multiple layers, PG and AL will pass these parameters only when they change from one layer to the next.

There is no processing of the Run File Editor parameters before they are sent to the SEM driver, so the interface program is very straightforward. For more information, see Pg_Cmdm.sys (External Program Names) (page 189) and the file "Pg_User.txt" in \NPGS\Projects. Pg_User.txt shows how to create a simple batch program that will demonstrate how and when the parameters are passed to the SEM driver. With that understanding, it should be easy to create the necessary driver to communicate with the SEM. Drivers for most models from FEI/Philips, Hitachi, JEOL, LEO/Zeiss, and Tescan are available at no charge.
Example Serial Interface Program
An example of a simple way to communicate with a JEOL 6400 that has the external interface option is as follows. If the program listed on line #9 of "Pg_Cmnd.sys" is "sem_cmnd.bat", to change the magnification it could have the single line:

tosem MG %1

In this example, "tosem.exe" would be a compiled BASIC program with the following lines:

100 OPEN "COM1:2400,N,8" AS #1
200 PRINT #1, COMMAND$;CHR(13);
300 IF EOF(1) THEN 300
400 INPUT #1, c$
500 CLOSE #1
600 END

Line 100 initializes the serial port. Line 200 sends the command that was provided on the command line when "tosem.exe" was called. (If your version of BASIC does not support reading from the command line, it can read the parameters from "%pg_io.tmp" instead.) Line 300 checks the error code. Line 400 reads the response from the SEM, which is then ignored. If a compiled version of BASIC is not available, instead of calling "tosem" in "sem_cmnd.bat", some versions of BASIC support calls like "basic /run tosem.bas MG %1". While this example is specific to a JEOL SEM, it shows how straightforward the communications can be. Note that a more advanced interface program for the JEOL 6400 is available with NPGS at no charge.

Special Uses for the Configuration Parameter
The "Configuration Parameter" parameter is not actually used within any NPGS programs. Therefore, it may be used as a user defined parameter for setting the total microscope configuration. For example, you may define several setups that will be selected based on the value of the "Configuration Parameter". Other schemes are also possible. For example, "1.40" may mean setup #1 at 40 kV, "1.20" may mean setup #1 at 20 kV, etc. However, since most lithography requires a reasonably careful setup of the microscope, the actual number of parameters that can be successfully changed is limited. Typically, only the magnification will be automatically set.

Another possibility is to use the "Configuration Parameter" to refer specifically to a single microscope parameter, such as the Spot Size or Coarse Beam Current. In that case, the actual parameter could be sent to the microscope to change the desired setting.

The default "Configuration Parameter" message in "Pg_RFE.sys" may be easily changed using the System File Editor from within the NPGS Menu program. Note that the "Configuration Parameter" was called the "Coarse Beam Current" in early versions of NPGS when JEOL SEM (with a coarse beam current setting) were the most widely used SEMs for lithography.

Initializing the SEM Interface
When attempting to control the SEM externally, be sure that the appropriate software on the SEM is enabled and that the communication parameters are properly set. For serial interfaces, both the software on the SEM and the software on the NPGS PC must use the same baud rate, data bits, stop bits, etc. On many SEM models, the external control software will need to be manually enabled each time the SEM is restarted. For example, for LEO/Zeiss SEMs, the interface software on the SEM is called RemCon.exe or RemCon32.exe, and on older FEI/Philips SEMs it is called SCS.exe, while newer FEI SEMs use a DCOM Ethernet interface.

Multipass Modes for FIB Milling
The following features are primarily intended for FIB milling applications. However, writing in multiple passes during e-beam lithography may be useful when substrate charging is a problem.

These special modes allow the user to specify multiple passes to be used when exposing entities in each pattern layer. In FIB milling applications, it is often advantageous to make multiple passes over the exposure area in order to improve the flatness of the milled area. The mode selection is set in the Run File Editor for each layer of a pattern. See the section “Multiple Pass Mode Prompt” at “Run File Editor: Pattern Entity” (page 103).
The “Layer Repeat” choice will activate the multiple pass layer mode for filled polygons, single pass lines, and wide lines. This mode will write all entities in the entire layer before repeating the layer the designated “N” number of times.

The “Layer Reverse” choice will reverse* the writing direction for each entity on each pass, but the same writing order will be used.

The “Entity Repeat” choice will activate the multiple pass entity mode for filled polygons, single pass lines, and wide lines. This mode will repeat each entity the designated “N” number of times before continuing to the next entity in the layer.

The “Entity Reverse” choice will reverse* the writing direction for each entity on each pass.

*Notes on “reverse” writing of entities: For single pass and wide lines, the writing direction will be reversed. For filled polygons, the sweep side will alternate between the user defined sweep side and the side that is closest to being half way around the polygon. For a simple rectangle, the sweep side will alternate between opposite sides, but for arbitrary filled polygons, the reverse sweep will not be exactly opposite of the normal sweep.

In all cases, the total dose will be entered in the Run File Editor and the writing of N passes will be done where each will receive 1/Nth of the entered dose. The lower dwell limit in the Run File Editor will be automatically adjusted to ensure that the applied dose has a dwell time of 0.2 usec or larger per point.

In general, it is expected that 5 to 10 repeats will generate smooth bottoms on milled areas. Larger numbers of passes can be used, however, with large number of passes, the dwell times for each pass can become very short. Some care must be given when specifying very large numbers of passes, otherwise the calculation overhead may become excessive.

The “Simulate Writing” button can be used to display a simulation of the multiple passes, which makes it easy to confirm the order and sweep directions for the passes. In the simulated writing, the color of the entity display will be incremented for each pass and will finish with the final color as used for the entity in the DesignCAD file.

Other special features for FIB milling include:

"Out from Center" (= Linetype 4) for wide circles, filled circles, and arcs. The default writing of these entities with the usual linetype of 1 will be from the outside towards the inside, however, if the linetype of 4 is used when the entities are designed, then the writing direction will be from the inside towards the outside.

"Perpendicular" (= Linetype 3) for wide lines. The default writing of wide lines with the usual linetype of 1 will have the sweep direction for each segment in a wide line be parallel to the length of the segment. When a wide line is designed with linetype 3, the sweep direction will be parallel to the end of each segment in the wide line. For a square end on a wide line, the starting sweep side will be perpendicular to the length of the segment.

**Pattern Writing with No (or a Slow) Beam Blanker**

When the microscope does not have a beam blanker, two changes must be made to the writing procedure. First, the beam must be stepped from point to point without including any long delays for settling. This is done automatically by the software and is transparent to the user when the "blanker" parameter in Pg.sys is set to zero and the “Continuous” mode is used. The second change deals with "dumping" the beam when it is not actually exposing the pattern. The simple solution is to have a fixed "dump" location at the edge of the field of view to which the beam is moved whenever it normally would be blanked. A more sophisticated solution, which has been implemented in NPGS, is to allow the user to design the exposure pattern with any number of dump locations. These dump locations can also be used to minimize the effects of large jumps in the beam position which are caused by the relatively slow settling times of the scan coils.
Changes to Pg.sys
When writing without a blanker, the following values in the Pg.sys file should be set as needed. Pg.sys can be changed using the System File Editor under "Options" in the NPGS Menu program. For more information, see Pg.sys (General System Parameters) (page 172).

Blanker - **When no blanker is used, the "blanker" value should be set to zero.** The following discussion assumes that the blanker value has been set to zero.

Settling Parameters - The "settle point" and "settle To" parameters are never used when writing without a blanker. In the "Normal" writing mode in a run file, the time constant and slew settling parameters are used, but are ignored when the "Continuous" mode is selected in the run file. The net effect is that when writing without a blanker, the "Continuous" mode will not perform any settling, which will be the same as the previous versions of NPGS. **When not using a fast blanker, the “Continuous” and “Pause/Continuous” modes should typically be used instead of the “Normal Writing” and “Pause” modes, respectively.** However, if the "Normal" writing mode is used, the settling times can be adjusted by the user so that the DACs will wait briefly at the start of each pattern element, where the wait time depends on the settling parameters and the change in DAC voltages and the change in distance on the sample. This will allow short jumps of the beam to have short settling times and long jumps to have long settling times, where the goal is to have the settling time be short enough to avoid over exposing the starting point of the entity, but long enough to minimize the settling "tail" that is often encountered for long jumps when no settling is provided. **To use the advanced timing capabilities of the "Normal" writing when a blanker is not used, the user will have to characterize the response of their SEM and enter the correct settling time constants and slew rates.** To do so will involve writing patterns with jumps of varying distances to single pass lines in the "Continuous" mode and measuring the resulting "tails" at the start of the lines. Once the time dependence of the settling of the SEM is determined, the values in Pg.sys can be set accordingly and the test can be repeated in the "Normal" writing mode. If the initial point in the lines are then overexposed, the settling time must be reduced by decreasing the appropriate settling time and/or increasing the appropriate slew rate.

Default Dump - The value of the "default dump" parameter should be set as desired. This value indicates the (x,y) dump position that will be used at the end of a pattern (when "blanker" is zero) that does not have any other dump points. Note that a value of (10,10) will put the beam in the extreme upper right corner of the writing field, for any voltage output range, and any value of for the Default Dump less than 10 will be scaled to the actual output voltage range.

Pattern Design
The main difference in pattern design for use without a beam blanker is that the order of the layout can be extremely important since the pattern file is processed sequentially when it is written. The advantage to this approach is that different parts of the pattern may make use of different dump locations. The disadvantage to this approach is that editing a pattern is more complicated because added or edited pattern elements typically are not saved in the desired order. However, the BasicCAD programs under the NPGS menu in DesignCAD, OrderCheck, OrderEntities, and OrderGroups, allow the user to check the writing order of pattern entities, change the order of individual pattern entities, and change the order of blocks of entities, respectively. For more information on these programs, see BasicCAD Programs Supplied with NPGS (page 76).

There are three different types of "dump points" that may be defined. They are created by running the program "NPGS - SetDump". Dump type 1 sets a dump location that is used before the next pattern element only. Dump type 2 sets a dump location that is used before and after the next pattern element only. Dump type 3 sets a dump location that is used before and after all following pattern elements until another dump point is encountered. In DesignCAD, the dump points 1, 2, and 3 are all displayed as dotted (line type 5) circles with RGB colors (0,0,0), (128,0,0), and (0,128,0), respectively. The dump location is always at the center of the circle and the circle radius, width, and line type scale are set for display purposes only and may be modified by the user and will not have any impact on the functionality of the dump point. **Even without a blanker, for many patterns dump points are not necessary.** The primary concern is how the beginning of small structures will be written when a blanker is not available. Normally, when a blanker is in use, the beam will be blanked while the scan coils are allowed to settle at the start of each pattern element. However, with no blanker, the NPGS software must eliminate the settling time.
The consequence is that if the beam has made a long jump to the starting point of a pattern element, then the scan coils may not be properly positioned and a "tail" may be seen as the coils settle to the correct position.

**Dump points may be set anywhere in the pattern, even inside other pattern elements.** For example, when writing large contact pads a dump point (3) may be set just inside a corner of each of the pads. (Note that PMMA will can become a negative resist if too much dose is received.) In all cases, dump points cannot be alone in a layer that does not contain any "ordinary" pattern elements.

The pattern SAMPLE0 is an example of a test pattern that uses dump points. The pattern consists of nine "wheels" of different colors that can each be exposed with a different dose. In this test pattern, each wheel has a dump point located 15 microns to the lower right from its center. Note that on some microscopes, when a blanker is not used, the starting points of the line segments making up the wheel will show a displacement error, if the length of the jump is too long relative to the response time of the scan coils, while in other cases, the pattern will be exposed with no significant distortions. In the wheel pattern, all of the spokes start at the center and the outer rim is made up of six segmented lines that write counter-clockwise starting at the 3, 1, 11, 9, 7, and 5 o'clock positions.

**Run Files**
The Run File Editor does not include the color of dump points in the list of dwell times, since they do not require any exposure parameters. However, the position of the dump point is used for the maximum "Magnification" calculation. This is necessary to make sure that all dump points will fall within the field of view of the microscope. The limits for the exposure times are unchanged when a blanker is not used.

**Pattern Writing**
During writing the beam will be dumped at the positions predefined in the pattern, and the only concern for the operator is how to position the beam before and after the pattern is written. From within the NPGS Menu program, manual control of the beam position is achieved using the command "Commands - Set DACs". A Custom Command can also be made to set the DACs to any value using the "\NPGS\Program\SetDACs xx yy" command, where xx and yy indicate the DAC voltages to output, where (10,10) will always be the upper right corner of the writing field. A useful technique when writing without a blanker is to reduce the magnification of the microscope when moving the stage between exposure sites. When the magnification is reduced and the beam is at the corner of the field of view (i.e., SetDACs ±10), the beam will be positioned relatively far from the writing area.

**Caution:** it is not recommended to leave the scan coils at high deflections at magnifications below 200x, because of the large currents involved which may overheat the scan coils.

**Pattern Alignment**
At the beginning of the alignment, the beam should be positioned in the same way as described above for the writing program. For the best results, during alignment pattern design, one dump point (of any type) should be set in each layer of the pattern that contains an alignment window. (If more than one dump point is in a layer, only the last one set will be used.) Whenever the beam needs to be blanked during or after the scan of a window, the beam will be jumped to the dump point for that window. If a layer does not have a dump point, then the last dump location that the beam was at will be used. If no dump points were defined, then the "default dump" will be used unless it is set to "0 0". In that case, the beam position will be left unchanged.

**Stage Control**
When there is no blanker available, the beam will be hitting the sample during stage moves and may leave a noticeable trace of exposure along the stage path. In this case, care should be taken to arrange the writing sequence of the patterns on the sample and the position of the final dump point to avoid having the beam move across a pattern during a stage move.

*If a slow blanker is available (commonly found on FEI and Zeiss FE models), it is usually possible to configure NPGS to automatically blank with the slow blanker during all stage moves.* This option is usually implemented using the batch file "MoveStg.bat" which may be found in \NPGS\Projects.
Special Note
When using a microscope with magnification transition values which depend on the direction of change of the magnification value (such as most FEI models), check that the "Scope*.bat" file in NPGS\Projects is not setting the magnification to a high value before setting it to the value in the run file. When these microscopes are using a fast blanker, it is best to have the extra magnification setting step included, but it should be bypassed when there is no fast blanker in use.

Script Commands
NPGS can use scripts in two ways:

1. A script can be run by a Custom Command button in the NPGS Menu program for NPGS v8.0 and later.
2. The Command Entity in a run file may contain a script that will be executed during the processing of the run file.

Note that the standard "Batch" file approach also implemented by NPGS will provide the flexibility needed for most applications. However, when that is not enough, almost anything can be automated from within the NPGS Menu program or from within a run file using scripting commands.

When executing programs from either Batch or Script commands, the default directory will be the current project. Consequently, if the command does not reside in the current project and if it is not found through the "PATH" statement, you must include the full path to the command.

In order to process the script commands, NPGS will call a script interpreter as defined at the beginning of the "Pg_Menu.sys" file. The two default interpreters are set to the Microsoft Windows Scripting Host (WSH) programs "WScript.exe" and "CScript.exe", which provide window based and console based scripting capabilities, respectively. These programs support both VBScript and JavaScript programs.

For new systems when the PC is supplied with NPGS, the WSH programs will be preinstalled. For systems supplied without the PC or for upgraded systems, the user must install the WSH programs before the script commands can be used with NPGS. The necessary files to install the WSH programs will be providing in the "WindowsScriptHost" directory on the NPGS distribution media. Also, complete information on downloading the most current versions of the WSH programs can be found at: "http://msdn.microsoft.com/scripting".

Advanced Use
Alternately, any other scripting program can be used if the WScript and/or CScript data lines in Pg_Menu.sys are modified accordingly, or if additional lines are added that follow the same format and numbering sequence. Note that the Pg_Menu.sys file must be modified with a text editor such as Windows Notepad while the NPGS Menu program is not running. To make this modification, the "WScript" or "CScript" label parameter, the "wsf" extension parameter, and the executable parameter should be changed as needed. The executable may or may not include a full path. In order to execute the script, NPGS will take the commands entered for the Custom Command or Command Entity and copy them to a file with the specified extension and then pass the file to the executable.

Stitching
Overview
Stitching involves writing multiple exposure fields so that the edges of each field accurately align to the nearest neighbor. Within NPGS, “stitching” is not a “function,” but rather it is a result of the correct combination of pattern writing size and accurate stage motion or accurate alignment. Consequently, there are several ways to achieve stitching, where each approach has its own advantages, disadvantages, and requirements regarding the hardware.

To produce writing fields that stitch together, the placement of each pattern must accurately correspond to the size of the pattern. In addition, the writing axes must be aligned to the stage axes,
otherwise, even with perfectly sized patterns written the correct distance apart, the fields will be rotated and poor stitching will result.

**Stitching with NPGS Alignment**

In most cases, the stage on the microscope being used will not be accurate enough to produce good stitching results. In such cases, it is essential to have registration marks in each writing field, so that after the stage is used to get to the approximate position that is needed, the NPGS Alignment feature can be used to manually or automatically align to the marks. Once the NPGS Alignment feature has been used to align to the marks (3 or 4 marks are required), the writing field will be transformed by a (2x2) matrix plus an xy offset, which will scale the writing to the marks.

The advantage of this approach is that a standard microscope stage, either an automated stage controlled by NPGS or even a completely manual stage, can be used. The disadvantage is that registration marks must be present in every field to be written.

**Stitching with an Accurate Stage**

If the microscope is equipped with an accurate stage, and if the writing field is accurately calibrated to both the correct size and the orientation of the stage axes, stitching can be performed without aligning to registration marks in every writing field.

*When stitching without alignment at each field*, i.e., blind stitching, the accuracy of the stage will be critical. And if the fields to be stitched are written at the exact size of the stage move, any stage error will result in gaps along the edges of the stitched patterns. To help avoid this problem, the file “Pg_FieldSize.txt” can be created by the user in the NPGS Project directory that is being used for the stitching. This file should have an entry in microns as listed below. (Everything besides the number on the first line of the file is ignored.)

```
0.100 microns
```

The value above will change the PG writing field (≥0 increase pattern size, ≤0 decrease).

The typical use will be to slightly increase the writing field size when stitching with a laser stage, so that even with small stage errors, the writing fields will still connect. For this use, the value above should be larger than the largest expected stage error by an amount equal to the ratio of the stage step distance to the writing field size. For example, if the stage error is expected to be +/-0.1 um or less and the patterns are to be written at a magnification that gives a writing field of 120 microns and the stage step size is 100 microns, then the value should be 2*0.1*(120/100) = 0.24 microns. This will make the writing within the 100 um step size actually be 100.2 um, so that even with the worst expected field to field stage error, the adjacent fields will still touch.

If this file does not exist in the current project, or if 0 is entered above, no changes will be made to the writing size. This file does not affect the pattern alignment process. Note that once this file is created in a project, all patterns will be increased accordingly, so it is best to create the file in a project dedicated to stitching.

Once the stage has been tested to confirm accurate positioning, other issues must also be addressed before 'blind' stitching can be successful.

Another fundamental issue is the calibration of the writing field size. For example, if the stage is 'perfect' in both accuracy and alignment to the writing axes, but a 200 um writing field is 0.5% too large, then an overlap of ~1 um would be expected. The actual situation regarding the writing field size can be much worse, since the typical SEM specification is usually that the microscope magnification is within +/- 3% across the operating conditions. This means that if the NPGS size calibration is correct at one set of operating conditions, then the microscope may introduce a significant size error at any other set of operating conditions. For most pattern writing, a 1% size error is not noticed, but when stitching, this size of error will often be very significant.

NPGS is designed that it defaults to assuming that the microscope is consistent in the microscope field size for all magnifications. While this obviously isn't a perfect solution, it works well for most applications where the error in the microscope calibration is not large enough to be a problem. In blind stitching where a better calibration for the writing field is required, there are two approaches.
One is to redo the NPGS calibration procedure (described section 3 of the NPGS Installation Guide) using the exact microscope conditions which are to be used for the stitching. In this case, those conditions will then give a better calibration and any other conditions will have whatever error is introduced by the microscope.

A better solution is to have registration marks on the sample so that the NPGS alignment feature can be used to align to the marks using the exact conditions for each write. Then, the resulting alignment corrections will be used to write all of the fields which are being stitched together (the 'Alignment - Use Previous' entity should be set in the run file). The benefit of this approach is that if 3 or 4 registration marks are used, NPGS can calculate a 2x2 matrix which will correct for independent X and Y scaling, as well as the situation when the X and Y writing axes of the microscope are not orthogonal (which is often the case). The downside is that the sample must have the marks fabricated before the normal writing. If marks can be made on another sample which is mounted at the same height as the one being written on, then the inconvenience can be reduced.

Another issue regarding blind stitching is that the writing axes must be carefully aligned to the stage movement. For example, if the stage is perfect and the writing field size is perfect, but the writing axes are misaligned by 1 degree relative to the stage directions, then a 200 um field would appear to have a mismatch at the corners of ~3.5 um.

When using registration marks to calibrate the writing field size, marks should also be available for use with the NPGS Global Rotation feature. In this way, the Global Rotation feature would be used to effectively align the stage coordinates to the registration marks which are widely space across the sample and a smaller set of marks which fits within the writing field would be used to calibrate and rotate the writing field to the axes of the marks using the NPGS Alignment feature. In this way, the effective stage axes, the sample axes (defined by the registration marks), and the writing axes can all be carefully aligned which is essential for successful stitching.

Before stitching is attempted, the question of how accurately aligned do the final features need to be positioned along the ‘stitched’ edges between exposures should be considered. Even if all issues above are taken care of, an additional concern is the position drift in the e-beam and/or stage. Every SEM will have drift in beam position over time, which may be 10's of nm's per minute or more. This can also be affected by outside influences, such as magnetic fields from elevators, nearby vehicles, or even the Earth's field which changes throughout the day. In regards to these issues, having registration marks at each writing field has the benefit of automatically compensating for slow beam and/or stage drifts, since each field is aligned just before it is written.

Run File Entities for Stitching
In each of the examples listed below, either the NPGS Alignment or an accurate stage must be used as discussed above.

**Pattern Entity:**
The simplest run file that can be used to produce stitching has a single pattern entity with multiple identical repeats, where the relative offset for each pattern is manually entered to yield the desired spacing in order to stitch the patterns together. A more complicated run file may list many unique patterns entities, where each has the correct relative offset. Obviously, making such run files can be tedious if the number of exposures is large, since each stage offset must be manually entered. For more information, see “Run File Editor: Pattern Entity (page 103)”.

**Array Entity:**
A more typical run file for the stitching of many identical exposure fields would make use of the “Array” entity. In this case, a single pattern will be exposed in an array, where the row and column spacing is set to match the size of the pattern being written. While this run file is easy to set up, it has the limitation that the array consists only of repeats of the single pattern. For more information, see “Run File Editor: Array Entity (page 107)”.

**Fracture Entity:**
For large writing areas, where each writing field being stitched together must have unique pattern features, the NPGS Fracture mode should be used. In brief, NPGS can write a single CAD file that covers a very large area by breaking the large file into smaller pieces where each piece defines a sub-field for writing. When this mode is used, NPGS will determine the correct stage coordinates so that
the sample will be moved and the pieces will be written at the correct positions, within the limitations of the stage accuracy. For more information, see “Run File Editor: Fracture Entity (page 108)”.

**X-Y-Focus Mode**

**Overview**
The "X-Y-Focus" mode allows NPGS to automatically set the microscope focus as the stage is moved to different locations on the sample. This mode assumes that the surface of the sample is a plane that may be tilted. After the microscope is optimized for writing, but before the patterns are actually written, the user must move the stage to different locations on the sample and focus on the surface. NPGS will acquire the focus value at each location, along with the (x,y) coordinates of the stage position. After the user has focused at 3 or more locations (up to 20), NPGS will perform a least squares fit of a plane to the (x,y,focus) data. Subsequently, when the patterns are being written, after the stage is moved to a new location for pattern writing, NPGS will calculate the ideal focus setting and will send it to the microscope.

This mode is normally used with both an automated stage and a digital microscope that allows the fine focus value to be read and set. Instead of using the fine focus of the microscope, the software can use an automated control of the fine z position of the stage, if available. Also, a manual mode can be used that will prompt the user to read and set the focus value on the microscope. The X-Y-Focus mode can even be used without an automated stage, if the user wants to type in the (x,y) stage positions manually.

**Activating the X-Y-Focus Mode**
The specifics of using the X-Y-Focus mode are as follows. In the NPGS system file "Pg_Cmd.sys", line #7 should be blank if this mode is to be completely disabled. For the mode in which the user will be prompted to read and manually set the focus, the word "manual" should be entered on line #7. When an external program is used to automatically read and set the fine focus value or the fine z height, the name of the program should be entered on line #7. If either the word "manual" or the name of an external program are entered, the X-Y-Focus mode will be active whenever NPGS, PG, or AL are run, unless it has been disabled in the Advanced Modes section of a particular run file.

In most cases, the external program used with the X-Y-Focus mode will be a batch program called “focus.bat” which will be found in the \NPGS\Projects directory. This batch program will contain the appropriate commands for the SEM in use to allow the focus value to be read and set by NPGS. When NPGS is shipped, if the SEM to be used has a serial or Ethernet interface that allows the focus to be controlled externally, the NPGS Installation Guide will have documentation on the program that communicates with the SEM. **Check the NPGS Installation Guide for additional information.**

**Communication with an External Program**
The communication between NPGS and the external program will be the same when it is using the microscope fine focus or the z height of an automated stage. When the external program is passed a "?" on the command line, it should communicate with the microscope (or stage) and return the value of the fine focus setting (or z height) to a temporary file called "%pg_io.tmp". The actual units do not matter, since NPGS will simply do the calculations with whatever units the external program uses. When a value is passed on the command line to the external program, it should set the fine focus (or z height) accordingly. In addition to the passing of commands through the command line, NPGS can communicate to an external program through a temporary file called "%pg_io.tmp". For more information, see **Files for NPGS** (page 199).

**Initializing the X-Y-Focus Mode**
When the X-Y-Focus mode is active and after the stage is moved, the NPGS software will acquire the stage position and will set the focus (or z) value accordingly. However, before patterns are written, the user must collect data so that the software can determine the tilt of the sample. **There are two ways to initialize the X-Y-Focus mode.** One method is to run "Commands - Direct Stage Control" from within the NPGS Menu program. The Direct Stage Control mode will ask the user to identify locations on the sample in order to determine the corrections for any rotation of the sample. If the X-Y-Focus mode is active, the user will then be instructed to move to different locations on the sample and focus on the surface. Once the X-Y-Focus data has been collected, the fit parameters will be saved to a file.
named "Pg_Focus.sys". For more information, see Pg_Focus.sys (X-Y-Focus Results) (page 199). Any subsequent run file will then automatically access the focus parameters saved in the data file.

A second method to initialize the X-Y-Focus mode is to enable the Global Correction mode within a run file. Normally, whenever the X-Y-Focus mode is used, the Global Correction mode will also be used. Then, when the run file is processed by NPGS, the user will be prompted to collect the X-Y-Focus data after the data has been collected for the Global Correction mode. The X-Y-Focus data will be saved to "Pg_Focus.sys" and will be used during the alignment and/or pattern writing within that run file, as well as during any run files processed subsequently.

Tips
Note that when resist is spun onto a small sample, it may be substantially thicker at the edges of the sample. You should keep this in mind when choosing the locations when collecting data to initialize the X-Y-Focus option. For the most accuracy in the fit calculations, the locations for the focus points should be widely spaced on the sample. If only three points are collected, the fit will be exact, but there will be no information on the uncertainty of each individual point, because even three random (non-linear) points will result in an exact fit for a plane. Four points that lie approximately at the corners of a square will show if one of the focus values is substantially different than the others when the points and deviations are viewed. It may be useful to initially collect eight points that lie approximately along the edges of a square (one on each corner, one on each side) and to view the listing of the points with their deviations. Doing so will make it clear if any individual points have large deviations, which indicates variations in the focusing procedure, or if all points have reasonably small deviations, which indicates that the points are accurately defining a single plane.

A trick for focusing on the surface of the PMMA is to set the microscope into spot mode for 10 seconds to a minute or so (depending on the cleanliness of your system). Typically, this will leave a small round contamination mark on the surface of the PMMA, which can then be used to determine the correct focus setting. Obviously, the areas where you determine the focus will have some degree of exposure, so you should pick locations that will not interfere with the patterns being written.

Another approach is to place colloidal gold balls onto the surface and subsequently use them for focusing. Microscopy supply companies such as Ted Pella and SPI sell suspensions of gold balls ranging in size from ~1nm to 250 nm and Alfa Aesar has gold balls of ~1 micron size and larger.
Customizing the System

System Files in each Project

Pg.sys (General System Parameters)

Pg.sys contains parameters that are used to control the timing and size when a pattern is written, as well as other miscellaneous system parameters. From within the NPGS Menu program, use "Options - System Files..." to edit this file.

--- NPGS System Parameters ---

Output Parameters...

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>max DAC rate</td>
<td>maximum step rate for DACs (MHz)</td>
</tr>
<tr>
<td>percent error</td>
<td>maximum allowed error in the exposure time (%)</td>
</tr>
<tr>
<td>mag scale</td>
<td>actual field of view (µm) * magnification</td>
</tr>
<tr>
<td>xy mirror</td>
<td>mirror options: 0=X, 1=None, 2=Y, 3=X&amp;Y</td>
</tr>
<tr>
<td>x mode</td>
<td>1=±2.5v, 2=±5v, 3=±10v, 4=Variable</td>
</tr>
<tr>
<td>x range</td>
<td>only for Variable mode (±volts)</td>
</tr>
<tr>
<td>y mode</td>
<td>1=±2.5v, 2=±5v, 3=±10v, 4=Variable</td>
</tr>
<tr>
<td>y range</td>
<td>only for Variable mode (±volts)</td>
</tr>
</tbody>
</table>

Blanker Parameters...

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>blanker</td>
<td>1=installed, 0=none</td>
</tr>
<tr>
<td>beam on</td>
<td>within ±5 volts, ~40mV resolution</td>
</tr>
<tr>
<td>beam off</td>
<td>within ±5 volts, ~40mV resolution</td>
</tr>
<tr>
<td>flash enable</td>
<td>0=off, 1=blanks between exposure points</td>
</tr>
<tr>
<td>flash threshold</td>
<td>flash for longer dwell, continuous for shorter (µs)</td>
</tr>
<tr>
<td>max blanker rate</td>
<td>to prevent overdriving slow Raith blankers (kHz)</td>
</tr>
<tr>
<td>dwell extension</td>
<td>time lost by some slow blankers blanker (µs)</td>
</tr>
</tbody>
</table>

Settling Parameters...

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>settle point</td>
<td>point to point pause: only when flash enabled (µs)</td>
</tr>
<tr>
<td>settle To</td>
<td>before each element: fixed time (msec)</td>
</tr>
<tr>
<td>settle TC_Vx</td>
<td>before each element: time constant for Vx (µs)</td>
</tr>
<tr>
<td>settle S_Vx</td>
<td>before each element: slew rate for Vx (volts/µs)</td>
</tr>
<tr>
<td>settle TC_Vy</td>
<td>before each element: time constant for Vy (µs)</td>
</tr>
<tr>
<td>settle S_Vy</td>
<td>before each element: slew rate for Vy (volts/µs)</td>
</tr>
<tr>
<td>settle TC_Dx</td>
<td>before each element: time constant X Distance (µs)</td>
</tr>
<tr>
<td>settle S_Dx</td>
<td>before each element: slew rate for X Distance (µm/µs)</td>
</tr>
<tr>
<td>settle TC_Dy</td>
<td>before each element: time constant Y Distance (µs)</td>
</tr>
<tr>
<td>settle S_Dy</td>
<td>before each element: slew rate for Y Distance (µm/µs)</td>
</tr>
<tr>
<td>min settle LSB</td>
<td>minimum value used in Vx,Vy time constant calc's (LSB)</td>
</tr>
<tr>
<td>min settle dist</td>
<td>minimum value used in Dx,Dy time constant calc's (µm)</td>
</tr>
</tbody>
</table>

Miscellaneous Parameters...

---
2000 operating system Windows 98 or 2000
66.6667 master clock clock installed in PCI516 board (MHz)
128 max memory maximum amount of memory to allocate (MB)
64 max transfer maximum number of xy points in PCI transfer (Kpts)
1 xy autocal 0=none, 1=xy gain/offset/linear
3 ADC image range 1=±2.5v, 2=±5v, 3=±10v (SMA connector)
1 time pause 0=no pause, 1=pause, 2=pause with beeps
10 10 default dump init/final dump if blanker <= 0 (±10v)
1 stage cmdns 1=numeric commands, 0=ASCII commands (old)
1 delete tmps 1=delete temporary Fracture files, 0=do not
2 show %done 2=graphical display, 1=numerical display, 0=none
5.0 show min dwell min. dwell of displayed pixels when "show %done"=2
1 stage offset 1=includes AL offset in stage moves, 0=do not
1 DAC message 1=notify if DAC mode/range has changed, 0=do not
1 round error 1=stop on PG(-1) error, 0=do not
* reserved for future use
* reserved for future use
* reserved for future use
* reserved for future use
* reserved for future use
* reserved for future use
* reserved for future use
* reserved for future use

End of listing.

Output Parameters...

DAC rate .......... This value shows the maximum step rate for the DACs (MHz). The official maximum speed is 5 MHz, while the absolute maximum allowed DAC speed supported by the software is one tenth the master clock speed. Note that in any case, the lithography will always benefit from the use of the lowest DAC step rate that allows the pattern to be written with the largest possible point separation.

percent error ........ This value indicates the maximum desired error in the exposure time. Note that for any setting of the "percent error" parameter, exposure times longer than 500 x 1/(master clock) will always be better than 0.2%, and similarly, exposure times longer than 100 x 1/(master clock) will always be better than 1.0%. For shorter exposure times, the DAC rate clock of the NPGS PCI516 board will be adjusted to give an accuracy better than the "percent error" value. Note that each time the clock frequency is adjusted, there is a settling delay of ~28 milliseconds, which will be negligible for most patterns. However, if a pattern has thousands of pattern elements with very short dwell times, it is best to have the pattern elements ordered so that only a limited number of switching between different exposure times is required. And in the case when a fast beam blanker is not available and dump points are not used, it can be beneficial to increase the allowed error to 1 or 2%, so that fast exposures will have few clock switching events. Note that if dump points are used when a fast blanker is not available, the switching delays will always be done when the beam is at a dump point.

mag scale .......... This value is the product of the actual field of view in microns times the magnification value of the microscope. This value is set when the absolute pattern size is calibrated. Example: mag scale = 90000 means that at 1000x the field of view will be 90 microns square, at 100x the field of view will be 900 microns square, etc.

xy mirror .......... This value is used to produce a mirror image of the pattern in either X or Y. Patterns are stored with x coordinates increasing to the right and y coordinates increasing upward. If this value is set to 0, the output voltages will be scaled to produce a mirror image in the X direction; a value of 1 will disable the xy mirror option, a value of 2 will produce a mirror image in the Y direction, and a value of 3 will produce a mirror image in both X and Y. Note that the direction of stage moves is not affected by this parameter. If stage moves are not in the correct direction, see Pg_Stg.sys (Stage Interface Parameters) (page 196).
x mode ................. This value sets the mode for the output range of the X DAC on the PCI516 board.
x range ............... When the "x mode" is set to Variable this value contains the maximum output of the X DAC (±volts).
y mode ................. This value sets the mode for the output range of the Y DAC on the PCI516 board.
y range ............... When the "y mode" is set to Variable this value contains the maximum output of the Y DAC (±volts).

Blanker Parameters...
blanker ............... This parameter must be set to 1 or 0:
  1: Setting it to 1 is for use with a fast beam blanker and will optionally cause the beam to be blanked between every exposure point if the "flash enable" mode is active, as described below. (Fast is defined as being able to turn off and on in a small fraction of the typical exposure time. A typical electrostatic blanker will have rise/fall times of < 100 nsec, while the maximum repetition rate will typically be from one to several MHz.)
  0: If no beam blanker is present, then "blanker" should be set to zero. When a layer in a run file is explicitly set to the "Continuous" mode and "blanker" is set to zero, the beam is not allowed to settle at the start of each pattern element. When a layer in a run file is set to the "Normal" mode and "blanker" is set to zero, the beam is allowed to settle at the start of each pattern element, however, the "settle To" time is skipped. The result is that if the "time constant" and "slew" values are properly set as described below, the beam will sit just long enough for the scan coils to approach the desired starting point without overexposing the starting point. If a dump point of type 3 is active, then the beam will be moved to the dump point during any wait due to calculations, even between the multiple DMA transfers required for very large areas. If a slow blanker is present, the "blanker=0" option will cause the beam to be blanked before and after each pattern and whenever writing is paused while waiting for user input, however, no blanking will be done between pattern elements.
beam on ............... This is the output voltage on the Blanker SMA connector of the PCI516 board when the beam is on. The value must be within ±5 volts and is set with ~40 mV resolution.
beam off ............... This is the output voltage on the Blanker SMA connector of the PCI516 board when the beam is off. The value must be within ±5 volts and is set with ~40 mV resolution.
flash enable ......... When this value is set to one, the exposure will be done with "flashes" of the beam at each exposure location. This is accomplished by stepping the beam while it is blanked and then unblanking the beam for the time specified in the run file. Activating this mode will make NPGS default to the same exposure method as older versions of NPGS, however, the new hardware is designed such that flashing the beam does not have any significant advantages. Consequently, this parameter should normally be set to zero.
flash threshold ..... When the "flash enable" parameter is set to one, this value will define an exposure threshold such that the beam will be flashed for longer dwell times, but will not be flashed for shorter dwell times, since most blankers do not support on/off repetition rates at the speeds at which the NPGS PCI516 board can write.
max blank rate ..... This parameter is intended to prevent overdriving of slow Raith blankers, which otherwise will overheat and fail. This option is different from the "flash threshold" in that it will still allow the beam to be flashed, but it will extend the settling time between points to reduce the blanking rate, as needed.
dwell extension .... This value may be changed to include any rise time delay inherent to the beam blanker (µsec). Specifically, the magnetic blanker on older JEOL SEMs typically "lost" between 1 to 2 microseconds every time the beam was turned on. If using a magnetic blanker, see the discussion in the next section for the "time loss" parameter in the NPGS 8.0 version of PG.sys for the procedure to determine the time lost by the blanker. For electrostatic blankers, this value will typically be 0.02.
Settling Parameters...

settle point ........... When the "flash enable" parameter is set to one, this value is used as the point to point settling time (µs).

settle To ............. When the "blanker" parameter is set to one, the beam will be blanked when it is moved between different pattern elements (and between every scan line in a one-sided filled polygon and when very large or complex filled polygons are broken into smaller polygons). After the beam is positioned at the start of each pattern element, the scan coils are allowed to settle with the beam blanked. The "settle To" parameter defines in msec the minimum settling time when "blanker" is set to one. When "blanker" is set to zero, "settle To" is not used.

settle times ........... The next 10 parameters define a sophisticated settling capability, which is intended to allow optimization of the pattern writing when no blanker is installed. The same parameters are also active when a fast blanker is used, however, in that case, the settling is not as critical if the "settle To" time is adequately long. When the beam is jumped between pattern elements, the response of the X and Y channels are independently modeled using an exponential time constant and a limiting slew rate for both the voltage input to the SEM as well as for the current driving the scan coils (as expressed in microns of distance on the sample). For each jump of the beam between pattern elements, the slowest of the four response times is used, i.e., X voltage settling, Y voltage settling, X distance settling, or Y distance settling. In summary, when at higher magnifications, the X and Y voltage settling times are expected to dominate, while at low magnifications, the X and Y distance settling times are expected to be longer. The X and Y channels can be independently set, since many Hitachi SEMs are known to have different response times for each channel. Note that to increase the delay time for a channel, either the time constant can be increased or the slew rate can be decreased. Conversely, to minimize the settling times, the time constant can be set to a small value and the slew rate to a large value. Also, note that the ideal time constants and slew rates will depend on the kV and working distance. However, when a blanker is used, the main consideration is that the settling time is long enough to allow the beam to be properly positioned and extra settling is acceptable, since the beam is blanked. Consequently, when a blanker is used, the "settle To" time is added to the slowest calculated time, to ensure adequate settling of the scan coils. But when a blanker is not used, the settling time must be somewhat shorter than what is needed for the scan coils to fully settle, otherwise, an overexposed spot will be formed at the start of the pattern elements. When a blanker is not used, optimizing the time constant and slew rates will minimize the exposure "tails" after long jumps of the beam that are seen when no settling time is provided. Note that when no blanker is used, setting a layer in a run file to the "Continuous" mode will disable this settling feature, which will reproduce the no-blanker, zero-settling approach used in older versions of NPGS.

settle TC_Vx ........ This is the pattern element settling time constant for the X voltage input to the SEM as described above. Increasing this value will increase the delay.

settle S_Vx .......... This is the pattern element slew rate for the X voltage input to the SEM as described above. Decreasing this value will increase the delay.

settle TC_Vy ........ This is the pattern element settling time constant for the Y voltage input to the SEM as described above. Increasing this value will increase the delay.

settle S_Vy .......... This is the pattern element slew rate for the Y voltage input to the SEM as described above. Decreasing this value will increase the delay.

settle TC_Dx .......... This is the pattern element settling time constant for the X distance the beam moves on the sample as described above. Increasing this value will increase the delay.

settle S_Dx .......... This is the pattern element slew rate for the X distance the beam moves on the sample as described above. Decreasing this value will increase the delay.

settle TC_Dy .......... This is the pattern element settling time constant for the Y distance the beam moves on the sample as described above. Increasing this value will increase the delay.

settle S_Dy .......... This is the pattern element slew rate for the Y distance the beam moves on the sample as described above. Decreasing this value will increase the delay.
Customizing the System

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min settle LSB......This value is multiplied by the voltage of the LSB for the current field size to determine the reference value used in the exponential calculation of the Vx and Vy time constant delays. Decreasing this value will increase the delay.

min settle dist......This value is the reference value used in the exponential calculation of the Dx and Dy time constant delays. Decreasing this value will increase the delay.

Miscellaneous Parameters...

operating sys ......This parameter should identify the operating system in use, i.e., Windows 98 or Windows 2000.

master clock........This parameter indicates the clock frequency of the master clock installed on the PCI516 board. The value entered must match the speed of the clock installed on the board and neither are to be changed by the user.

max memory ........This parameter sets the upper limit (in Mbytes) on the amount of PC memory allocated for storing exposure points during pattern writing. Each xy pair requires 8 bytes. Note that this value does NOT limit the total number of points that NPGS can calculate and write, since the memory allocated will be reused as needed. The value entered should be smaller than the physical RAM in the NPGS PC, so that Windows will not have to perform disk swapping during the pattern writing.

max transfer........This parameter sets the upper limit on the transfer size for groups of xy pairs that will be sent to the PCI516 board during pattern writing. This value should not be set greater than 64 kPts.

xy autocal...........A value of one sets the PCI516 calibration to the full gain/offset/linearization mode, which is recommended.

ADC range ...........This parameter allows the user to set the input voltage range for the ADC that is used to read the SEM image signal through the SMA connector on the PCI516 board. In all cases, the input voltage should be set to a range that is greater than the expected output from the image output of the SEM.

time pause ..........If the user wants the program to pause after displaying the intermediate writing summary, set to 1. To eliminate the pause, set to 0. Set to 2 for use when the PC monitor must be turned off during pattern writing. When set to 2, PG will repeatedly beep at different points in the program until the user hits any key: When the writing is paused before a layer, a single beep will sound every 10 seconds. Before a subsequent pattern, two beeps will sound every 10 seconds. After the last pattern in a run file, three beeps will sound every 15 seconds. If an error occurs, 10 beeps will sound every 15 seconds. The "Non Stop Writing Mode" in the Run File Editor and the 'N' or 'n' options for NPGS will override the 'time pause' setting, except when 'time pause' is 2 and an error has occurred.

default dump ........When the pattern is written, if "blanker" is set to zero, the DACs will be set to the values given as the "default dump", where (+10,+10) defines the upper right corner of the writing field. Note that the actual output voltages will be flipped and scaled by NPGS as needed depending on the value of the "xy mirror" and "xy mode/range" parameters.) If "0 0" is entered for the default dump, the beam is not moved before the pattern is written. When the pattern is finished writing, the beam will again be set to the default dump unless a dump point was encountered in the pattern. In that case, the beam will be set to the last dump point that was used in the pattern. If no dump point was in the pattern and the default dump is "0 0", the DACs will be left unchanged at the end of the pattern writing.

stage cmdns ........This parameter determines how the pattern "XY Move..." parameter in the Run File Editor will be interpreted by NPGS. A value of 0 will make the software compatible with older systems where the "XY Move..." parameters could be almost any ASCII text that would simply be passed on to the stage driver. A value of 1 will make the software interpret the "XY Move..." parameter as "x,y" numeric values with units of microns. A setting of one is normally used and is required when an automated stage is used with NPGS and the Array or Fracturing mode is used.

delete tmps ........This parameter is only used when the NPGS Fracturing mode is active. A value of 0 will leave the temporary fractured files on the hard disk after NPGS finishes, while a value of 1 will delete the temporary files.
show %done ....... This parameter will cause PG to display status information during pattern writing. A value of 2 will enable a graphical display of the pattern as it is calculated, a value of 1 will enable a numerical display, while a value of 0 will blank the screen completely during pattern writing. Note that the graphical display and the numerical display are synchronized to the calculation of the exposure points of the pattern, which will typically be substantially faster than the actual exposure of the points. This difference comes from the fact that the NPGS software is optimized to minimize the calculation overhead by isolating the actual writing from calculations. The net result is that the pattern writing is as efficient as possible, however, the real time display of the pattern progress is not possible. Note that when the numerical percentage is displayed, it is the percent of the pattern file that has been read, which is generally a good indication of the total exposure time. However, in some cases, the number of bytes defining a pattern element within the pattern file does not correspond well to the actual exposure time. In either display mode, once the pattern calculation has finished, the remaining time for the pattern writing will be displayed.

show min dwell .... When the "show %done" parameter listed above is set to "2", this value will determine the minimum dwell time for the pixels that will be graphically displayed. While the graphical display of the pattern will typically have no effect on the total writing time, if the pattern has very short exposure times, the graphical display may increase the writing time. Consequently, this parameter allows the user to disable the graphical display for pattern entities with short exposure times. Note that the display time is scaled to the pixels needed to display the entity on the screen, so the minimum pixel dwell time does not correspond exactly to the dwell time for the entity. For example, if filled polygon with a small point spacing has 10 exposure points that are represented by each screen pixel, then the polygon will be displayed when the "show min dwell" value is 10 microseconds and the actual exposure point dwell time is ~1 microsecond or greater.

stage offset ........ This parameter affects the control of automated stages when run files containing alignment patterns are processed by NPGS.exe. A value of 1 will cause NPGS.exe to read the xy offset contained in the file "Pg_Align.sys" created by AL after each alignment. NPGS.exe will then add the offset determined during alignment to the xy movements in the next stage command. This will cancel out any propagating errors caused by a rotation between the sample axes and the stage axes. When this option is enabled, the "Stage: Mode..." option in the Auto-Align system files "Pg_AA[1-3].sys" can be disabled or set to a higher threshold value. By including the correction using the "stage offset" option, an extra stage movement during the alignment process can often be eliminated, which results in faster alignment. When the value is 0, the alignment offset will not be included in the subsequent stage command.

DAC message...... If this value is set to one, the user will be notified if the DAC mode/range of the PCI516 board is not already set to the values in the Pg.sys file of the current project directory. If the value is set to zero, the user will not be notified.

round error ........... When this value is set to one, whenever a shift of the pattern (typically after a large alignment offset) causes any exposure points to fall outside of the available writing field, the PG(-1) error will be displayed and the pattern writing will stop. If this value is set to zero and any exposure points fall outside of the available writing field, the NPGS software will not terminate the pattern writing, even though the resulting pattern may have some exposure points that are not placed correctly.

Pg_Auto.sys (Automated Commands)
Pg_Auto.sys is an optional file. The file contains parameters for up to four auto processing events. Each event can trigger the self calibration of the PCI516 board (by selecting the "1=xy" option), as well as up to four other commands (2=CommandA through 5=CommandD), which are defined by the user at the end of the file. For each event, the threshold time for activating the event, the processes for the event, and the list of arguments to pass to the external programs are defined by the user in the pg_auto.sys file.
The integers for the argument list are as follows:

0....................none
1....................microscope magnification entered for the pattern in the run file
2...................."mag scale" parameter from pg.sys in the current project
3....................configuration parameter entered for the pattern in the run file
4....................measured beam current entered for the pattern in the run file
5....................the full path of the current project directory

Note that negative values can be entered for the argument list, as discussed below.

The executables for the user defined commands A through D must exist in the x:\NPGS\Projects directory.

Whenever NPGS.exe is processing a run file, it will check if any events have passed their threshold time before each pattern in the run file is processed. Note that the threshold time is referenced to the last time the event was triggered. For the calibration of the PCI516 board, the threshold time is compared to the last time of the board calibration, which may have been initiated in any project. However, for the commands A through D, the threshold time is only compared to the last time the event was triggered in the current project directory. For example, if the board calibration has a threshold time of 600 minutes (10 hours), it will typically only be triggered the first time NPGS.exe is run each day. Alternately, if the threshold time for an event is 10 minutes and NPGS.exe is processing 20 patterns that each take 3 minutes to write, then the event would be triggered every 12 minutes.

Also, in addition to the time check described above, an event will be triggered when NPGS processes a run file and the value of any of the arguments indicated with a positive number changes from one pattern to the next. For example, if event #2 passes the magnification as an argument as designated by a positive "1" in the argument list in pg_auto.sys, then event #2 will be triggered before any pattern is written that has a magnification that is different from the previous pattern. To pass an argument to an event process without enabling this check, use the negative of the number shown for the argument in pg_auto.sys. For example, if the #2 argument list in pg_auto.sys consists of the line "-2, -4", then both the magnification and the beam current would be passed to the commands for event #2, however, the event would not be triggered when these values change from one pattern to the next. Note that this check regarding the change of the arguments only uses the values from the first layer in the run file. Consequently, changes of the magnification, configuration parameter, or beam current from one layer to the next within a single pattern are not checked. Such patterns should not be used when the automated commands are active.

Typically, the contents of the pg_auto.sys file are not modified by the user.

**Pg_AL.sys (Alignment Parameters)**

Pg_AL.sys contains the parameters for customizing the alignment program AL. From within the NPGS Menu program, use "Options - System Files..." to edit this file.

A full description of each parameter is given after the file listing:

```
********************** NPGS-AL system parameters ****************************
******************************************************************************
```

```
0                Display matrix           (0=none, 1=some, or 2=all)
0                Window centering option   (0=max two, 1=avg of all)
1                Beep on error                    (0 or 1)
1                Use opt 1 for output if possible (0 or 1)
0                Initial mode    (0=Norm,4=SEM,6=SS ovrwrt,7=SS ave)
1                Initial pixel size               (1 or 3)
1                Initial step size                (1 to 9)
0                Secondary mode  (0=Norm,4=SEM,6=SS ovrwrt,7=SS ave)
2                Secondary pixel size             (1 or 3)
1                Secondary step size              (1 to 9)
.99 .99          X and Y field of view border     (.5 to 1)
```
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-20000 20000     Min and Max contrast values      (+/- 30,000)
50 100           Initial Min and Max contrast      (+/- 30,000)
.1 .3            Auto contrast Min and Max         (0 to 1, Max < 1 - Min)
.5 1.9           Min and Max allowed Mag.          (.5 < 1 and 1 < 2)
.001            Magnification tolerance           (0 to 1)
.001            Rotation tolerance                 (0 to 1)
.001            Offset tolerance                   (0 to 100 microns)
1.0             Reserved for Future Use
1.0             Reserved for Future Use
1.0             Reserved for Future Use
1.0             Reserved for Future Use

********************** RGB Color Assignment ***********************

1                      Default Palette Number           (0 to 3)
Red    Green  Blue     Description...
0      0      0        Background color
0      10     250      Palette 0: Base Data Color       (0 to 255)
250    250    20       Palette 0: Highlighted Data Color(0 to 255)
80     80     80       Palette 0: Darkest Overlay      (0 to 255)
80     80     80       Palette 0: Brightest Overlay     (0 to 255)
0      0      255      Palette 1: Darkest Data          (0 to 255)
255    0      0        Palette 1: Brightest Data        (0 to 255)
80     80     30       Palette 1: Darkest Overlay       (0 to 255)
255    255    90       Palette 1: Brightest Overlay     (0 to 255)
10     10     10       Palette 2: Darkest Data          (0 to 255)
250    250    250      Palette 2: Brightest Data        (0 to 255)
80     80     30       Palette 2: Darkest Overlay       (0 to 255)
90     200    60       Palette 2: Brightest Overlay     (0 to 255)
250    250    250      Palette 3: Darkest Data          (0 to 255)
10     10     10       Palette 3: Brightest Data        (0 to 255)
90     160    60       Palette 3: Darkest Overlay       (0 to 255)
80     80     30       Palette 3: Brightest Overlay     (0 to 255)

End of listing.

Additional information on each parameter follows:

Display Matrix ...... This determines the amount of information that is displayed when the transformation matrix is calculated. '0' displays no information, '1' displays the new and total matrix, and if four window alignment is being used, '2' causes all four intermediate matrices to be displayed as well.

Win. Centering ..... This determines how the alignment windows will be displayed on the computer screen. '0' will cause the windows to be centered such that the average of the two windows with maximum separation will be used. '1' will use the average of all windows. This only affects the display of three or four windows when they are not placed symmetrically about their average position.

Beep on error....... Use '1' for beeps, '0' for no beeps.
Use opt 1 ............. This affects the output matrix that is used by PG when 2, 3, or 4 windows are used for alignment. If set to '0', the matrix will always be the full 2 by 2 matrix plus x and y offsets. If set to '1', the matrix will be simplified to just a total magnification and offsets when possible (see the description of "Pg_Align.sys" given below). Since the calculation time in PG is slower when using the full matrix, this option allows the faster option to be used if the alignment corrections are within the magnification and rotation tolerances listed below.

Initial mode .......... This sets the default initial scan mode used for the first set of windows. (0=Normal, 4=SEM, 6=Single Scan overwrite, 7=Single Scan averaging.)
Initial pixel size..... This sets the default pixel size for the first set of windows. If the size is 1, then each point scanned in the window (the actual point spacing is set by the Center-to-Center distance in the Run File Editor) is displayed as one pixel on the screen. If the size is 2, then a scanned point is displayed as four pixels on the screen.
Initial step size ..... This sets the default step size for the first set of windows. The step size determines how many of the calculated points in the windows are to be
scanned. Entering '1' will cause every point to be scanned and '9' will cause every ninth point to be scanned.

Sec. mode ............ Default scan mode for all windows after the first set.
Sec. pixel ............ Default pixel size for all windows after the first set.
Sec. step size ...... Default step size for all windows after the first set.

X and Y field ........ These numbers determine the "buffer" region around the field of view during alignment. If they are both 1.0, then the alignment windows may be transformed in any way within the full field of view of the microscope. If they are less than 1.0 the field of view allowed for transformations will be reduced. For example, .90 will reduce the field of view by 10% in each direction. These parameters are intended to help reduce the likelihood that a transformation matrix will be created that causes the subsequent pattern written by PG to be out of bounds.

MinMax contrast .. These are the defaults for the minimum and maximum contrast limits that may be set for the image display.
Initial contrast....... These are the initial contrast values used for image display. If the brightness control on the microscope is consistently set, then the image will consistently fall within the same range and that range can be set here. These values are only important for the first window that is scanned for each alignment, since the contrast option is automatically run after the first window is scanned.

Auto contrast....... When the auto contrast option (A) is run it determines the maximum and minimum data values for the selected window(s). The MIN and MAX must be between -1 and 1. If the autocontrast numbers are positive, then the contrast limits are set based on the histogram of the image intensity data. For example, if MIN is set to 0.10, the lower contrast limit will have 10% of the pixels in the image below that limit, and if the MAX value is set to 0.30, the upper contrast limit will have 30% of the pixels in the image above that limit. If the autocontrast values are negative, the older method from NPGS v8.0 and earlier will be used where the contrast limits are calculated as follows, where only the brightest and darkest pixels are considered:

\[
\begin{align*}
Cont_{\text{min}} &= Data_{\text{min}} + (-1 \times \text{MIN} \times Data_{\text{diff}}), \\
Cont_{\text{max}} &= Data_{\text{max}} - (-1 \times \text{MAX} \times Data_{\text{diff}}),
\end{align*}
\]

where \( Data_{\text{diff}} = (Data_{\text{max}} - Data_{\text{min}}) \) and "MIN and MAX" are the values entered above. For example, in this case, 0.3 for the MAX will set the upper limit of the contrast 30% of the way down from the maximum data value and 0.1 for the MIN will set the lower contrast limit 10% of the way up from the minimum data value.

Min&Max Mag..... These are the minimum and maximum values that may be entered by the user for the magnification or for the A or D elements of the transformation matrix.
Mag. tolerance ..... This is the default tolerance for the magnification and for the A and D elements of the transformation matrix. For one window alignment, if the magnification is within this amount of 1.0, then it will be set to one. For 2, 3, or 4 window alignment, if the matrix elements A and D are within this amount of each other, then they will be set to their average value.

Rotation tol......... This is the default tolerance for the rotation elements B and C of the transformation matrix. If the absolute values of both B and C are less than this tolerance, then the values of both will be set to zero. This effectively sets the minimum size of the rotation that will be included in the transformation matrix, since smaller rotations will be ignored.

Offset tol. .......... This is the default tolerance for the x and y offsets. If the absolute value of the x or y offsets are less than this value, then x or y value will be set to zero. For example, a 1 nm offset probably isn't worth including in the transformation matrix.

Reserved ............. The next values are reserved for future use.
Default Palette ....This value defines which of the following color schemes will be used as the default when AL is started. The default setting of 1 uses a color scheme which will display bright alignment features as red structures on a blue background.

Color Assign ........ This section of the system file contains columns of numbers that determine the colors of the four color palettes. Under the "Red, Green, Blue" column labels in the comment line, the components for each color are define, where the allowed entries range from 0 to 255. For example, '0 0 0' is black, '255 0 0' is bright red,
'80 80 80' is a medium shade of gray, and '250 250 20' is bright yellow. Note that Palette #0 is unique in that it displays 1/10 of the image data as the highlighted color and the other 9/10's as the base data color. When Palette #0 is selected within AL, the [ and ] keys can be used to move the highlighted section to see where the pixels of different intensities fall within the image. For the other three palettes, the data colors are displayed such that the rgb color components linearly change from the darkest value to the brightest value.

**Pg_AA[1,2,3].sys (Auto-Align Parameters)**

*Pg_AA[1,2,3].sys* contain the parameters for customizing the Auto-Alignment feature of AL. From within the NPGS Menu program, use "Options - System Files..." to edit this file. Following the first two header lines are 10 parameter lines that contain one or two values followed by a brief description and the value limits. These 10 parameter lines will override the values entered in the file "Pg_AL.sys" when the Auto-Alignment feature is used. Following the next comment line are 31 lines that contain the parameters used to customize the operation of the Auto-Alignment feature. The format for all three Auto-Alignment system files is identical. A full description of each parameter is given after the file listing:

```
*************** NPGS-Auto Align #1 System Parameters ***************
*************** (next 10 override Pg_AL.sys) ***************
1          Window centering option      (0=max two, 1=avg of all)
1          Use opt 1 for output if possible              (0 or 1)
2          Initial Step Size                             (1 to 9)
1          Secondary Step Size                           (1 to 9)
.1           Auto Contrast Min and Max      (0 to 1, Max < 1 - Min)
.99           X and Y field of view border                 (.5 to 1)
.5           Min and Max allowed Mag.           (.5 < 1 and 1 < 2)
.001        Magnification tolerance                       (0 to 1)
.001        Rotation tolerance                            (0 to 1)
.001        Offset tolerance                    (0 to 100 microns)

*************** (new parameters for Auto-Align)***************
2          # of Times to Scan Windows before Aligning    (2 to 9)
2          # of Times to Align Each Set of Windows       (1 to 9)
.2          Use Previous Matrix, if available       (0=no,0<x<=1=yes)
0          Auto Contrast      (0=all windows, 1=individual windows)
50          Threshold Color                  (1=lowest, 100=highest)
0          Inverse Option     (0=search for bright marks, 1=dark)
1          Enhance Image During Filtering           (1=yes, 0=no)
fefa        Initial Pre-Align Keystroke Commands      (<= 10 char)
eaa         Secondary Pre-Align Keystroke Commands    (<= 10 char)
0          Coarse: Mode (-1=never,0=before 1st windows,1=always)
1          Coarse: Option             (1=fast or 2=more accurate)
8          Coarse: Step when Option=2          (1 to 25)
.05         Coarse: Bins when Option=2          (.001 to 1)
0          Coarse: # of Times to Beep after Alignment (0 to 10)
1          Fine: Mode       (-2=custom, -1=never, 1=always)
2          Fine: Window Center (0 to 3; # of moves to find Max)
-5         Fine: Window Half-Width          (<0=Auto, >0=Fixed)
0          Fine: Weighting for Overlay in Fit Calc (-100 to 100)
.8          Fine: Threshold for Fine Window       (0.1 to 1.0)
.95        Fine: Threshold for Position Average      (0.1 to 1.0)
0          Edge: Mode       (-1=never,0=after last windows,1=always)
1          Edge: Option      (1=rectangular or 2=arbitrary windows)
-10        Edge: Step Size for Checking Overlay       (-50 to 50)
4          Edge: Acceptable Distance to Border        (-100 to 100)
3          Edge: # of Edge Errors before Terminating (1 to 9)
1          Stage: Mode (-1=never,0=after bad matrix,>0=threshold)
```

End of listing.
Additional information on each parameter follows:

1st 10 lines.........These lines contain parameters that override the defaults given in "Pg_AL.sys" so that each Auto-Alignment system file can give complete control over the operation of the Auto-Alignment feature. See the discussion on "Pg_AL.sys" for a description of these parameters.

# Scans..............All windows in a set will be scanned this number of times before the Auto-Alignment calculations are initiated. This number along with the "Counts" number in the run file for the alignment pattern determine the amount of signal averaging to be done before Auto-Aligning.

# Align................This is the number of times that a set of windows will be Auto-Aligned before continuing to the next set or terminating AL. For best results when compensating for sample rotation, alignment should be done at least twice. However, if two sets of windows are used, then aligning once to each set should be sufficient.

Prev. Matrix.........If the value is greater than 0, the Auto-Alignment feature will start with the alignment matrix calculated from the last alignment (saved as "Pg_Align.sys"), if it is available. Since a series of alignments will typically have the same rotation with different offsets, this option allows AL to start with the matrix from the previous alignment, which can increase the speed and accuracy of the alignment process. If this option is used, any old "Pg_Align.sys" file should be deleted before aligning to the first set of registration marks. This will be done automatically by NPGS. If the value is 1, the previous matrix will be used when the windows are initially opened and the matrix determined by the Auto-Align process will be used for subsequent pattern writing. If the value is between 0 and 1, it will be used as the allowable percentage error between the previous matrix and the newly calculated matrix. Specifically, after a new matrix is determined during Auto-Alignment, the four points: (1,1), (1,-1), (-1,1), and (-1,-1) will be transformed using the new and previous matrices and compared. Let A,B,C,D be the four points after the transformation using the previous matrix and A',B',C',D' be the four points after using the new matrix. For each point, the tolerance is checked by comparing |A-A'| to T|A|, where T is the threshold entered for the "Use Previous Matrix" parameter (for example, 0.1 would allow a 10% change). If any of the four points are outside of the tolerance, the new matrix will be rejected and the previous matrix will be used. This will not affect the XY offset. This mode of operation is useful when many alignments are to be done and it is expected that all of the matrices will be similar. If a bad set of alignment marks is encountered, this mode will reject the bad matrix that results and use the previous matrix instead. If the parameter value is 0, any previous matrix will be ignored. When an autoalignment fails the previous matrix test, the message "Invalid matrix during Alignment" will be added to the LastRun.log file.

Auto Contrast......The Auto-Alignment feature will automatically set the display contrast before doing the alignment calculations. This option tells the routine to set the contrast for each window individually or to use a single contrast setting based on all intensity values in all windows. The individual option would be useful if registration marks used in the same set of windows have different compositions. For example, if aligning to existing structures on a sample defined by optical lithography, a corner of a gold bonding pad may be used as one alignment mark and a mesa in the substrate may be used as a second mark.

Thresh. Color.......This value ranges between 1 and 100, where 1 denotes the darkest color and 100 denotes the brightest color. When the autoalignment routine does the calculations on the displayed image, the pixels are weighted by their color number, however, any pixels below this threshold will be ignored. Setting the threshold to 1 will use all data in the displayed information, however, increasing the threshold can improve the speed and accuracy of the alignment since the background information can be eliminated. Setting the threshold too high will decrease the accuracy of the alignment if the mark intensity is below the threshold.

Inverse Option ......Typically, registration marks will appear bright against a dark background, however, this option will allow alignment to be done if the marks are dark on a...
Customizing the System

System Files in each Project

- Customizing the System

System Files in each Project

Enhance.............. If this option is enabled, the filtering commands: 'e'=enhance and 'g'=generate edges, will not decrease the intensity of a pixel if the Auto-Alignment feature is looking for bright marks and will not increase the intensity if looking for dark marks. This is useful since the 2nd derivative method used for 'e' and 'g' would otherwise make each edge have a bright and dark side. Then, when the pixel intensities near the edge are averaged, the effect of the filtering would be lost. By enabling this option, the edges of bright marks will become brighter and the edges of dark marks will become darker when the image is processed using one of the filtering commands.

Init. Keystroke...... Up to 10 characters may be entered that correspond to the normal AL keystroke commands. These commands will be executed before the alignment calculations are started using the initial set of windows. Typically, one or more of the filtering commands, 'e' and 'i', would be entered, followed by the autocontrast command 'a'. For example, the command string "fefa" would do a spatial average of the images, then enhance the edges, followed by another spatial average, and finally the images would be redisplayed with the contrast optimized. When testing the effectiveness of different combinations, the command ' ' may be used to pause the processing so that the intermediate results may be viewed.

Sec. Keystroke..... Up to 10 characters may be entered that correspond to the normal AL keystroke commands. These commands will be executed before the alignment calculations are started using any set of windows after the initial set.

Coarse: Mode ...... The Auto-Alignment feature uses a coarse alignment scheme followed by a fine alignment scheme. The purpose of the coarse alignment routine is to quickly determine the approximate location of the mark with no regard to the current overlay position, while the fine alignment routine will do a more accurate evaluation starting from the current overlay position. For this option, -1=completely disable the coarse alignment routine, 0=only do the coarse alignment before the 1st set of windows (typically coarse alignment will be unnecessary for subsequent sets), and 1=always do the coarse alignment.

Coarse: Option...... The fast option simply positions the overlays at the average position of the brightest pixels. This option works well if there is no other structure (or bright spots) besides the mark to be located within the windows. The more accurate option will step the overlay over the pixel positions in the window and use the average of the best fits. The Step and Bins parameters below give more information.

Coarse: Step........ This value defines the step size when the Coarse Option is 2. A step size of 1 will evaluate the overlay fit at every pixel in the window, while a step size of 25 will evaluate the fit at every 25th pixel. Typically, a value between 4 and 10 will give a reasonably fast Coarse Alignment and will have a reasonably good discrimination against structures in the image besides the desired mark.

Coarse: Bins......... This value defines the amount of averaging to use when the Coarse Option is 2. For example, a value of .10 will average the positions of the overlay locations that have fit values in the highest 10% of those tested. Likewise, a value of .02 will only average the positions that have values in the highest 2% of those tested.

Coarse: # Beeps .. This option will make the software beep after positioning each overlay at the Coarse Alignment position. It is useful when evaluating the speed/accuracy of different Coarse Alignment configurations, since the position of the overlays will be flashed to the screen during the beeps.

Fine: Mode.......... The Fine Alignment calculation will determine the best fit to the image starting from the current overlay positions. The choices are: 1=always, -1=never, and -2=custom. If the Coarse Mode and Fine Mode both equal -1, no Auto-Alignment will be done. The custom option will allow the user to have direct

bright background. If the Inverse Option is enabled, the Threshold Color should be set as if the bottom color of the color bar is the highest number and the top color is #1. In either case, a lower threshold will use more of the data. All marks must either be brighter or all marks must be darker than the background. In all discussions about the Auto-Alignment feature, references to bright marks should be interpreted as dark marks, if this option is enabled.
access to the image data and to write their own program to evaluate the fit. For more information, see Auto Alignment: Custom Processing (page 126).

Fine: Center.........The Fine Alignment routine first searches in x and y from the current overlay positions looking for a better fit to the image. This parameter tells the routine how many times to repeat this quick search. Each repeat will begin from the best fit location of the previous search.

Fine: Half-Width...When doing the final calculation, the Fine Alignment routine evaluates the fit for the overlay by stepping the reference location over every pixel within a rectangle. If positive, this parameter tells the routine to always search a square of this number of pixels out from the center. If negative, the routine will search in the ±x and ±y directions until the calculated fit parameter falls below the fit parameter at the center times the "Fine: Threshold for Fine Window" parameter discussed below. In all directions, at least this number of pixels (absolute value) will be searched.

Fine:Weight...........This value is only in v9 or higher auto-alignment system files. The normal operation during the Auto Alignment routine is that pixels defining the shape of the registration mark to be found are compared to the image data. These pixels include those within closed overlay structures, such as a zero width line that defines the perimeter of the mark, as well as the pixels of non-closed overlay structures, such as lines of zero width that do not form a closed polygon. When the "Fine: Weighting" value is not zero, in addition to using the pixels described above, the overlay pixels displayed on the screen are also used, but they are multiplied by the weighting factor. For example, if the weighting factor is zero, the auto alignment is identical to that of previous versions of NPGS. But if the weighting factor is positive, then the overlay pixels will add more to the "fit" value when they are on the mark, where a larger positive value will make them contribute more than the regular alignment pixels. Effectively, this will make the best fit have as much of the overlay as possible be on the mark. The interesting use of the weighting value is when it is set to a negative value. In this case, the interior of a closed polygon in the overlay will add to the fit when it is on the mark, while the overlay itself will subtract when it is on the mark. This feature is very powerful when the inside or outside corner of a large feature is to be found, since by using a negative weighting factor the best fit will be obtained when the overlay is right on the edge of the mark. Without using this negative weighting, the typical alignment to a corner of a large feature will require a more complicated overlay design in order to be sensitive to locating the edge.

Fine: Thres. Win ...This value is used when the "Fine: Half-Width" value is negative. For example, if this value is .8, then the Fine Alignment routine will look at the fit values in ±x and ±y around the maximum up to a distance where the fit value falls below 80% of the fit at the maximum location. The effect of this search is to dynamically determine a rectangular window that contains the locations of the best fits to the image. By making this threshold lower, the routine will search a larger area and will be less likely to contain only a false maximum, however, the calculation time will be increased.

Fine: Thres. Ave ..After finding the window of locations to consider, all points within the window will be evaluated and the locations of the best fits will be averaged. This parameter tells the routine how good the fits must be in order to be included in the final average. For example, a value of .95 will result in an average of all locations that have fit values within 5% of the single best fit found within the window. Since the registration marks may vary slightly from their ideal size and since the edges may have isolated bright spots, it is best not to just find a single location with the best fit. This averaging technique provides a good fit even when the registration marks vary significantly from their ideal size and it is good at avoiding fits that are skewed by isolated bright spots on the mark.

Edge: Mode ............After finding the best fit for the registration mark, the Auto-Alignment routine can check if the overlay falls on or near the edge of the window. This may happen if the initial sample position is such that the registration marks are only partially within the alignment windows. If an edge is detected, the current overlay fits will be used to recalculate the alignment matrix and then the alignment process will be repeated. After recalculating the alignment matrix, the windows should move to totally cover the registration marks. If the alignment procedure
is repeated because an edge was detected, the current alignment will not be included in the count that is compared with the "Scan #" parameter discussed earlier. A value of -1 will disable this option, a value of 1 will check for edges after every set of windows, and a value of 0 will check only after the last set of windows. If the overlay is designed to be very close or outside of the alignment window, then this option should be disabled. For example, when searching for the edges at only the corner of a large bonding pad, improved performance can sometimes be obtained by designing the overlay to extend outside of the window.

**Edge: Option**
A value of 1 will produce a fast check for rectangular windows. If the windows are not rectangular, a value of 2 will ensure that the edges are accurately checked. The check for arbitrary windows is slower than the check for rectangular windows.

**Edge: Step**
When checking if the overlay falls outside of the window, not every overlay pixel needs to be tested. Instead, this parameter tells the routine how many pixels to skip when checking. For example, a value of 2 will check every other pixel, a value of 3 will check every third pixel, etc. If zero is entered, a default value equal to the number of pixels in the displayed overlay divided by eight will be used. If a negative value is entered, the default will be used unless it is greater than the magnitude of the entered value. In that case, the magnitude of the entered value will be used. The default value will give a fast and accurate check for rectangular windows, however, if arbitrarily shaped windows are used, a value between -3 and -10 may be best.

**Edge: Border**
This parameter tells the routine how close the overlay can be to the window edge (in pixels) without causing the alignment to be repeated. A value of 0 will cause the alignment to be repeated only if the overlay hits the edge of the window. If the "Edge: Option" parameter is set for rectangular windows, a positive value will effectively make the allowed area smaller and a negative value will make the allowed area larger. In this case, a negative value will allow the overlay to fall outside the window without causing the alignment to be repeated. If the "Edge: Option" parameter is set for arbitrary windows, both positive and negative values will make the allowed area smaller.

**Edge: # Errors**
This parameter sets the number of times that a single set of windows will be rescanned due to an edge overlap before terminating the alignment process. Typically, an edge will be encountered only once or twice before a good fit is determined.

**Stage: Mode**
The Auto-Alignment feature has the capability to send a coarse correction to an automated stage before doing the final alignment. This capability allows the routine to minimize the offset in the final alignment. A value of -1 will disable this option, a value of 1 will send the correction only after the first set of windows, and a value >0 will be interpreted as a threshold in microns where the correction will only be sent if the calculated offset is greater than the threshold. For example, a value of 2 would cause the coarse correction to be sent to the stage only when the calculated offset is greater than 2 microns. In order to use the stage option, the name of the stage interface program must be entered in the "Pg_Stg.sys" file using the System File Editor within the NPGS Menu program. Also see "stage offset" in "Pg.sys".

By default, this feature assumes that the stage axes and the sample axes are parallel. However, if the Global Correction mode has been used a file "Pg_Angle.sys" will have been created which will relate the stage coordinates to the sample coordinates. Whenever this file exists in the current directory, it will be used during the Auto-Align coarse correction to convert the offset determined by the alignment to the correct offset for the actual stage coordinate system.

**Pg_Beam.sys (Auto-Beam Reading Parameters)**

Pg_Beam.sys contains the parameters used for controlling the NPGS Beam Current Checking. From within the NPGS Menu program, use "Options - System Files..." to edit this file. "Pg_Beam.sys" listing:
Customizing the System

**************** Beam Current Checking System File ****************

0         Beam Current Checking: 1=enable, 0=disable

internal  Reading Program: external program name or 'internal'

1         Reading Mode: 0=absolute(pA), 1=relative to 1st reading

.5        Error Threshold: ratio of readings to initial reading

5         Minimum Time Between Current Readings: minutes

2         Check Before: 1=pattern,2=layer,3=entity,4=dump pt,5=end

0         Activate Parallel Port Pins for F.Cup: 1=yes, 0=no

0x3bc     Address for Parallel Port: 0x278, 0x378, or 0x3bc

3.0       Delay When Changing Value of Port: 0 to 30 seconds

3.0       Delay After Turning Off Blanking: 0 to 30 seconds

1000      Internal Mode # of ADC Readings to Average: 1 to 32,000

3         Internal Mode ADC range: 0=±1.25v, 1=±2.5v, 2=±5v, 3=±10v

0.0       Internal Mode Offset: corrects for offset in voltage read

1.0       Internal Mode Scaling: converts (reading+offset) to pA

0         Move Auto-Stage to Faraday Cup to Make Reading: 1=yes, 0=no

1500      X Location of Faraday Cup: microns

1500      Y Location of Faraday Cup: microns

End of listing

Additional information on each parameter follows:

Enable .................. If set to 1, this parameter activates the Beam Current Checking mode, while 0
               disables the mode. When enabled, NPGS will correct for drift in the beam
               current by adjusting the exposure time per point for each pattern element.
               Consequently, the exposure times per point in the run file should not be close to
               the hardware maximum for the exposure mode being used. The allowed range
               is from ~0.2 μsec to over 1 hour per point example, so this is not much of a
               limitation. If the correction requires an exposure time longer than the maximum
               allowed, the exposure will be done at the maximum time, and an error message
               will be displayed when the pattern writing is completely finished. Also see the
               "Threshold" parameter below that allows the user to set the maximum
               acceptable drop in beam current.

Prog. Name .......... This parameter has four options: [1] Enter the name of an external program
               that will make the beam current measurement; [2] Enter the word "internal"
               which will cause PG to use the NPGS hardware to read the beam current
               through an A/D converter; [3] Enter an external program name that is preceded
               by the character '&'; [4] Enter an external program name that is preceded by the
               character '*'.

               Any external program listed here should be located in the "\NPGS\Projects"
               directory or it must be available in a directory listed in the MSDOS "PATH".
               When using a Keithley 485 Picoammeter with GPIB (IEEE 488.2) interface
               and a Computer Boards GPIB card, a program can be provided at no charge
               that is designed to work with the NPGS Automated Beam Reading feature.

               Additional information on case [1*]: If this option is used, the external program
               must make the measurement and return the beam current reading to the
               temporary file "%pg_io.tmp" in the current Project directory. When the external
               program is called by PG, the command is actually:

               prog_name #current #configuration

               where "prog_name" is specified in this system file, "#current" is the measured
               beam current as given in the run file, "#configuration" is the SEM configuration
               parameter as given in the run file. The external program will typically ignore
               the two parameters that are passed, but in some cases it may be possible for
               the program to make use of them. For example, the external program may be
               able to actually adjust the beam current in order to obtain the correct value, rather
               than to simply report how much it has drifted.
A special mode is activated when an external program name is entered, even when the “ Enable” parameter is set to zero. This special mode will activate the manual Get Beam Reading button on the main NPGS Menu.

**Additional information on case [2]:** In this case, PG will use an A/D converter in the NPGS hardware to make a measurement of the beam current. Typically, this approach will have limited resolution, depending on the picoammeter that is used. Also, see the three “Internal Mode” parameters below.

**Additional information on case [3]:** In this case, the external program will be called to insert the Faraday cup and the “internal” mode will be used to read the beam current. If the external program name is "chg_cup", the value to enter is "&chg_cup". Before the beam is read, the following command will be issued: "chg_cup I". The ‘I’ should make the program insert the Faraday cup. After the beam is read, the command will be "chg_cup R", which should retract the cup. The actual beam reading will be done as if the "internal" mode were specified. If "chg_cup" cannot read from the command line, the parameter "I" or "R" will also be present in the file "%pg_io.tmp".

**Additional information on case [4]:** In this case, the external program will be called as in case [3] and it will be called to make the beam reading as in case [1]. If the external program name is "program", the value to enter is "*program". To summarize, in this mode the external program will be called three times. First, it will be passed the character 'I' when it should insert the Faraday cup, then it will be passed the parameters as listed in case [1] when it should read the beam current, and finally, it will be called with the parameter 'R' to retract the cup. If "program" cannot read from the command line, for each call the appropriate parameter(s) will also be present in the file "%pg_io.tmp". The analog reading will not be performed. If you wish to have three separate programs to insert, read, and retract, a batch file can be used to call the appropriate individual program. For example, the following "program.bat" file will respond differently for each call by PG:

```bash
@echo off
if "$1" == "I" goto insert
if "$1" == "R" goto retract
REM this is where the beam would be read...
echo R
echo BEAM READ: $1...
REM return expected value as measured value...
echo $1 > %pg_io.tmp
goto end
:insert
REM this is where the Faraday cup would be inserted...
echo R
echo INSERT CUP

:goto end
:retract
REM this is where the Faraday cup would be retract...
echo R
echo RETRACT CUP

:goto end
:end
pause
```

The "echo" commands above are for illustration purposes only and would be replaced by the appropriate commands to control the Faraday cup and to make the beam reading. The final "pause" is also for demonstration only.

Mode................If set to 0, the beam current readings will be interpreted as absolute measurements in pA. In this case, the exposure times will be scaled to compensate for the difference between the measured value and the value listed in the run file. If set to 1, the relative mode will be used, where the first beam
current reading is used as a reference and subsequent readings are compared to the first. In the relative mode, it is assumed that initially the beam current will be set to the value given in the run file.

**Threshold**
Each beam current measurement will be compared with the first measurement and if the ratio is less than the given threshold value, an error message will be displayed. This allows the user to specify a lower limit for the change in the beam current before the program stops writing patterns. It also stops the pattern writing if the microscope filament fails. If the run file specifies a large beam current for the initial writing and then changes the specified current to a smaller value, the software will properly handle the situation. For example, if the threshold is set to 0.70, the first current is 100 pA, and the second current is set to 10 pA, then the software would signal an error only if the first current dropped to 70 pA and the second dropped to 7 pA.

**Min. Time**
The readings are made at discrete intervals of time, with a minimum interval specified by this parameter. Ideally, the interval should be as long as possible to avoid wasting time on unnecessary readings, while it should be short enough to adequately compensate for the drift. For example, if the beam usually drifts 5% in 60 minutes (1% in 12 minutes), an interval of 5 minutes would typically be reasonable, since the corrections would be made before the current changes by ½%. This parameter sets the minimum time between readings, while the actual time will depend on the following parameter as well.

**Check Before**
This parameter specifies when the software should consider making a current measurement. For each choice, the software will check the time since the last reading and will make a new reading if appropriate. The choices are: 1= before each new pattern, 2= before each new layer within each pattern, 3= before every entity within each layer, 4= only when the beam is at a dump point, 5= only at the end of a pattern. Choice 2 should be used if the run file uses different beam currents on different pattern layers. In that case, NPGS will always make a reading after the beam current has been changed, even if the minimum time interval has not passed. Choice 4 is typically used when no blanker is available. Choice 5 is best when an automated stage is being used to move to the location of the Faraday cup. Since any motion of the typical SEM stage will introduce some placement error, it is best to measure after a pattern has finished and use the measured beam current value for the next pattern to be written.

**Activate Port**
If the Faraday cup can be inserted into the beam path by remote control, this parameter will activate control of two TTL pins on a parallel port of the PC. Both pins will be toggled, while only one will normally be used for the control. Pin #14 will be normally HI and pin #17 will be normally LO. Both pins will change state when the Faraday cup is to be inserted, and will change back when it is to be retracted.

**Port Address**
This parameter specifies the address of the parallel port to be used. The choices are: 0x278, 0x378, or 0x3bc.

**Port Delay**
This parameter allows the user to specify a delay after each change in the value of the parallel port. It allows the software to wait for a slow mechanical device.

**Blanking**
If a beam blanker is in use, this parameter will specify the delay after the blanker is deactivated (i.e., beam turned on) before each measurement. This delay allows the picoammeter to settle before the measurement is made. Setting the delay time to zero will prevent any change in the state of the blanker.

**Readings**
When the "internal" mode is used, this parameter specifies how many readings of the ADC should be averaged. Each reading is made with 16-bit resolution. A differential reading is made on the pins 16B (Hi) and 17B (Low) of the multipin connector on the PCI516A board (not present on the PCI516B version) and each reading takes ~2.7 μsec. When using Keithley picoameters, the resolution of the analog output is typically quite low and does not work well for this use. A better option can be to use an external program to read the meter through a GPIB or serial interface.

**ADC Range**
This parameter is used to set the input range of the ADC input on the PCI516 board’s multipin connector that is used to read the voltage.
Offset ................... When the "internal" mode is used, after the appropriate number of readings are averaged, the offset listed is added to the measured value. If the analog voltage being read is not directly proportional to the beam current, the offset should be set to the correct value to compensate.

Scaling .................. When the "internal" mode is used, after the offset is added, the result is then multiplied by this scaling factor. If the Absolute Mode is used, this should convert the value to pA.

Move Stage .............. If the Faraday cup is located on an automated stage, this parameter should be set to 1, otherwise it should be 0. If an automated stage is to be used, the parameters in "Pg_Stg.sys" should also be set properly.

X Location .............. This parameter is the X location of the Faraday cup in microns using the coordinate system of the stage. When the stage is to be moved to the Faraday cup, the software will first prompt the stage driver for the current location of the stage. Then the stage will be moved to the Faraday cup location, as specified in this file. After the beam is measured, the stage will be moved back to the original location. Since this motion will typically introduce an error in the original location of the stage, the "Check Before" parameter discussed above should be set to 5 if alignment is being done before pattern writing or possibly to 1 if no alignment is being done.

Y Location .............. This parameter is the Y location of the Faraday cup in microns using the coordinate system of the stage. In some cases, the X and/or Y stage coordinates times "-1" should be entered for the X and Y locations, respectively.

**Pg_Cmdn.sys (External Program Names)**

Pg_Cmdn.sys contains lines for commands that are run at different points during the execution of PG and AL. From within the NPGS Menu program, use "Options - System Files..." to edit this file.

Any executables listed in this system file should be copied to the "\NPGS\Projects" directory. If an executable is not found in that directory, it must be in the current project or it must be available in a directory listed in the MSDOS "PATH" statement.

A brief explanation of each command follows:

1. Signals first pattern written in PG.
2. Signals next pattern written in PG.
3. Signals pause for layer in PG (example: “PlayWav 1 2” or “tune 1.3”).
4. Signals successful finish of PG.
5. Signals error while executing PG (example: “PlayWav 2 3” or “tune 4.8”).
6. (not used).
7. Name of focus driver used by PG and AL or 'manual'.
8. (not used; previously name of stage driver used by PG and AL)
9. Name of scope driver used by PG and AL.
10. Command executed at start of PG and AL*.
11. Command executed at end of PG and AL*.
12. Command executed at start of NPGS.exe.
13. Command executed at successful finish of NPGS.exe.

Lines 1,2,3,4,5,10, and 11 are self-explanatory. Note that the example "tune" programs are run internally, rather than by a call to an external program. Any other command name will be run externally.

Line 6 is not used in the current version of the software.
Line 7 controls the X-Y-Focus option. For more information, see X-Y-Focus Mode (page 170).

Line 8 is not used in the current version of the software. Previously, it held the name of the stage driver. The name of the stage driver is now contained in the file "Pg_Stg.sys".

Line 9 defines the interface for a digital microscope. For more information, see Interfacing to the Microscope (page 162).

Lines 10 and 11 are run by both PG.exe and AL.exe* as indicated.
*The letter 'a' will be added as an argument when the command is sent to Al.exe. This tells the external program when the call is from Al.exe vs. Pg.exe.

Lines 12, 13, and 14 are run only by NPGS.exe as indicated.

If any of the commands are to be skipped, simply leave the appropriate line blank. For example, if an analog microscope is used, then line 9 should be blank. Lines 10 through 14 may be used for any commands that the user wants executed. For example, a log of start and finish times could easily be maintained by executing simple batch programs at the start and end of each run. A more creative use would be to call a program that could notify the user by e-mail when NPGS.exe has successfully finished processing a run file or if an error has been encountered.

External commands are handled by Windows in a 32-bit environment. The external programs can have functions ranging from playing sound files (see wav.exe in Miscellaneous Files (page 205)) to sending e-mail when a run file has finished.

**Pg_Errors.sys (Error Management)**

Pg_Errors.sys contains a listing of the errors that can be skipped during the processing of a run file.

Normally, when NPGS.exe, Pg.exe, or Al.exe encounters any error condition, the processing of the run file will be interrupted. The Pg_Errors.sys file allows the user to specify how many times each error can be skipped, i.e., the processing of the run file will be continued automatically. The default is to set all entries to zero, which interrupts the processing for any error.

For more information about individual error messages, see “Errors: Pattern Writing (NPGS, PG, AL) (page 230)".

From within the NPGS Menu program, use "Options - System Files..." to edit this file. "Pg_Errors.sys" listing:

```
When an error is encountered during the processing of a run file, the processing will normally be terminated. These settings indicate how many times NPGS.exe will skip each individual error.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
The following errors may be skipped in NPGS.exe...
0  NPGS (101) too many vertices needed during fracturing
0  NPGS (102) invalid field number during fracturing
0  NPGS (103) error fracturing pattern entity: crossing point not found
0  NPGS (104) error fracturing pattern entity: undetermined crossing point
0  NPGS (105) error fracturing wide line
0  NPGS (106) error checking ordering of polygon vertices
0  NPGS (200) stage error
0  Reserved
0  Reserved
0  Reserved
0  Reserved
0  Reserved
0  Reserved
0  Reserved
0  Reserved
```

---

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The following errors may be skipped in PG.exe...

0          Reserved
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
0          PG (-6)     PCI516 DMA Transfer Error
0          PG (-5)     PCI516 Buffer Clocking Bit Error
0          PG (-2)     error in PCI516 operations
0          PG (-1)     round() argument error
0          PG (0)      memory allocation error
0          PG (2)      bad pattern file...no header
0          PG (3)      error opening pattern file
0          PG (5)      option $d nonexistent
0          PG (6)      error during polyfill()
0          PG (7)      too many points in a line entity
0          PG (8)      illegal color in DC data file
0          PG (9)      invalid exposure values
0          PG (10)     bad or missing run file parameters
0          PG (17)     file 'pg_align.sys' not found in current directory
0          PG (18)     (Circle or Arc Width)/(Line Spacing) is too large
0          PG (20)     an old run file is calling a new pattern file
0          PG (21)     a new run file is calling an old pattern file
0          PG (63)     error reading beam current in '%%pg_io.tmp'
0          PG (64)     error reading stage location in '%%pg_io.tmp'
0          PG (200)    stage error
0          Reserved
0          Reserved
0          Reserved
0          Reserved
0          Reserved
0          Reserved
0          Reserved
0          Reserved
0          Reserved
0          Reserved
0          Reserved
0          Reserved

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

The following errors may be skipped in AL.exe...

0          AL (-2)     error in PCI516 operations
0          AL (-1)     round() argument error
0          AL (0)      memory allocation error
0          AL (2)      bad pattern file...no header
0          AL (3)      error opening pattern file
0          AL (4)      option not implemented
0          AL (5)      option nonexistent
0          AL (6)      error during polyfill()
0          AL (7)      too many points for polyfill()
0          AL (8)      illegal color in DC data file
0          AL (9)      invalid exposure values
0          AL (10)     bad or missing run file parameters
0          AL (13)     too many points needed
0          AL (18)     (pattern line width)/(Line Spacing) is too large
0          AL (20)     an old run file is calling a new pattern file
0          AL (21)     a new run file is calling an old pattern file
0          AL (32)     image not properly fitting into display area,
0          AL (43)     Auto-Aligned position produced invalid matrix
0          AL (44)     error creating temporary file
0          AL (45)     error writing to temporary file
0          AL (46)     error opening temporary file for reading
0          AL (47)     error reading temporary file
0          AL (64)     error reading stage location in '%%pg_io.tmp'
0          AL (200)    stage error
0          Reserved
0          Reserved
0          Reserved
0          Reserved
0          Reserved
Customizing the System

Pg_Mag.sys (User-Defined Magnification Values)

Pg_Mag.sys contains a list of user-defined magnification values that can be retrieved by hitting the “+” or “-” keys when a magnification value is selected in the Run File Editor.

From within the NPGS Menu program, use "Options - System Files... - System File Editor - Pg_Mag.sys" to edit this file. Windows Notepad or another text editor can also be used, as long as the file format is not changed.

The first line in Pg_Mag.sys will enable or disable the user-defined values. When the user-defined values are disabled, the “+” and “-” keys will still be active for the magnification prompts in the Run File Editor, but the values will be automatically generated.

When the user-defined values are active, the same values that are available on the microscope should be entered. Note that the values can be in any order and “10” should be entered for any unused entry.

For convenience, the “_” (underline) key will be treated the same as “-” (minus), and the “=” (equal) key will be treated the same as “+” (plus).

Most older model SEMs will only provide discrete values of magnification, so it can be useful to have the +/- mode select the same values. New SEM models will often allow any integer value for the magnification, in which case, the automatic mode will often be fine. However, it can also be useful to determine the optimum magnification values for your work and to enter them into Pg_Mag.sys, so that they can easily be selected using the +/- keys.

Pg_Optimize.sys (Beam Optimization Parameters)

Pg_Optimize.sys contains a list of parameters used by the Pg_Optimize.exe program. See Beam Optimization with Pg_Optimize (Beta) (page 147) for additional information. This program allows the user to systematically optimize the focus, x stigmator, and y stigmator settings of a digital microscope which allows external control of these functions.

The Pg_Optimize.sys file will not be included in an NPGS update or with a new NPGS installation for all microscope models, since this feature is only compatible with certain digital microscopes. From within the NPGS Pg_Optimize program, use the "Configure" button to edit this file.

An example "Pg_Optimize.sys" listing for use with an FEI microscope which uses the FEI DCOM Ethernet interface follows:

Settings for Check Boxes...
1  1=Make Left Click/Right Click button skip Center
1  1=Middle click on Left/Right button to select Better
10 Maximum number of seconds to wait for external commands
Settings for Focus Control...
0.002 Focus: Default Step Size for Checking +/-
0.0005 Focus: Default Fine Adjustment Step Size
0.0001 Focus: Minimum Allowed Step Size
0.010 Focus: Maximum Allowed Step Size
3 Focus: Minimum Allowed Output Value
25 Focus: Maximum Allowed Output Value
Settings for X Stigmator Control...
0.1 XStig: Default Step Size for Checking +/-
0.05 XStig: Default Fine Adjustment Step Size
0.001 XStig: Minimum Allowed Step Size
1 XStig: Maximum Allowed Step Size
-100 XStig: Minimum Allowed Output Value
100 XStig: Maximum Allowed Output Value

Settings for Y Stigmator Control...
0.1 YStig: Default Step Size for Checking +/-
0.05 YStig: Default Fine Adjustment Step Size
0.001 YStig: Minimum Allowed Step Size
1 YStig: Maximum Allowed Step Size
-100 YStig: Minimum Allowed Output Value
100 YStig: Maximum Allowed Output Value

External Commands to control Microscope Functions...
(All programs must exist in \NPGS\Projects. Use '!' to skip command.)

```
Pg_QXT put_ScanMode,1 <SEM scan> Scan Button: 1st Program
Scan Button: 2nd Program
Scan Button: 3rd Program
Scan Button: 4th Program
Scan Button: 5th Program

Pg_QXT clr_FWD2 <degauss> Degauss Button: 1st Program
Degauss Button: 2nd Program
Reserved
Reserved

Focus Program to Read Focus
Focus Program to Write Focus
XStig Program to Read X Stigmator
XStig Program to Write X Stigmator
YStig Program to Read Y Stigmator
YStig Program to Write Y Stigmator

End of listing
```

An example "Pg Optimize.sys" listing for use with a Zeiss/LEO microscope which uses the "RemCon" serial interface follows:

Settings for Check Boxes...
1 1=Make Left Click/Right Click button skip Center
1 1=Middle click on Left/Right button to select Better
10 Maximum number of seconds to wait for external commands

Settings for Focus Control...
0.002 Focus: Default Step Size for Checking +/-
0.0005 Focus: Default Fine Adjustment Step Size
0.0001 Focus: Minimum Allowed Step Size
0.010 Focus: Maximum Allowed Step Size
3 Focus: Minimum Allowed Output Value
25 Focus: Maximum Allowed Output Value

Settings for X Stigmator Control...
0.2 XStig: Default Step Size for Checking +/-
0.05 XStig: Default Fine Adjustment Step Size
0.0001 XStig: Minimum Allowed Step Size
1 XStig: Maximum Allowed Step Size
-100 XStig: Minimum Allowed Output Value
100 XStig: Maximum Allowed Output Value

Settings for Y Stigmator Control...
0.2 YStig: Default Step Size for Checking +/-
0.05 YStig: Default Fine Adjustment Step Size
0.0001 YStig: Minimum Allowed Step Size
1 YStig: Maximum Allowed Step Size
-100 YStig: Minimum Allowed Output Value
100 YStig: Maximum Allowed Output Value

External Commands to control Microscope Functions...
(All programs must exist in \NPGS\Projects. Use '!' to skip command.)
Customizing the System

System Files in each Project

Pg_LEO32 RATE-8;

<SEM scan>
Scan Button: 1st Program
Scan Button: 2nd Program
Scan Button: 3rd Program
Scan Button: 4th Program
Scan Button: 5th Program

Pg_LEO32 MAC-2;)

<degauss>
Degauss Button: 1st Program
Degauss Button: 2nd Program
Reserved
Reserved

Focus
Program to Read Focus
Focus
Program to Write Focus
XStig
Program to Read X Stigmator
XStig
Program to Write X Stigmator
YStig
Program to Read Y Stigmator
YStig
Program to Write Y Stigmator

End of listing

The units for the Focus, XStig, and YStig values will depend on the microscope in use. For the FEI and Zeiss microscopes used with the files listed above, the focus units are millimeters.

The 5 lines shown above for the Scan Button and the 2 lines for the Degauss Button will be executed in the order shown when the corresponding button is clicked. For testing, it may be useful to put an exclamation point ‘!’ in front of a line to temporarily prevent that line from being executed when the button is clicked. Any text following the ‘<’ symbol will be ignored and can be used as a comment. See the NPGS documentation on the Pg_QXT.exe and Pg_LEO32.exe programs for information on the command arguments shown above.

In the examples above, the “Focus”, “XStig”, and “YStig” commands are batch files in the \NPGS\Projects directory which are created specifically for the microscope being used. These should be tested to ensure that the microscope consistently and reliably changes the appropriate microscope settings as expected.

For use with other microscope models, please send e-mail to ‘info@jcnabity.com’ to confirm if the microscope supports the external control of the focus and stigmator settings. If support is available, the appropriate files and settings will be provided at no charge.

Pg_RFE.sys (Run File Editor Defaults)

Pg_RFE.sys contains the defaults used by the Run File Editor. From within the NPGS Menu program, use "Options - System Files..." to edit this file.

The groups of parameters that may be modified from within the NPGS System File Editor are shown below. The other parameters in the Pg_RFE.sys file should not typically be modified by the user.

Numeric Limits, Prompts, and Units

This group has six columns of data:

Minimum and Maximum

The first two columns allow the user to specify an absolute minimum and maximum that will be accepted by the Run File Editor for the associated prompt. These values are always to be entered in the default units for the prompt, even if the multiplier below is used to change the displayed units.

Multiplier

The next column allows a multiplier to be entered, which can be used to scale the prompt value so that it can be expressed in units different than the defaults. For example, if nanometers are preferred instead of angstroms, then the multiplier should be set to 10 (ten angstroms in a nanometer) and the units in the corresponding prompt should be changed. Note that the values stored in the run files will always be in the original default units.

---

System Files in each Project ● Page 194
Format
This column allows the user to specify the number of decimal places that will be displayed within the Run File Editor for the associated values.

Prompt Label
This column allows the user to specify the text labels that will be displayed within the Run File Editor for the associated values. **Note that the command prompts which are displayed in PG and AL can include the special characters "<" and ">". When these characters are displayed in PG and AL, they will be flashed to highlight the prompt.** For example, when the magnification must be set manually, these characters can be used as a reminder which will be flashed when it is time to set the magnification during pattern writing or alignment.

Units
This column allows the user to specify the units that will be displayed within the Run File Editor for the associated values. Note that the units for the origin offset must always be microns and for all other values that allow the "Multiplier" to be changed, the units and multiplier must be changed together as described above. The default units are as follows:

- **Origin Offset**: \( \mu \text{m} = 10^{-6} \text{ meters} \) (cannot be changed)
- **Magnification**: (none)
- **Center-to-Center**: \( \text{Å} = \text{Angstroms} = 10^{-10} \text{ meters} \)
- **Line Spacing**: \( \text{Å} = \text{Angstroms} = 10^{-10} \text{ meters} \)
- **Configuration Parameter**: (none)
- **Measured Beam Current**: \( \text{pA} = 10^{-12} \text{ Amps} \)
- **Dwell**: \( \mu\text{sec} = 10^{-6} \text{ seconds} \)
- **Area Dose**: \( \mu\text{C/cm}^2 = 10^{-2} \text{ Coulombs / meter}^2 \)
- **Line Dose**: \( \text{nC/cm} = 10^{-7} \text{ Coulombs / meter} \)
- **Point Dose**: \( \text{fC} = 10^{-15} \text{ Coulombs} \)

**Exposure Parameter Defaults…**
These are the default parameters that are used when a new run file is created and can be modified by the user, as desired.

*It is a good idea to set the magnification, beam current, and optionally the spacings and doses that are normally used in your run files.*

**Alignment Parameter Defaults…**
These are the default parameters that are used when a new run file is created and can be modified by the user, as desired.

*It is a good idea to set the magnification, beam current, and optionally the spacings and doses that are normally used in your run files.*

**Advanced Mode Defaults…**
These are the default parameters that are used when a new run file is created.

**Fracture Entity Defaults…**
These are the default parameters that are used when a new Fracture Entity is added to a run file.

**Command Entity Pause Default…**
This value defines the default pause mode for the Command Entity as follows:

1 = Before Only (pause before executing command)
-1 = Before Only* (pause before executing command, unless Non-Stop mode)
2 = After Only (pause after executing command)
-2 = After Only* (pause after executing command, unless Non-Stop mode)
3 = Before/After (pause before and after executing command)
-3 = Before/After* (before and after executing command, unless Non-Stop mode)
0 = Never (never pause before executing command)
-9 = Skip (skip command completely)

**Comment Entity Display Default**
This value defines the default display mode for the Comment Entity as follows:

1 = Always (always display comment when run file is processed)
-1 = Always* (display when run file is processed, unless Non-Stop mode)
0 = Never (never display comment; useful for internally documenting run file)

**Button Definitions**
This section allows the user to assign labels and commands from the RFE menus to the buttons. Note that the "&" character in a button label will designate the button shortcut letter accessed through the "Alt" key. Buttons must not share the same shortcut letter with each other or with the main menu choices.

**Pg_Stg.sys (Stage Interface Parameters)**

*Pg_Stg.sys* contains the parameters used for communication with a stage driver. From within the NPGS Menu program, use "Options - System Files..." to edit this file. "Pg_Stg.sys" listing:

```
Stage: Driver Name
1 Stage: Precision (# of digits, 0 to 6)
1 Stage: X Conversion from Microns (.001 gives mm)
1 Stage: Y Conversion from Microns (.001 gives mm)
( Stage: Command String #1 (initial)
, Stage: Command String #2 (middle)
); Stage: Command String #3 (final)
? Stage: Prompt for Current Stage Position (1 character)
```

End of listing

**Additional information on each parameter follows:**

- **Driver Name**........ This is the name of the stage driver that will be called whenever PG or AL need to move the stage. (Note that in older systems, this name was also listed on line #8 of "Pg_Cmdn.sys", however, that convention is no longer used.). The executable listed here should be located in the "\NPGS\Projects" directory or it must be available in a directory listed in the MSDOS "PATH".

- **Precision**........... The Precision parameter defines the number of digits to the right of the decimal point to be used in defining the offset distance which will be passed to the stage driver.

- **X Conv.**............. This value is a conversion factor to be applied to the x offset distance before it is passed to the stage interface. For example, a value of 1 will keep the units as microns and a value of .001 will convert the units to millimeters. If the Global Correction mode is not used and the sign of the calculated offset is opposite to the desired stage direction, then the X Conversion value should be multiplied by -1. If the Global Correction feature is used, it will automatically determine the appropriate sign. The value must be within ±1e4.

- **Y Conv.**............. This value is a conversion factor to be applied to the y offset distance before it is passed to the stage interface. If the Global Correction mode is not used and the sign of the calculated offset is opposite to the desired stage direction, then the X Conversion value should be multiplied by -1. If the Global Correction feature is used, it will automatically determine the appropriate sign. Typically, the magnitude of "X Conv." and "Y Conv." should be the same. The value must be within ±1e4.

- **String #1** .......... The actual string passed to the stage interface program will be of the form: [1]x[2]y[3]. x and y are the offset values multiplied by the conversion factor above and are given as floating point numbers with the precision from above. The strings [1], [2], and [3] are replaced by up to 12 characters listed as String #1, String #2, and String #3, respectively. For example, if the Precision is 3, X Conversion is .001, Y Conversion is .001, String #1 is "\", String #2 is ",", String
#3 is ");", and the calculated coarse offsets are 2 microns in x and 3 microns in y, then the resulting string passed to the interface program would be: "((0.002,0.003);". Special characters can be included by holding down the "Alt" key while typing their ASCII code in decimal format on the numeric keypad. For example, to include the symbol "μ", hold the "Alt" key and type "230". The "μ" symbol will be displayed when the "Alt" key is released. White space characters, such as "space" = 32, are not allowed. Note that the command prompts which are displayed in PG and AL can include the special characters "<" and ">". When these characters are displayed in PG and AL, they will be flashed to highlight the prompt. For example, when the stage position must be set manually, these characters can be used as a reminder which will be flashed when it is time to move the stage during pattern writing or alignment.

String #2 .............. These characters are used as described above.
String #3 .............. Ditto. It is also recommended to include a command in this string to pause after the stage is moved. This will allow the stage to settle before PG or AL continues.

Prompt ................. When using the Global Stage Correction or X-Y-Focus modes, the software must be able to prompt the stage for its current X,Y coordinates. This prompt will be sent to the stage driver when it should return the coordinates. The response of the driver should consist of the current X and Y stage coordinates separated by at least a carriage return. For example, when prompted for the coordinates, the stage driver might output:

123.4  X position in Microns
567.8  Y position in Microns

where each position is the first value on separate lines followed by a comment of up to 40 characters. The driver must also create a temporary file called "%pg_io.tmp" that contains the same two lines of data.

**Pg_Log_Pre.sys (Auto Logging Parameters)**

*Pg_Log_Pre.sys* contains the default parameters used for the NPGS Auto Logging Mode. The parameters shown below are examples and this file can be modified by the user to document any number of parameters as long as the corresponding changes to the entries in "Pg_Log.sys" are made. For more information, see Auto Logging Mode (page 142).

<Pre-Writing Log File>
Sample Information...
Sample #1  Sample/Wafer ID
none  Secondary ID
InP  Substrate
SAL601  Resist
75-125nm  Resist Thickness

Microscope Settings...
25kV  Accelerating Voltage (kV)
7  Gun Bias
2.2  Filament Current (A)
60  Emission Current (µA)
2  Aperture #
10  Working Distance
5  Spot Size/Coarse Probe Current
Slow 2  Scan Mode
0.0  Scan Rotation
0.0  Tilt

Interference Control...
<0.3 µTpp  Magnetic Field Reading
Off  Fluorescent Lights
On  PC Monitor
General Comments...
Comment Line 1
Comment Line 2
Comment Line 3

**Pg_Log_Pre.sys & Pg_Log_Post.sys (Auto Logging Parameters)**

*Pg_Log_Post.sys* contains the default parameters used for the NPGS Auto Logging Mode. The parameters shown below are examples and this file can be modified by the user to document any number of parameters as long as the corresponding changes to the entries in "Pg_Log.sys" are made. For more information, see Auto Logging Mode (page 142).

Post-Writing Comments...
Yes              Successful Completion
<1%              Total Beam Current Drift
Moderate         Focus Change After Exposure
Comment Line 1
Comment Line 2
Comment Line 3

**Pg_Image.sys (Scaling Factor for Image Data)**

*Pg_Image.sys* is read by both AL.exe and Pg_Image.exe. Only the value on the first line should be changed directly by the user using a text editor. The single value contained on the first line is used to scale the image intensity data. Normally, the value will be 1.0, which does not cause any change to the intensity data. However, if the SEM image signal is inverted with respect to the bright/dark image on the SEM, a value of -1.0 can be used to flip the data before it is displayed by Pg_Image or AL. Note that only the Amray 1400 and Amray 1845 have been known to need the value to be set to -1.0, while all other models in use with NPGS use the default value. The other values in pg_image.sys are modified by pg_image.exe and should not be directly changed by the user.

**Pg_Align.sys (Alignment Results)**

*Pg_Align.sys* is created by AL when it saves the alignment parameters to the hard disk for use by PG. There are two formats for this file. Both formats consist of three lines with the format option number (0 or 1) on the first line and the x and y offsets (in microns) on the third line. Option 0 is used by AL when a full transformation matrix is saved. In that case the second line consists of the matrix elements (A B C D) represented as long integers where 65536 denotes a matrix element value of 1. Thus, the listing below describes a matrix producing a rotation of $5^\circ$ with a +5 micron offset in both x and y directions:

```
0
65287 -5712 5712 65287
5.000 5.000
```

Option 1 is used by AL when only the magnification and offsets are stored. In that case the second line consists of only one number, which is the magnification for the pattern to be written (1.00 = no change).

This system files contains parameters that are not normally modified by the user and/or the file will only be created when the corresponding feature is used. However, if needed, from within the NPGS Menu program, "Options - System Files - System File Editor" can be used to edit this file.

**Pg_Angle.sys (Global Rotation Results)**

*Pg_Angle.sys* is created by NPGS when the Global Correction mode or the user-control stage mode is used. There are two different formats for the file. The first format contains only one line with the first value being the rotation between the stage coordinates and the sample coordinates in radians as shown (everything after the first value is ignored):

```
0.785398 Global Rotation Angle (Radians) for Stage
```
The second format contains four lines listing the parameters of a 2x2 transformation matrix to convert from sample coordinates to stage coordinates. The transformation matrix for a simple rotation of 30° is shown below (everything after the first value in each line is ignored):

\[
\begin{array}{c}
0.866025 & \text{Global Rotation Matrix Element A} \\
-0.500000 & \text{Global Rotation Matrix Element B} \\
0.500000 & \text{Global Rotation Matrix Element C} \\
0.866025 & \text{Global Rotation Matrix Element D}
\end{array}
\]

If the requested stage motion in sample coordinates is \((x, y)\), the offset sent to the stage will be \((x', y') = (Ax + By, Cx + Dy)\). When reading an existing "Pg_Angle.sys" file, NPGS will automatically determine if the file contains a simple rotation or a full matrix.

This system files contains parameters that are not normally modified by the user and/or the file will only be created when the corresponding feature is used. However, if needed, from within the NPGS Menu program, "Options - System Files - System File Editor" can be used to edit this file.

**Pg_Focus.sys (X-Y-Focus Results)**

*Pg_Focus.sys* is created by NPGS when the X-Y-Focus mode is used. The file has four lines. The first three lines contain the A, B, and C parameters of the fit to the focus data, i.e., \(\text{focus} = Ax + By + C\). The fourth line contains the number of X-Y-Focus points collected by the user when the fit was calculated.

\[
\begin{array}{c}
0.00008432 & \text{Focus Parameter A (Focus=Ax+By+C)} \\
-0.00012033 & \text{Focus Parameter B} \\
120.17831 & \text{Focus Parameter C} \\
5 & \text{Number of Data Points}
\end{array}
\]

For more information, see X-Y-Focus Mode (page 170).

This system files contains parameters that are not normally modified by the user and/or the file will only be created when the corresponding feature is used. However, if needed, from within the NPGS Menu program, "Options - System Files - System File Editor" can be used to edit this file.

**Other Files in each Project**

**Files for NPGS**

**Pg_Menu_Start.bat and Pg_Menu_End.bat**
The *Pg_Menu_Start.bat* and *Pg_Menu_End.bat* files are optional files that will be executed by Menu.exe whenever a project in which they exist is entered or left, respectively. If the files by the same names exist in \NPGS\Projects, then they will executed whenever Menu.exe is started or terminated, respectively.

It is recommended to have the following command listed in the file \NPGS\Projects\Pg_Menu_Start.bat":

\`
\NPGS\Program\NPGS  !CalCheck
```

The command listed above will cause NPGS.exe to check if the NPGS PCI516 board used with NPGS v9 or higher needs to be recalibrated based on the auto calibration timing value in *Pg_Auto.sys*. If the time since the last calibration is longer than the value in *Pg_Auto.sys*, the auto calibration routine for the board will be run.

**Pg_Menu.sys**
The *Pg_Menu.sys* file is the main configuration file for the NPGS Menu program, which is customized, for each project directory. The parameters in this file are all set within the NPGS Menu program and
there is seldom any need to modify it directly. If this file gets corrupted within a project directory, a replacement file can be copied from "NPGS\Projects" or another project directory.

*In fact, to copy all of the settings from one project to another, including the custom commands, you can simply copy this file from the current project to another project.* Note that copying the file to the current project will not produce the desired results.

**Project.log**  
The Project.log file will contain a running log of all exposures made by NPGS for the current project. The default behavior is to log the date, time, project, run file, and command options for every exposure. When the NPGS Auto Log feature is used, the parameters defined in Pg_Log_Pre.sys will be automatically appended to the log file after the default parameters. If the user manually runs Pg_Log_Pre.sys or Pg_Log_Post.sys from the "File - Log Files..." menu, these parameters will also be appended to the Project.log file.  For more information, see Auto Logging Mode (page 142).

**Pg_Popup.txt**  
The Pg_Popup.txt file is used to check if the introductory startup screen should be displayed each time the NPGS Menu program is launched. If this file is not found, the startup screen will be displayed and the file will be created. The file is only checked in the project that is initially opened when the Menu program starts. To reactivate the startup screen for a project, delete this file from the project directory.

**Pg_UseAlign.txt**  
When a run file that contains alignment entities is processed in the Non-Stop mode by NPGS.exe, before any writing begins, the Pg_Align.sys file from any previous alignments will automatically be deleted to avoid starting with an invalid alignment. To disable this feature, simply create a file in the current project called "Pg_UseAlign.txt". When this file is present, Pg_Align.sys will never be deleted by NPGS.exe.

**Pg_Log.def**  
The Pg_Log.def file is the default definition file for the NPGS Auto Logging feature. If any changes are made to this definition file, the appropriate changes must also be made to the system files referenced within the definition file. *Note that the user is encouraged to customize this file and the referenced system files to provide the best documentation for each application.* For more information, see Auto Logging Mode (page 142).

**%PGCMD???.bat**  
These batch files are created when the NPGS Command feature is used in the DOS Batch mode. The ?? will be replaced with the number of the Command Entity from the run file.

**%PGCMD???.wsf**  
These script files are created when the NPGS Command feature is used in the Windows Scripting mode (with either WScript or CScript). The ?? will be replaced with the number of the Command Entity from the run file.

**%PGCMT???.txt**  
These text files are created when the NPGS Comment feature is used. The ?? will be replaced with the number of the Comment Entity from the run file.

**%pg_beam.tmp**  
The %pg_beam.tmp file is created by the automated beam reading feature. For more information, see Automated Beam Current Reading (page 145).

**%PG_IO.tmp**  
The %pg_io.tmp file is a temporary file that may be used for communicating between NPGS and an external program. There are four cases where external programs can be used with "%pg_io.tmp". Two of them are defined in "Pg_Cmd.sys" and they are the drivers for focus control and microscope control. The third is used for automated stage control as defined in "Pg_Stg.sys". The fourth program is defined in "Pg_Beam.sys", which is the external driver used for Faraday cup control and/or external reading of the beam current.
In all cases, whenever NPGS calls one of the above external programs, in addition to passing parameters on the program command line, NPGS will also save the parameters to the file "$pg_io.tmp". If the external program is unable to accept parameters passed on the command line, it can simply read this file instead. Also, whenever an external program is expected to return one or more values to NPGS, it may optionally save the values on separate lines in the file "$pg_io.tmp". NPGS will first try to read any values returned in the normal fashion and if no valid values are found, it will then read "$pg_io.tmp".

Note that NPGS, PG, and AL will also create other temporary files with names in the format of "%____.tmp". These files will be created and delete as necessary and do not have parameters that are to be modified by the user.

**Files for DesignCAD v21E**

A unique copy of each of the following files will be maintained in each project directory. When the NPGS Menu program starts DesignCAD Express v21.2, it will automatically use these files from the current project directory and will ensure that any changes made within DesignCAD Express v21.2 will be saved back to the correct project directory. While most of these files will never be directly modified by the user, the following list may be helpful if files within a project are ever accidentally deleted or corrupted.

**NPGS_DC21E_RefreshFiles.txt**
The file isn’t actually used by DesignCAD. Instead, if this file is missing from the current directory, the NPGS Menu program will copy all of these files from the \NPGS\Projects directory. If this file is missing from the \NPGS\Projects directory, the NPGS Menu program will copy all files from the directory: \NPGS\Program\Backups\DC_21Exp. The list of files copied by the NPGS Menu program is kept in \NPGS\Program\NPGS_DC21e_FileList.txt.

**NPGS_DC21E_REGISTRY.reg**
The NPGS_DC21E_REGISTRY.reg file is a copy of the DesignCAD Express v21.2 registry that is kept in each project. Certain DesignCAD parameters, such as the recent file list, are maintained in the Windows Registry and this file allows each project to have a unique setup.

**NPGS_DC21E_WORKSPACE(Default).dws**
The NPGS_DC21E_WORKSPACE(Default).dws file is a binary file that contains the parameters found under the DesignCAD “File - Workspace” option. The parameters in this file are set from within DesignCAD and the file should NOT be directly modified by the user. From within DesignCAD, the box to use the default DesignCAD workspace template should always have a check mark.

**NPGS_DC21E_NPGS_Menu1.dma**
The NPGS_DC21E_NPGS_Menu1.dma file is an ASCII file that defines the DesignCAD Custom Menu for use with NPGS. The parameters in this file are set from within DesignCAD, but can be modified in Notepad. It is unlikely that a user would ever need to directly modify this file. Incorrect data in this file may disable parts of the pull down menu within DesignCAD.

Other files are listed below. These will normally only be modified through DesignCAD:
Customizing the System

Other Files in each Project

- NPGS_DC21E_AdInit.sys
- NPGS_DC21E_cmdlist.ini
- NPGS_DC21E_custom.ini
- NPGS_DC21E_DC_AutoSave.ini
- NPGS_DC21E_DC_Color.ini
- NPGS_DC21E_DC_Command.ini
- NPGS_DC21E_DC_Dimension.ini
- NPGS_DC21E_DC_Draw.ini
- NPGS_DC21E_DC_FilePath.ini
- NPGS_DC21E_DC_General.ini
- NPGS_DC21E_DC_Grid.ini
- NPGS_DC21E_DC_Layer.ini
- NPGS_DC21E_DC_ListItem.ini
- NPGS_DC21E_DC_PaperSpace.ini
- NPGS_DC21E_DC_Print.ini
- NPGS_DC21E_DC_Startup.ini
- NPGS_DC21E_DC_Text.ini
- NPGS_DC21E_DC_Toolbar.ini
- NPGS_DC21E_DCShape.sys
- NPGS_DC21E_DcCursorC.sys
- NPGS_DC21E_DcExpCmd.ini
- NPGS_DC21E_DceXpkey.ini
- NPGS_DC21E_DcHatch.sys
- NPGS_DC21E_DcHatchc.sys
- NPGS_DC21E_DcScheme.sys
- NPGS_DC21E_DcScheme.sys
- NPGS_DC21E_DcLStyle.sys
- NPGS_DC21E_Encrypt.ini
- NPGS_DC21E_LangExt.ini
- NPGS_DC21E_Macrocmd.ini
- NPGS_DC21E_Multiline.sys
- NPGS_DC21E_Plotter.dat
- NPGS_DC21E_ShapeAlphabet.sys
- NPGS_DC21E_NPGS_Keyboard1.dkf
- NPGS_DC21E_NPGS_Tools1.dct
- NPGS_DC21E_NPGS_Tools2.dct

Files for DesignCAD v16E

A unique copy of each of the following files will be maintained in each project directory. When the NPGS Menu program starts DesignCAD Express v16.2, it will automatically use these files from the current project directory and will ensure that any changes made within DesignCAD Express v16.2 will be saved back to the correct project directory. While most of these files will never be directly modified by the user, the following list may be helpful if files within a project are ever accidentally deleted or corrupted.

NPGS_DC16E_RefreshFiles.txt
The file isn’t actually used by DesignCAD. Instead, if this file is missing from the current directory, the NPGS Menu program will recopy all of these files from the \NPGS\Projects directory. If this file is missing from the \NPGS\Projects directory, the NPGS Menu program will copy all files from the directory: \NPGS\Program\Backups\DC_16Exp. The list of files copied by the NPGS Menu program is kept in \NPGS\Program\NPGS_DC16e_FileList.txt.

NPGS_DC16E_REGISTRY.reg
The NPGS_DC16E_REGISTRY.reg file is a copy of the DesignCAD Express v16.2 registry that is kept in each project. Certain DesignCAD parameters, such as the recent file list, are maintained in the Windows Registry and this file allows each project to have a unique setup.

NPGS_DC16E_WORKSPACE(Default).dws
The NPGS_DC16E_WORKSPACE(Default).dws file is a binary file that contains the parameters found under the DesignCAD "File - Workspace" option. The parameters in this file are set from within
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DesignCAD and the file should NOT be directly modified by the user. *From within DesignCAD, the box to use the default DesignCAD workspace template should always have a check mark.*

**NPGS_DC16E_NPGS_Menu1.dma**
The *NPGS_DC16E_NPGS_Menu1.dma* file is an ASCII file that defines the DesignCAD Custom Menu for use with NPGS. The parameters in this file are set from within DesignCAD, but can be modified in Notepad. It is unlikely that a user would ever need to directly modify this file. Incorrect data in this file may disable parts of the pull down menu within DesignCAD.

Other files are listed below. These will normally only be modified through DesignCAD:

- NPGS_DC16E_AdInit.sys
- NPGS_DC16E_cmdlist.ini
- NPGS_DC16E_custom.ini
- NPGS_DC16E_DC_AutoSave.ini
- NPGS_DC16E_DC_Color.ini
- NPGS_DC16E_DC_Command.ini
- NPGS_DC16E_DC_Dialog.ini
- NPGS_DC16E_DC_Dimension.ini
- NPGS_DC16E_DC_Draw.ini
- NPGS_DC16E_DC_FilePath.ini
- NPGS_DC16E_DC_General.ini
- NPGS_DC16E_DC_Grid.ini
- NPGS_DC16E_DC_Layer.ini
- NPGS_DC16E_DC_PaperSpace.ini
- NPGS_DC16E_DC_Print.ini
- NPGS_DC16E_DC_Startup.ini
- NPGS_DC16E_DC_Toolbar.ini
- NPGS_DC16E_DcCursorC.sys
- NPGS_DC16E_DcExpCmd.ini
- NPGS_DC16E_DCEXPKEY.INI
- NPGS_DC16E_DcLStyle.sys
- NPGS_DC16E_DcScheme.sys
- NPGS_DC16E_DCShape.sys
- NPGS_DC16E_Encrypt.ini
- NPGS_DC16E_LangExt.ini
- NPGS_DC16E_Multiline.sys
- NPGS_DC16E_NPGS_Keyboard1.dkf
- NPGS_DC16E_NPGS~Tools1.dct
- NPGS_DC16E_NPGS~Tools2.dct
- NPGS_DC16E_ShapeAlphabet.sys

**Files for DesignCAD LT2000**
A unique copy of each of the following files will be maintained in each project directory when *DesignCAD LT 2000* is installed. When the NPGS Menu program starts DesignCAD LT2000, it will automatically use these files from the current project directory and will ensure that any changes made within DesignCAD LT2000 will be saved back to the correct project directory. While most of these files will never be directly modified by the user, the following list may be helpful if files within a project are ever accidentally deleted or corrupted.

**NPGS_DC_REGISTRY.reg**
The *NPGS_DC.REGISTRY.reg* file is a copy of the DesignCAD LT2000 registry that is kept in each project. Certain DesignCAD parameters, such as the recent file list, are maintained in the Windows Registry and this file allows each project to have a unique setup. If this file is missing from the current directory, the NPGS Menu program will recopy all of these files from the \NPGS\Projects directory. If this file is missing from the \NPGS\Projects directory, the NPGS Menu program will copy all files from the directory: \NPGS\Program\Backups\DC_LT2000.
DCADLT.ini
The DCADLT.ini file is the main initialization file for DesignCAD LT. Most of the parameters in this file will be set from within DesignCAD, however, some of the "Startup Settings" must be changed manually. For use with NPGS, the "Disable3DMode" parameter should always be initialized to 1 (one).

DCLTCMD.ini
The DCLTCMD.ini file is the primary DesignCAD Command Customization File. It is unlikely that a user would ever need to directly modify this file. Incorrect data in this file may disable basic functions within DesignCAD.

DCLTKEY.ini
The DCLTKEY.ini file is the secondary DesignCAD Command Customization File. This is where the NPGS BasicCAD programs (found on the NPGS menu within DesignCAD) are defined. It is unlikely that a user would ever need to directly modify this file. Incorrect data in this file may disable functions on the NPGS menu within DesignCAD.

NPGS_DC_TOOLS1.dct
The NPGS_DC_Tools1.dct file is an ASCII file that defines the commands in the user’s custom toolbox within DesignCAD. The parameters in this file are set from within DesignCAD. It is unlikely that a user would ever need to directly modify this file. Incorrect data in this file may disable custom toolbox commands within DesignCAD.

NPGS_DC_MENU1.dma
The NPGS_DC_Menu1.dma file is an ASCII file that defines the DesignCAD Custom Menu for use with NPGS. The parameters in this file are set from within DesignCAD. It is unlikely that a user would ever need to directly modify this file. Incorrect data in this file may disable parts of the pull down menu within DesignCAD.

NPGS_DC_KEYBOARD1.dkf
The NPGS_DC_Keyboard1.dkf file is an ASCII file that defines the DesignCAD Keystroke Command. The parameters in this file are set from within DesignCAD. It is unlikely that a user would ever need to directly modify this file.

NPGS_DC_WORKSPACE1.dws
The NPGS_DC_Workspace1.dws file is a binary file that contains the parameters found under the DesignCAD “File - Workspace” option. The parameters in this file are set from within DesignCAD and the file should NOT be directly modified by the user. From within DesignCAD, the box to use the default DesignCAD LT2000 workspace template should always have a check mark.

Files for DesignCAD 6.1
A unique copy of each of the following files will be maintained in each project directory. When the NPGS Menu program starts DesignCAD 6.1, it will automatically use these files from the current project directory and will ensure that any changes made within DesignCAD 6.1 will be saved back to the correct project directory. While most of these files will never be directly modified by the user, the following list may be helpful if files within a project are ever accidentally deleted or corrupted.

DCCAD2.sys
This is an ASCII file containing initialization parameters for DesignCAD 6.1. The parameters in this file are all set within DesignCAD and there is no need to modify it directly.

NPGS.bsc
This is a BasicCAD file that is run every time DesignCAD 6.1 is started. Some initialization commands for DesignCAD 6.1 must be defined here.

Master Files
This master set of files is located in "\NPGS\Projects\" and is used when a new project is created or when replacing a corrupt file in an existing project. Care should be taken when changing these files, since they may affect other users!
Customizing the System

**PG_*.sys**
These are the master set of system files that are used whenever a new project is created. Typically, the only time the user will modify one of these files is to make sure that the correct "mag scale" parameter is entered in Pg.sys.

**NPGS_Master.log**
The NPGS_Master.log file will contain a running log of all exposures made by NPGS. The default behavior is to log the date, time, project, run file, and command options for every exposure.

**Pg_Menu_Start.bat and Pg_Menu_End.bat**
These are optional files that will be executed whenever Menu.exe is started or terminated, respectively. If the files by the same names exist in a project directory, then they will be executed by Menu.exe whenever a project in which they exist is entered or left, respectively.

**Pg_Log.def**
The Pg_Log.def file is the default definition file for the NPGS Auto Logging feature, which is used whenever a new project is created. If any changes are made to this definition file, the appropriate changes must also be made to the system files referenced within the definition file, which are typically "pg_edit_pre.sys" (for Pre-Write parameters) and "pg_edit_post.sys" (for Post-Write parameters).

**DC*.ini**
These are the master set of initialization files for DesignCAD LT2000 that are used whenever a new project is created.

**NPGS_DC21E_*.***
These are the master set of customization files for DesignCAD Express v21.2 that are used whenever a new project is created. These files will automatically be copied by Menu.exe from \NPGS\Program\Backups\DC_21Exp if DesignCAD Express v21.2 is installed.

**NPGS_DC16E_*.***
These are the master set of customization files for DesignCAD Express v16.2 that are used whenever a new project is created. These files will automatically be copied by Menu.exe from \NPGS\Program\Backups\DC_16Exp after DesignCAD Express v16.2 is installed.

**NPGS_DC_*.***
These are the master set of customization files for DesignCAD LT2000 that are used whenever a new project is created. These files will automatically be copied by Menu.exe from \NPGS\Program\Backups\DC_LT2000 if DesignCAD LT2000 is installed.

***.exe**
Any user executables that are to be called by NPGS should be copied to this directory. This includes programs for automated stages, digital microscopes, IEEE picoammeters, as well as any other programs listed in Pg_Cmd.sys. When writing and/or aligning patterns, NPGS will first try to run programs from \NPGS\Projects, and if they are not found in that directory, they must be available in a directory listed in the "PATH" statement of the operating system.

**Miscellaneous Files**

**Pg_Pause.exe**
This program is useful within batch programs, since it provides more flexibility than the standard "pause" command. See Pg_Pause.txt for an example of how to use this program within user defined batch files. The program is located in "\NPGS\Projects" and should be referenced by its full path name when run within batch files.

The command line options are as follows:

```
Pg_Pause ? ............................................ displays help information and can create sample batch file to demonstrate the use of ERRORLEVEL switching based on user response
```
Customizing the System

Pg_Pause [no argument] ......................... will prompt for Yes/No response
Pg_Pause [delay > 0] ......................... will give Yes/No prompt and wait for delay seconds
before continuing
Pg_Pause [delay >0] [a] ......................... will prompt for any key and wait for delay seconds before
continuing
Pg_Pause [delay < 0] ......................... will wait for delay without any prompt

Pg_Pause.exe will return ERRORLEVEL=1 for Yes and ERRORLEVEL=2 for No. The maximum
delay time is 600 seconds.

Tune.exe
This is a program that can play five simple tunes. The basic use is “tune #” where # can be one to
five to select the tune and any fractional part will set the speed. For example, “tune 2.9” will play tune
2 very slowly, while “tune 2.1” will play it very quickly. For use with Windows 7, the PlayWav.bat file
listed below is recommended for playing sounds.

Another option is that if the # is preceded by a plus sign (+), the window will be make active, if it was
currently minimized. Since NPGS runs some batch files as minimized by default, this can be used to
automatically restore them. Similarly, if the # is preceded by a negative sign (-), the window will be
minimized. If the # is zero, the + and – will still work, but no tune will be played.

If tune.exe is called with two arguments, the second will be a repeat time. For example, if you want
NPGS to pause and wait for user input during some command sequence, the command “tune 2 20”
would cause the second tune to play every 20 seconds until the user hits a key. This option has a
repeat time from 1 to 600 seconds. This mode automatically restores a minimized window.

PlayWav.bat
This is a batch file that makes it easy to use Wav.exe to play user defined wav files within NPGS. The
default settings will play either a chime or the ring of a traditional telephone. For example, “PlayWav 2
3” will play the telephone ring three times. This command and similar commands can be entered for
the notification commands listed in Pg_Cmd.sys. PlayWav.bat and Wav.exe are compatible with
Windows 7.

Wav.exe
This is a program that can play nearly any Windows compatible sound file. This program can be used
to replace the simple tune commands found in “Pg_Cmd.sys” or it can be used within batch files
called by NPGS. The program is located in “\NPGS\Projects\” and should be referenced by its full
path name when included in a batch program, but the full path is not needed when used in the
Pg_Cmd.sys commands. This program is “freeware” and is distributed with the “wav.txt” file that
describes its use.

PDF_ExePath.txt
This is a text file that is created to hold the full path to the Adobe software for displaying PDF files.
When NPGS is run in Administrator mode, this file will be created when the PDF version of the NPGS
Manual is viewed. Once this file is created, it will be used when NPGS is run in a non-Administrator
mode.

Windows Explorer.lnk
This is a shortcut to the Windows Explorer program that shows how to have Explorer start in a
specified directory. To use this shortcut, copy it to the Windows desktop. The shortcut is found in
“\NPGS\Temp\”.

*.bmp
These are bitmaps that can be used as the Windows Desktop background. The files are located on
the original NPGS Installation CD in the directory “\NPGS_Background_Files” and can be copied to
the main Windows directory for use, i.e., C:\Windows or C:\WinNT.

NPGS Configuration Files
This set of configuration files is located in “\NPGS\Program\”. Other files including the main NPGS
executables are also located in this directory and should not be changed.
Parameters in the following files affect all project directories and should NOT be modified by the user, unless indicated below.

**PG_SETUP.sys**
This is the main setup file for the NPGS Menu program. This file contains the error messages, menu labels, button labels, and prompts displayed within the NPGS Menu program.

**PG_PRJDIR.sys**
This file contains the names of all project directories used within the NPGS Menu program. It will automatically be updated as needed by the NPGS Menu program.

If a project directory is accidentally removed from the project list, it can be added back to the NPGS project list by modifying this file using the format:

"C:\092NPGS\092Projects\092Samples\092".

*Alternately, if an existing project directory is not shown in the project list within the NPGS Menu program, the "Project - Create" command can be used and NPGS will present the option to overwrite the system files in the project or to use the existing system files in the project, if a complete set is present.*

**PG_PRJSAV.sys**
This is a backup version of Pg_PrjDir.sys. It will automatically be used by the NPGS Menu program, if Pg_PrjDir.sys is detected to be corrupt. If the user finds that projects are missing from the Project List in the NPGS Menu program, this file can manually be copied over the Pg_PrjDir.sys file.

**PG_STARTPRJ.sys**
This file contains the name of the default project to be used when the NPGS Menu program starts. It will automatically be updated as needed by the NPGS Menu program.

**DC_OPEN.sys**
This file contains the parameters that define which file formats will be displayed when the NPGS File Open command is used within DesignCAD. Normally, this file will not be modified by the user, however, if GDSII or CIF files with extensions besides those which are predefined are routinely used, it may be convenient to add them to the lists contained in this file. In that case, the user will also need to modify the "NPGS_Open.bsc" file, so that files with the new extensions are automatically converted to the DesignCAD 2D format.

**PG_EDIT*.def**
These files define how the PG_EDIT program will handle the various system files that can be edited by the user. The file "Pg_Edit0_Master.def" contains the file definitions for the main NPGS system files. Other "Pg_Edit*.def" files may be present that contain file definitions for other files that can be edited using PG_EDIT.exe. These definition files are very powerful in that they define parameter types, ranges, and lengths, in addition to providing on line help for each item.

The supplied "Pg_Edit*.def" definition files that reside in \NPGS\Program should NOT be changed, however, new definition files can be created within each project if it would be convenient to edit custom defined files within the NPGS Menu program. For example, if a custom stage is made for the microscope, it would be easy to create a definition file that would allow a system file containing operational parameters for the stage to be edited by PG_EDIT.

**DesignCAD Files**

**DesignCAD Express v21.2**
DesignCAD Express v21.2 must be installed in the directory "\NPGS\DC21Exp". Additional sub-directories may contain other DesignCAD files, such as fonts and sample drawings, however, NPGS only directly accesses the files in the top directory. The DesignCAD settings for each project are kept in the project itself, so there is no need to modify any files in the main DesignCAD directory.
The BasicCAD programs supplied with NPGS for use with DesignCAD Express v21.2 are kept in the directory "\NPGS\BasicCAD\DC21E". If the user wishes to add BasicCAD programs, they may be copied to this directory for use by all projects or they may be kept in an specific project.

Backups of the files for DesignCAD Express v21.2 are located in:
\NPGS\Program\Backups\DC_21Exp
These files will automatically be copied by the NPGS Menu.exe program when the "NPGS_DC21E_RefreshFiles.txt" file is missing.

**DesignCAD Express v16.2**
DesignCAD Express v16.2 must be installed in the directory "\NPGS\DC16Exp". Additional sub-directories may contain other DesignCAD files, such as fonts and sample drawings, however, NPGS only directly accesses the files in the top directory. The DesignCAD settings for each project are kept in the project itself, so there is no need to modify any files in the main DesignCAD directory.

The BasicCAD programs supplied with NPGS for use with DesignCAD Express v16.2 are kept in the directory "\NPGS\BasicCAD\DC16E". If the user wishes to add BasicCAD programs, they may be copied to this directory for use by all projects or they may be kept in an specific project.

Backups of the files for DesignCAD Express v16.2 are located in:
\NPGS\Program\Backups\DC_16Exp
These files will automatically be copied by the NPGS Menu.exe program when the "NPGS_DC16E_RefreshFiles.txt" file is missing.

**DesignCAD LT2000**
DesignCAD LT2000 can be installed in the directory "\NPGS\DC2000LT". Additional sub-directories may contain other DesignCAD files, however, NPGS only directly accesses the files in the top directory. The DesignCAD settings for each project are kept in the project itself, so there is no need to modify any files in the main DesignCAD directory.

The BasicCAD programs supplied with NPGS for use with DesignCAD LT2000 are kept in the directory "\NPGS\BasicCAD\LT2000". If the user wishes to add BasicCAD programs, they may be copied to this directory for use by all projects or they may be kept in an specific project.

Backups of the files for DesignCAD LT2000 are located in:
\NPGS\Program\Backups\DC_LT2000

**DesignCAD DOS**
The latest version of NPGS also supports DesignCAD 2D versions 6.0 and 6.1 for DOS. While all new NPGS installations will exclusively use the Windows version of DesignCAD, for maximum compatibility, upgraded systems may continue to use the DOS DesignCAD. On an upgraded system, DesignCAD 2D for DOS will be left in the original directory, which will be named "\DC6". The DesignCAD settings for each project are kept in the project itself, so there is no need to modify any files in the main DesignCAD directory.

The BasicCAD programs supplied with NPGS for use with DesignCAD for DOS are kept in the directory "\NPGS\BasicCAD\DC6". If the user wishes to add BasicCAD programs, they may be copied to this directory for use by all projects.

Backups of the files for DesignCAD for DOS are located in:
\NPGS\Program\Backups\DC_V60 (for DesignCAD v6.0)
\NPGS\Program\Backups\DC_V61 (for DesignCAD v6.1)

**Help Files**
This set of help files is located in "\NPGS\Program\" unless otherwise noted.

**NPGS Manual.chm**
The NPGS Manual.chm file contains the NPGS User's Manual in the Microsoft Help HTML 1.2 format. This file can be viewed from within the NPGS Menu program under the Help menu.
NPGS_Manual.pdf
The NPGS_Manual.pdf file contains the NPGS User’s Manual in the PDF file format. This file can be viewed from within the NPGS Menu program under the Help menu, if a reader program is associated with the pdf file format in Windows. If a printed manual is desired, this file can be printed using the free Adobe PDF Reader software. A link to the Adobe download page is provided at "www.jcnability.com/download.htm".

NPGS_Manual.hlp
The NPGS_Manual.hlp file contained the NPGS User's Manual in the older Microsoft WinHelp format, but has been replaced by the PDF version.

NPGS_Prompt.hlp
This file contains the information displayed by the "What’s This" prompt within the NPGS Menu program and the Run File Editor.

NPGS_Pg_Edit.hlp
This file contains the information displayed by the "What’s This" prompt within the NPGS System File Editor.

NPGS_DC21e_FileList.txt
This file contains the list of files that are copied between each user’s project and the \NPGS\DC21Exp directory when using DesignCAD Express v21.2. Normally, the files in this list should not be changed. The exception can be if another custom toolbox is to be added to DesignCAD Express v21.2. For example, two custom toolboxes, NPGS_Tools1.dct and NPGS_Tools2.dct are already included.

NPGS_DC16e_FileList.txt
This file contains the list of files that are copied between each user’s project and the \NPGS\DC16Exp directory when using DesignCAD Express v16.2. Normally, the files in this list should not be changed. The exception can be if another custom toolbox is to be added to DesignCAD Express v16.2. For example, two custom toolboxes, NPGS_Tools1.dct and NPGS_Tools2.dct are already included.

NPGS_DC.hlp
This is file contains the NPGS User's Manual for DesignCAD LT2000 in the standard Microsoft Help format. This file can be launched from within DesignCAD LT2000 using the "NPGS - Help" option or by double clicking from within Windows Explorer.

DCADLT.ann
This file contains the NPGS Annotations that are found in the DesignCAD LT2000 help documentation under the paperclip icon. This file is normally saved as read only to prevent any changes from being made, however, if the read only setting is cleared, the annotations within the DesignCAD LT2000 help can be modified. Note that DesignCAD LT2000 will only access a copy of this file that is located in the Windows default help directory, i.e., "C:\Windows\Help" for Win 95/98. If the NPGS annotations are not displayed within the DesignCAD LT2000 help, you should copy the "DcadLT.ann" file from "\NPGS\Program\Backups\DC_LT2000" to the appropriate Windows Help directory.

Temporary Files
These files are located in "\NPGS\Temp".

*.dc2
These files are backups of pattern files that have been processed by the BasicCAD programs under the "NPGS" menu in DesignCAD. *If a pattern file is corrupted during processing, the original file can be copied from this directory.*

*.tmp
These are temporary files used to ensure that the NPGS Menu program, BasicCAD programs, CIF & GDSII conversion programs, and DC_Open all know what is currently being processed. The user should never change these files.
%testaccess.tmp
This file is used to confirm that the current Windows login has the necessary file access privileges to read and write files in key directories within NPGS. Normally, this file will be deleted after each use.

%MenuLog.tmp
This file will be created every time Menu.exe is run. It will contain diagnostic information regarding the operation of Menu.exe.

%pg_image.tmp
This file is created by Pg_Image.exe when acquiring an image. Pg_Image has two modes for image acquisition where one mode works best for single core processors and the second mode works best for newer dual core processors. When the single core mode is used on a dual core CPU, the scanning process may have multiple scanning errors which can slow down the acquisition. The first line of the %pg_image.tmp file will show the number of errors in the last scan in the single core mode and the second line will show the image size. Whenever Pg_Image starts, it reads the %pg_image.tmp file and if the error number is too large, the dual core mode will automatically be used. This arrangement allows Pg_Image to dynamically adjust to the best mode for the current CPU.

gds_dc2*.*
These temporary files are created by the GDSII Conversion program.

cif_dc2*.*
These temporary files are created by the CIF Conversion program.
Hardware

SEM Input Connectors

About half of the microscopes used for lithography have BNC inputs and do not require any other input adapter, while on other microscopes, the XY inputs will be in a multiple pin input connector. For the common models using this arrangement, an adapter will be provided with NPGS to convert from the multiple pin connector to BNC inputs. BNC to SMA cables will be needed to connect NPGS to the BNC inputs.

When another external system, such as WDS or EDS for X-ray analysis, also needs to control the beam position, an issue of sharing a single XY input can arise. In this case, either the cable(s) from NPGS and the other system must be manually swapped, a manual switch must be installed to select the system to access the XY inputs, or an SEM Input Relay Adapter will be required. The SEM Input Relay Adapter will allow NPGS and the other system to simultaneously be connected and the controlling system can be selected by a flip of a switch. For most SEM models, this adapter can be purchased as an accessory with NPGS.

Note that a few models of SEMs will have multiple inputs for external systems.

In all cases, before doing lithography, the SEM must be switched from the normal internal scan generator to the external XY control. On most microscopes the external control will be enabled using a remote switch provided with NPGS (most JEOL and Hitachi models), however, some will be changed entirely through the SEM software (Philips/FEI XL30 series). A third category is when both a switch and software is used to enable the external control (LEO/Zeiss models).

Note that in addition to enabling the external control of the XY beam position, in most cases, the external control of the beam blanker must also be manually enabled. Typically, this is done using a switch on the control electronics for the blanker.

PCI516 Board (NPGS v9 or higher)

Calibrating the PCI516

The PCI516 board has a self-calibration feature that can be run manually using the "Commands - Calibrate DACs" option within the NPGS Menu program. This command will reset the board and then calibrate both the blanking on/off output voltages and the entire 16 bit range for both the x and y DAC outputs.

Every time the PC is rebooted, the PCI516 board’s self-calibration must be run to ensure that the DAC output ranges are properly set. Consequently, during the NPGS installation a shortcut in the Windows Startup directory will be added so that the calibration program will be run every time the PC is rebooted. (The shortcut is named ‘Initialize_PCI516.lnk’ and will be found in the ‘\NPGS\Projects’ directory and must be copied to the ‘C:\Documents and Settings\All Users\Start Menu\Programs\Startup\’ directory.) The board will be calibrated using the values in the Pg.sys file for the last project used.

After the initial calibration, the program will wait for a time (in minutes) listed in "\NPGS\Projects\Pg_Cal.txt" before calibrating the board a second time. This is to ensure that the PC has stabilized in temperature after a cold start. During this time, the PC can be used, however, patterns should not be written before the second calibration has completed.

If an error message is display during the self-calibration, see “Self-Calibration Failure (page 256)”.

Configuring the PCI516

Whenever handling the PCI516 board or cables connected to the board, ALWAYS use proper anti-static precautions, such as an anti-static wrist strap.
The PCI516 board has only three jumpers that may be manually set by the user. Installing the jumper "J420" will limit the frequency response of the ADC input on the SMA connector, while removing it will allow the maximum frequency response. For connections to the image signal from an SEM, the reduced frequency response is recommended. This jumper is installed when the board is shipped.

When installed, jumpers J9 and J13 set the output resistance of the X and Y DAC channels, respectively, to <0.5 ohms, and when removed, the output resistance is 50 ohms. These two jumpers are not installed when the board is shipped.

Jumpers J6 and J420 must always be installed.

All other configuration settings for the PCI516 are contained in the Pg.sys file. For more information, see Pg.sys (General System Parameters) (page 172).

**Connections to the PCI516**

**Whenever handling the PCI516 board or cables connected to the board, ALWAYS use proper anti-static precautions, such as an anti-static wrist strap.**

The PCI516 has four SMA connectors (Standard SMA, Coaxial Plug Receptacle, Kings # 875-9-1 or equivalent), with the functions as shown in the figure.

The PCI516A has a 34 pin high density connector (Standard 34-pin 0.050" Dual-ribbon socket connector; Robinson Nugent P50E-034-S-TG or equivalent). This connection is not used for NPGS and has been removed from the newer PCI516B version of the board.

**PCI516 DAC Outputs**

**Manual Control**

Manual control of the beam position while at a command prompt is achieved by using the program "\NPGS\Program\SetDACs" as described below. In addition, SetDACs has several advanced mode that are used by the NPGS software. **The X and Y DAC outputs are on the two middle SMA connectors, i.e., X is the third closest and Y is the second closest SMA connector to the 34 pin connector on the PCI516 board.**
SetDACs ...........returns the current DAC mode and range parameters
SetDACs r.........enters the SetRange mode to dynamically change output range

SetDACs v ..........sets DACs to x_range*v/10 volts and y_range*v/10 volts*
SetDACs x y .......sets DACs to x_range*x/10 volts and y_range*y/10 volts*
SetDACs x y a ......sets DACs to x volts and y volts (if within current output range)

SetDACs c..........blanks beam, calibrates DACs, and sets output to (0,0)
SetDACs C ..........does 'c' option and saves calibration time for use by NPGS
SetDACs I ..........does 'c' option, waits, then does 'C' option
SetDACs d ..........enters the diagnostic mode for the PCI516 board

*These values are scaled to the current output range and the xy_mirror parameter in Pg.sys. For example, if the board output ranges are set to ±3.6 volts for X and ±5.0 volts for Y, and the mirror parameter is set to invert the Y voltage (typical for FEI SEMs), using SetDACs 10 10 would produce the voltages of +3.6 on X and -5.0 on Y, which will put the beam in the upper right corner of the writing field. In other words, for the general use of SetDACs, the user doesn't need to know the specific output voltage ranges that are being used, but rather, simply that a value of (10,10) will move the beam to the upper right corner, (-10,-10) will move the beam to the lower left corner, and (0,0) is the center of the writing field. This approach gives the user easy control of the beam position within the writing field, while eliminates the need for the user to know the specifics of the calibration that their microscope requires.

Control of the DAC outputs is also available from within the NPGS Menu program using the "Commands - Set DACs" menu item, which uses the same "SetDACs" program.

XY Mirror
Since most microscopes require a mirror image in the X and/or Y input, SetDACs checks the system file "Pg.sys" in the current directory for the setting of the mirror parameter. The overall effect is that the output voltages will always produce a right-handed coordinate system on the CRT if the "xy mirror" parameter is properly set. For example, if a X mirror output is required, "SetDACs 5" will put -5 volts on X and +5 volts on Y.

DAC Output Voltage Range
The output range of the PCI516 used by NPGS is defined in the Pg.sys file. For more information, see Pg.sys (General System Parameters) (page 172).

Maximum DAC Output Current
The DAC outputs are limited to ±20 mA. When the output range is between ±5 volts they must be connected to at least 250Ω, and when the range is ±10 volts, they must be connected to at least 500Ω.

ADC Inputs
ADC Input
The 16 bit ADC inputs can read voltages within ±10 volts. The maximum input to the A/D converters must be within ±15 volts. The input range used by NPGS is defined in Pg.sys. For more information, see Pg.sys (General System Parameters) (page 172).

It has been observed that Zeiss FE SEMs can occasionally produce a voltage spike on their image output which can damage the PCI516A board. When using the PCI516A board with this type of SEM, a BNC surge suppressor should be installed between the SEM image output and the PCI516A image input. The 2nd generation PCI516B board has built in surge suppression on the ADC input.

NPGS uses a differential reading of the ADC on the SMA input connector to acquire the microscope image signal. The Image Input is the SMA connector farthest from the 34 pin connector on the PCI516A board or farthest from the empty area on the metal bracket on the PCI516B board.

The ADC input is used at a fixed rate of ~2.7 microseconds per conversion.
If a long BNC cable is used between the SEM and the NPGS adapter input, ringing may occur. In some cases, adding a 50 or 75 ohm terminator at the NPGS end can eliminate the ringing. Only add this terminator if you know it will not adversely affect the microscope.

A single jumper (J420) is installed on the PCI516 board to limit the frequency response of the ADC input. This is the recommended setting for use with the image signal from an electron microscope.

Blanker Control Connector (BCC)
The Blanking Control Connector output on the PCI516 board can be manually controlled using the program "\NPGS\Program\BCC" from a command prompt as described below. **The BCC is the SMA connector closest to the 34 pin connector on the PCI516 board.**

- BCC off ............... sets the BCC output to the beam-off state
- BCC 0 .................. sets the BCC output to the beam-off state
- BCC on ................. sets the BCC output to the beam-on state
- BCC 1 .................. sets the BCC output to the beam-on state

Control of the BCC output is also available from within the NPGS Menu program using the "Commands - Set Blanker" menu item, which uses the same BCC program.

If a blanker in use with NPGS does not have a manual override switch, under Windows 95/98, desktop icons called "Beam On" and "Beam Off" can be made to directly run "BCC 1" and "BCC 0". This allows the blanker to easily be controlled without entering the NPGS Menu program or a DOS window. **Alternately, from within the NPGS Menu program, two of the Custom Command buttons can be set to turn the beam on and off for easy control of the state of the beam.**

The PCI516 BCC output is optimized for a blanker input impedance between 50 and 100 ohms (up to ~300 ohms will also give acceptable performance). If the blanker input has high impedance, ringing may result, especially if a long cable is used between the BCC and the blanker input. If the blanker input does not have an adjustable input resistance, the best approach is to measure the input resistance and use a "tee" and a terminator that will give 50 to 100 ohms when in parallel with the blanker. If a terminator cannot easily be connected at the blanker input, an SMA/SMA inline 50 or 75 ohm terminator can be used at the output of the BCC.

The actual voltages of the on/off states are defined in Pg.sys. For more information, see Pg.sys (General System Parameters) (page 172).

Advanced PCI516 Register Information
In the case of a board malfunction, the “Help – Hardware Diagnostics” menu item in the NPGS Menu program can be used to access a low level diagnostic program for the PCI516 board. When the board is working properly and is in a standby state, the register listing will typically be as follows:
Note that the Board Control register should be 0x3808 when the board is idle. The other values may vary depending on the parameters in the Pg.sys file and on the last use of the board.

If all values are reported as 0xFFFFFFFF, it can indicate that the board is not properly seated in the PCI slot.

**Advanced PCI516 Component Information**

The information presented here is not required for normal use of the board.

The PCI516 has 7 sockets to allow easy updates, if needed. Each socket number and function is described below:

- **U50** - This contains the Master Clock.
- **U44** - This holds the 100 series firmware.
- **U63** - This holds the 200 series firmware.
- **U60** - This holds the 300 series firmware.
- **U57** - This holds the 400 series firmware.
- **U59** - This holds the 500 series firmware.
- **U56** - Empty.
Error Messages

Errors: NPGS Menu program

The following error message may be displayed by the NPGS Menu program. Most messages will be self-explanatory, while others will have additional information listed below.

"NPGS Menu: Run-time error ‘x’

This error message indicates that the Menu program has terminated due to an unexpected error. Please report the conditions which reproduce this error, so that it can be resolved.

"nvtdm.exe" error

This Windows error may be seen when a Custom Command uses the ‘Batch: Full Screen’ mode when running under Windows 7.

"Menu Initialization Error"

"The NPGS Menu program is already running! Please use the Windows Start Bar to access the program."

Only one copy of the NPGS Menu program can be run at once. If this error message is encountered when Menu.exe is not running, then the file "\NPGS\Temp\NpgsMenuRunning.tmp" must be deleted, which will then allow Menu.exe to run.

"Menu(A180) Exit Prompt"

"DesignCAD and/or NPGS writing functions are currently active. These processes must be terminated before you can exit the NPGS Menu program."

The NPGS Menu program should not be terminated if DesignCAD or any writing functions are still active. You may use the Windows "Start Bar" to access any active programs. Sometimes, this warning will be displayed if the functions have been terminated in the previous second or two. In that case, simply click the exit command again.

"Menu(A187) NPGS Integrity Check: Delete/Rename Warning!"

"Deleting or Renaming 'filename' may prevent NPGS from running properly! Do you really know what you are doing???

The warning is to prevent you from deleting or renaming a file that is essential to the operation of NPGS. Unless you are absolutely sure that deleting or renaming the specified file will not interfere with the proper operation of NPGS, click "No".

"Menu(A187) NPGS Integrity Check: Delete/Rename Warning!"

"Deleting or Renaming 'filename' will cause an error if any run file that references this pattern is processed! Do you want to continue?"

This warning is less severe than the one immediately above, but it is still important. If a pattern file is renamed or deleted, any run file that uses that name will become invalid. Only rename or delete patterns with care.

"Menu(A191) Pg_Menu.sys Error!"

"There was an error reading the Pg_Menu.sys file in the current project. Do you want to replace the defective file with the copy from the \NPGS\Projects directory? (Selecting 'No' will close the program.)"
If there are any errors reading the Pg_Menu.sys file, this error message will be displayed.

This error has also been seen when running NPGS v9 under some non-US versions of Windows XP when the language is not set to English and the decimal symbol is set to a comma. The decimal symbol can be changed to a "." (period) through the Windows Control Panel using the "Regional and Language Options" choice.

"Menu(A195) NPGS Integrity Check: System File Version Update"

"The NPGS system file below should be updated to the latest version:
Drive:\FullPath\FileName
Do you want to have NPGS update the file?
(If 'No' is selected, some parts of NPGS may not function properly.)"

Every time NPGS Menu v9 or higher is started, it checks the system files in the \NPGS\Projects directory, and every time before a project directory is displayed, the system files in the project are checked. If an old version of a NPGS system file is found and if a valid backup copy is available, this message is displayed which allows the user to have NPGS update the file to the latest version. It is highly recommended to allow NPGS to update the file. Note that most, but not all of the original values from the older file will be copied to the updated file.

When updating a system file in the \NPGS\Projects directory, backups from \NPGS\Program\Backups\Misc_Files\ are used, while system files in a user's projects will be updated using the corresponding file in the \NPGS\Projects directory.

"Menu(A197) NPGS Integrity Check: System File Update Error!"

"The NPGS system file below is an old version:
Drive:\FullPath\FileName
However, NPGS cannot automatically update it. You must replace the file shown to ensure that NPGS functions properly."

The checking described above for "Menu(A195)" also applies in this case, however, this error message indicates that a valid backup could not be found. The user must replace the old system file with a valid copy from a backup or from another project directory.

"The NPGS system file below appears to be corrupt:
Drive:\FullPath\FileName
However, NPGS cannot automatically fix it. You must replace the file shown to ensure that NPGS functions properly."

The checking described above for "Menu(A195)" also applies in this case, however, this error message indicates that a corrupt file has been found and a valid backup could not be found. The user must replace the old system file with a valid copy from a backup or from another project directory.

"Menu(A200) NPGS Integrity Check: Corrupt System File!"

"The NPGS system file below appears to be corrupt:
Drive:\FullPath\FileName
Do you want to have NPGS replace the file with a valid copy? (If 'No' is selected, some parts of NPGS may not function properly. If 'Yes' is selected, you may need to use 'Options - System File Editor' to update some parameters in the file.)"
The checking described above for "Menu(A195)" also applies in this case, however, this message indicates that a corrupt file has been found, and that a valid backup is available. It is highly recommended to allow NPGS to replace the file with the backup version or to immediately copy a valid copy of the file from another source. In either case, the user should use the NPGS System File Editor to check the parameters in the file, since the backup version may have different values than the original file.

This error has also been seen when running NPGS v9 under some non-US versions of Windows XP when the language is not set to English and the decimal symbol is set to a comma. The decimal symbol can be changed to a "." (period) through the Windows Control Panel using the “Regional and Language Options” choice.

"Menu(A210) NPGS Integrity Check: Project Files"
"The following files are missing from the default Projects directory (\NPGS\Projects):"

This message indicates that essential NPGS files are missing from the default project directory. In order to run the NPGS Menu program, you must allow NPGS to copy replacement files from one of the projects listed. You should select one of the listed directories and then click OK to have NPGS copy the necessary files.

"Menu(A210) NPGS Integrity Check: Project Files"
"The following files are missing from 'Project Name'"

This message indicates that essential NPGS files are missing from the specified project. In order to access the project, you must allow NPGS to copy replacement files from one of the other projects listed. You should select one of the listed directories and then click OK to have NPGS copy the necessary files.

"Menu(-4) Directory Error"
"A required NPGS directory is missing or corrupt! Please reload NPGS from your most recent backup!"

Either the directory "\NPGS\Projects" does not exist or the Windows directory reported by the operating system does not exist. The first case can be corrected by reinstalling NPGS, while the second case will typically indicate a serious problem with Windows itself.

"Menu(-3) Initial File Error"
"The Pg_Setup.sys file is corrupt!"

"Menu(-2) Initial File Error"
"There was an error reading Pg_Setup.sys!"

"Menu(-1) Initial File Error"
"There was an error opening Pg_Setup.sys!"

"Menu(1) Initialization Error!"
"There was an error setting up the file list!"

"Menu(2) Initialization Error!"
"Error setting the Small Icon List! Possible bad file name!"
"Menu(3) File Read Error"
"There was an error reading data from file "

"Menu(4) File Read Error"
"There was an error End-Of-File prematurely reached in file "

"Menu(5) External Program Error"
"The external program could not be found."

This error message was sometimes seen in older releases of NPGS when the user clicked a Custom Command button on the NPGS Menu which was using a Batch mode, i.e. “DAC (0,0)” and others. The problem could be caused when the NPGS PC was connected to a network and the Domain Administrator had placed restrictions through Windows so that no “.pif” files could be processed on the PC. A second cause was under 64 bit Windows 7 which does not support PIF files. Both of these issues have been eliminated, since the current release of NPGS no longer uses PIF files.

"Menu(11) Initialization Error!"
"There was an error opening the Pg_PrjDir.sys file."

"Menu(12) Initialization Error!"
"There was an error reading from the Pg_PrjDir.sys file."

"Menu(13) Update Error!"
"There was an error opening the Pg_PrjDir.sys file to write to it."

This error has been seen when running NPGS v9 or higher under Windows XP and the user’s login does not have full file access privileges. See “NPGS Menu program does not launch properly (page 243)” for complete details.

"Menu(14) Update Error!"
"There was an error writing to the Pg_PrjDir.sys file."

"Menu(15) Initialization Error!"
"There was an error opening the pg_StartPrj.sys file."

"Menu(16) Initialization Error!"
"There was an error reading from the pg_StartPrj.sys file."

"Menu(17) Update Error!"
"There was an error opening the Pg_StartPrj.sys file to write to it."

"Menu(18) Update Error!"
"There was an error writing to the Pg_StartPrj.sys file."

"Menu(19) Notice!"
"You cannot remove the project from the list that is currently being used!"

"Menu(20) System Error!"
"Not all the NPGS Sys files exist for creating a new project!"

"Menu(21) Error!"
"This project already exists in this directory!"
"Menu(22) Error!" "Can only create projects in the projects directory (or other project directories)!

"Menu(23) Error!" "Unable to create this project path!"

"Menu(31) Initialization Error!" "There was an error reading from the Pg_Dir.sys file."

"Menu(33) Update Error!" "There was an error opening the Pg_Dir.sys file to write to it."

"Menu(34) Update Error!" "There was an error writing to the Pg_Dir.sys file."

"Menu(35) Notice!" "The directory does not exist or is currently unavailable!"

"Menu(36) Error!" "The Source Directory does not exist or is currently unavailable!"

"Menu(37) Error!" "The Destination Directory does not exist or is currently unavailable!"

"Menu(38) Error!" "Error trying to copy file(s)!"

"Menu(39) Error!" "Error trying to delete file(s)!"

"Menu(50) Notice!" "There was a duplicate entry."

"Menu(51) Notice!" "The directory does not exist or is currently unavailable!"

"Menu(53) Initialization Error!" "There was an error reading from the Pg_Dir.sys file."

"Menu(54) Update Error!" "There was an error opening the Pg_Dir.sys file to write to it."

"Menu(55) Update Error!" "There was an error writing to the Pg_Dir.sys file."

"Menu(60) Initialization Error" "Error setting the Small Icon List! Possible bad file name!"

"Menu(70) Error!" "The first DAC value must be between -10 and 10 (inclusive)"
"Menu(71) Error!"  "The second DAC value must be between -10 and 10 (inclusive)"

"Menu(200) Initialization Warning!"  "The menu/button command has already been assigned a command in Pg_Menu.sys!"

"Menu(201) Initialization Error!"  "End Of File prematurely reached while reading Pg_Menu.sys."

"Menu(202) Initialization Error!"  "There was an error opening the Pg_Menu.sys file."

"Menu(203) Initialization Error!"  "There was an error reading from Pg_Menu.sys file."

This error has been seen when running NPGS v9 under some non-US versions of Windows XP when the language is not set to English and the decimal symbol is set to a comma. The decimal symbol can be changed to a “.” (period) through the Windows Control Panel using the “Regional and Language Options” choice.

"Menu(210) Initialization Error!"  "There was an error opening the Pg_Menu.sys file for writing."

"Menu(211) Initialization Error!"  "There was an error writing to Pg_Menu.sys file."

"Menu(220) Integrity Check"  "The NPGS hardware must be installed in order to use NPGS for pattern writing."

See PCI516 Board (page 255) for more information.

"Menu(221) Error!"  "There are no projects in the Project list or the requested project cannot be found. The application is terminating."

"Menu(222) Error!"  "The requested project cannot be found! The application is terminating."

"Menu(223) Error!"  "The requested project path does not exist! The application is terminating."

"Menu(224) Notice!"  "The NPGS Menu program has been started in the 'Locked' mode using a command line option. Consequently, the current project cannot be changed."

"Menu(225) Exe Error!"  "This command cannot be executed because its external command information is not properly set up."

"Menu(226) External Execution Error"  "Error while creating the Batch file to execute a Custom Command."
"Menu(228) Batch File Error"

"Error while trying to set up a batch file to execute a Custom Command."

"Menu(230) Access Error!"

"This command is already running! Please go to the Windows Start bar to access the program."

"Menu(332) Error!"

"Another copy of the Run File Editor cannot be opened."

"Menu(235) Error!"

"A problem has been encountered while copying/loading the registry information before launching."

It has been observed that this error can be caused a problem with the automatic loading of a '.reg' file into the Windows Registry by NPGS Menu. When launching DesignCAD Express v21.2, NPGS will load the file 'NPGS_DC21E_registry.reg' from the current Project into the Windows Registry. When launching DesignCAD v16.2, NPGS will load the file 'NPGS_DC16E_registry.reg'. When launching DesignCAD LT 2000, NPGS will load the file 'NPGS_DC_Registry.reg'. It has been seen that the error can be eliminated by manually double clicking in Windows Explorer on the appropriate file name listed above. This action manually causes the '.reg' file to be loaded and subsequent loading by NPGS has then worked.

"Menu(236) Error!"

"The DesignCAD registry information could not be copied. Changes made in last DesignCAD session will not be saved!"

"Menu(237) NPGS Integrity Check: CRITICAL ERROR..."

"The NPGS Menu program cannot run! The following files are missing from the directory '\NPGS\Program'. These files should be copied from the NPGS distribution CD or from a recent system backup."

The listed files are essential for the proper operation of NPGS. They must be replaced before NPGS will load.

"Menu(238) NPGS Integrity Check: WARNING..."

"The following files are missing from the directory '\NPGS\Program'. These files should be copied from the NPGS distribution CD or from a recent system backup. Otherwise, some NPGS functions will not be available."

The listed files should exist, but they are not essential to the operation of NPGS. However, it is strongly recommended that they be replaced, so that all NPGS functions will operate as expected.

"Menu(241) Critical Error"

"The Pg_Menu.sys file found in the \NPGS\Projects directory appears to be corrupted. The NPGS Menu program is now terminating!"

This error message will only appear if error #A191 has been encountered and the master Pg_Menu.sys file is corrupted. In this case, you must replace the defective file with a valid version from a previous backup.
"Menu(242) Warning"
"You have selected not to update the Pg_Menu.sys file in this project. The NPGS Menu program is now terminating."

This message will occur if the user selects not to replace Pg_Menu.sys after error #A191 has been encountered. In order to have NPGS function properly, you must either allow NPGS to copy the master Pg_Menu.sys file, or you must replace the defective file with a valid version from a previous backup.

"Menu(250) File Copy Error"
"Could not copy the file! Try again or cancel."

"Menu(251) File Rename Error"
"Could not rename the file! Try again or cancel."

"Menu(255) Create New Directory"
"Directory or file already exists!"

"Menu(260) Initialization Error!"
"There was an error opening the Pg_PrjDir.sys file."

"Menu(261) Initialization Error!"
"There was an error reading from the Pg_PrjDir.sys file."

"Menu(262) NPGS Integrity Check: Project Files"
"There are no project directories from which to restore the missing files in this directory! The program will quit now."

This message indicates that one or more essential files are missing from all project directories. This message will follow another message that lists the missing file(s). Normally, if an essential file is missing from a project directory, NPGS will prompt the user to select another Project where the missing file(s) can be copied from. In the unlikely case that one or more files are missing from all projects, this message will be displayed and the user must copy the missing files from a recent backup.

"Menu(263) NPGS Integrity Check: Project Files"
"There was an error restoring the files! After clicking OK, please select a different Project to restore from, or click cancel to quit..."

"Menu(264) NPGS Integrity Check: Project Files"
"You have canceled the updating/copying of the files in this directory. The program will quit now."

When NPGS detects that one or more files are missing from a project, a list of the missing files and a list of other directories where the missing files can be copied from are displayed. To have NPGS copy the files, the user must highlight one of the directories in the list and click OK. Note that the "OK" button will not be active unless a directory is selected.

"Menu(265) NPGS Integrity Check: Project Files"
"You have canceled the updating/copying of the files in this directory. The next most recent project directory will be used..."

"Menu(266) NPGS Version Check"
"This feature is only available in NPGS v9 or higher."

"Menu(267) NPGS Version Check"
"Long file names cannot be used with NPGS v8.0 in the Office Mode under Windows NT or Windows 2000."

**Errors: Run File Editor**

The following error messages may be displayed by the Run File Editor. Most messages will be self-explanatory, while others will have additional information listed below.

"RFE(80) Pg_RFE.sys Error!"
"Error loading the Run File Editor's system file! Please check 'pg_rfe.sys' in the current project."

"RFE(81) File Error!"
"The pattern file listed in the entity that you are trying to Paste/Insert does not exist!"

"RFE(82) Notice!"
"To save a run file, all patterns must have valid names!"

*NPGS does not allow a run file to be saved until valid entries are made for all pattern names for the entities on the left hand side of the display.*

"RFE(83) RFE File Check"
"You cannot delete the only entity. Click OK to exit the Run File Editor."

"RFE(90) Run File Error!"
"There was an error opening the run file: 'runfile'"

"RFE(91) Run File Error!"
"There was an error reading from the run file: 'runfile'"

"RFE(92) Run File Error!"
"Error reading the header information in run file: 'runfile'"

"RFE(93) Run File Error!"
"Error reading the Pattern data in run file: 'runfile'"

"RFE(94) Run File Error!"
"Error reading the Array data in run file: 'runfile'"

"RFE(95) Run File Error!"
"Error reading the Fractured data in run file: 'runfile'"

"RFE(96) Run File Error!"
"Error reading the MoveOnly data in run file: 'runfile'"

"RFE(97) Run File Error!"
"Error reading the Command data in run file: 'runfile'"

"RFE(98) Run File Error!"
"Error reading the Comment data in run file: 'runfile''

"RFE(99) Run File Error!"
"Error reading the Align data in run file: 'runfile''

"RFE(100) Run File Error!"
"Error while updating all command mode menus during the loading of: 'runfile'"

"RFE(101) Run File Error!"
"Error loading/initializing the fracture mode pattern: 'runfile'"

"RFE(102) Run File Error!"
"Error loading/initializing the fracture mode pattern (with alignment data): 'runfile'"

"RFE(103) Run File Error!"
"Error reading pattern data while loading: 'runfile''

"RFE(104) File Error!"
"Unexpected End-Of-File reached (in fractured mode with alignment data) while reading run file: 'runfile'"

"RFE(105) File Error!"
"A skip layer (in fractured mode with alignment data) was encountered unexpectedly while loading run file: 'runfile'"

"RFE(106) File Warning!"
"A skip layer (in fractured mode with alignment data) was expected while loading run file: 'runfile'"

"RFE(107) File Error!"
"Error in the pattern data of run file: 'runfile'"

This error message may result from a pattern that contains a “dump point” as the only entity in a layer. In that case, the dump point should be moved to a layer with other pattern elements.

"RFE(108) File Error!"
"Error setting layer indices during load of run file: 'runfile'"

"RFE(109) File Warning!"
"Too much layer data in run file: 'runfile'"

"RFE(120) Run File Error!"
"There was an error opening to write to the run file: 'runfile'"

"RFE(121) Run File Error!"
"There was an error writing to the run file: 'runfile'"

"RFE(122) Run File Error!"
"Error writing the header information in run file: 'runfile'"

"RFE(123) Run File Error!"
"Error writing Pattern data to run file: 'runfile'"

"RFE(124) Run File Error!"
"Error writing Array data to run file: 'runfile'"

"RFE(125) Run File Error!"
"Error writing Fractured data to run file: "

"RFE(126) Run File Error!"
"Error writing MoveOnly data to run file: 'runfile'"

"RFE(127) Run File Error!"
"Error writing Command data to run file: 'runfile'"

"RFE(128) Run File Error!"
"Error writing Comment data to run file: 'runfile'"

"RFE(129) Run File Error!"
"Error writing Alignment data to run file: 'runfile'"

"RFE(130) Run File Error!"
"Error writing pattern data to run file: 'runfile'"

"RFE(131) Run File Error!"
"Error writing fractured mode pattern data to run file: 'runfile'"

"RFE(132) Run File Error!"
"Error writing fractured mode pattern data with align data to run file: 'runfile'"

"RFE(140) Pg_RFE.sys Initialization Error!"
"There was an error opening the Pg_RFE.sys file."

"RFE(141) Pg_RFE.sys Initialization Error!"
"There was an error reading from the Pg_RFE.sys file."

"RFE(142) Pg_RFE.sys Initialization Error!"
"Error reading prompt information (Min,Max,Mult,Frmt,Lbl,Unit)."

"RFE(143) Pg_RFE.sys Initialization Error!"
"Error reading prompt default information."

"RFE(144) Pg_RFE.sys Initialization Error!"
"Error reading allowed/excluded character information."

"RFE(145) Pg_RFE.sys Initialization Error!"
"Error reading (LHS) advanced mode prompts."

"RFE(146) Pg_RFE.sys Initialization Error!"
"Error reading (RHS) advanced mode prompts."

"RFE(147) Pg_RFE.sys Initialization Error!"
"Error reading common (LHS) prompts."
"RFE(148) Pg_RFE.sys Initialization Error!"
   "Error reading Align prompts."

"RFE(149) Pg_RFE.sys Initialization Error!"
   "Error reading Pattern prompts."

"RFE(150) Pg_RFE.sys Initialization Error!"
   "Error reading Array prompts."

"RFE(151) Pg_RFE.sys Initialization Error!"
   "Error reading Fractured prompts."

"RFE(152) Pg_RFE.sys Initialization Error!"
   "Error reading MoveOnly prompts."

"RFE(153) Pg_RFE.sys Initialization Error!"
   "Error reading Command prompts."

"RFE(154) Pg_RFE.sys Initialization Error!"
   "Error reading Comment prompts."

"RFE(155) Pg_RFE.sys Initialization Error!"
   "Error reading combobox options."

"RFE(156) Pg_RFE.sys Initialization Error!"
   "Error reading menu options."

"RFE(157) Pg_RFE.sys Initialization Error!"
   "Error reading other text and statusbar help text."

"RFE(158) Pg_RFE.sys Initialization Error!"
   "Error setting up combobox options for all prompts."

"RFE(159) Pg_RFE.sys Initialization Error!"
   "Other setup errors."

"RFE(160) Pg_RFE.sys Initialization Error!"
   "End Of File prematurely reached."

"RFE(165) Pg_RFE.sys Initialization Checks!"
   "Error reading from Pg_Cmd.sys for XY-Focus and SEM enable checks."

   These system files are read before any run file is created, so that the defaults may be properly set.

"RFE(166) Pg_RFE.sys Initialization Checks!"
   "Error reading from Pg_Stg.sys for Stage enable check."

   This system file is read before any run file is created, so that the defaults may be properly set.

"RFE(167) Pg_RFE.sys Initialization Checks!"
"Error reading from Pg_Beam.sys for Beam enable check and TimeBetweenReads and CheckBeamRdBefore values."

This system file is read before any run file is created, so that the defaults may be properly set.

"RFE(168) Pg_RFE.sys Initialization Checks!"
"Error reading from Pg.sys for BccClock, MagScale, and Blanker values."

This system file is read before any run file is created, so that the defaults may be properly set.

"RFE(175) Initialization Error!"
"There was an error opening the pattern file: 'pattern'"

"RFE(176) Initialization Error!"
"There was an error reading from the pattern file: 'pattern'"

"RFE(177) Error!"
"No pattern header."

The pattern file being read does not have header information stored properly.

In DesignCAD, use the menu command "Options - Options", then select the "General" tab and mark the box for "Save Parameters with Drawing".

"RFE(178) Error!"
"Bad scaling parameter in pattern."

The second line must be a header entity line (20 or 41). If the header entity is in the old format (20), at least twelve lines must be in the header followed by a ".". The 12th line must have the scaling parameter (i.e., # of DesignCAD storage units per μm). If the header entity is in the new format (41, version 4.0 through 6.1), the first number must be the scaling parameter.

"RFE(179) Error!"
"Invalid color (non RGB format)."

"RFE(180) Error!"
"An invalid color was found in the pattern file: "

There is an error in the DesignCAD pattern file. The Run File Editor is reading an invalid color number (i.e., greater than 255 or less than 1).

"RFE(181) Error!"
"Layer data is not properly grouped in pattern file: 'pattern'"

When reading a DesignCAD 2D file, NPGS expects that each layer that has pattern elements will appear in numerical order. Any file that is saved using the "NPGS-Save" function in DesignCAD will be processed by an external program so that the layers will be in the proper order. If a pattern is saved using the normal "File-Save" function in DesignCAD, the pattern entities may not be grouped by layer and consequently cannot be read by NPGS.
"RFE(182) Error!"
"Layer numbering is out of order in pattern file: 'pattern'

See RFE(181).

"RFE(183) Error!"
"Need to set this entity to fracture mode before loading this pattern file: 'pattern'

"RFE(184) Error!"
"Too many points in pattern file: 'pattern'

NPGS v9 allows up to 1000 points in any drawing element that is to be written.

"RFE(185) Error!"
"There were no layers or no valid entities in the pattern file: 'pattern'

This error can result when the pattern file either has no layers defined or when the pattern file has no pattern entities to write. Examples are when there are no pattern entities below layer 21 or when only non-writing entities, such as text or dump points, exist in the file.

"RFE(187) Information"
"There are no pattern files in the current project directory! You should either create a pattern using DesignCAD or copy a pattern from another project."

"RFE(190) Error!"
"The image format of this file is not supported."

The DesignCAD 'Load Image' command can load a number of image formats into a DC2 file, however, only '.bmp' files can be written.

"RFE(191) Error!"
"Only one bitmap is allowed in each pattern layer. Move this bitmap to a different layer in the pattern."

Multiple bitmaps can be in a single DC2 file, however, each bitmap must be in a separate drawing layer.

"RFE(192) Error!"
"Invalid bitmap: The pixel dimensions are not equal in X and Y."

When a bitmap is loaded into DesignCAD the aspect ratio must not be changed. Similarly, after a bitmap is loaded, it must not be stretched.

"RFE(193) Error!"
"Invalid bitmap pattern file: Error reading dimensions."

"RFE(194) Error!"
"Bitmap File Not Found."

When a bitmap is loaded into a DC2 file, only a reference to the full path of the bitmap is saved in the DC2 file. Consequently, once the DC2 file is created, if the original bitmap file is deleted, renamed, or moved from the original
directory, this error will result when the DC2 file is loaded into the Run File Editor.

**Errors: Pattern Writing (NPGS, PG, AL)**

The following error messages may be displayed by NPGS, PG, and AL.

**Messages listed below as PG(#) may be generated by NPGS and AL as NPGS(#) and AL(#), respectively. Messages listed below as AL(#) or NPGS(#) are unique to those programs.**

**Negative error numbers are at the end of the list.**

*When using NPSG v9 or higher*, numbered errors reported by NPGS, PG, and AL can be skipped by setting the appropriate values in “**Pg_Errors.sys** (Error Management) (page 190)”.

**BCC Calibration FAILED.** *(Time=X secs)*
- A self-calibration program for the PCI516 board is routinely run to calibrate the board outputs and to check the status of the board. Normally, the BCC calibration will successfully complete in 5 seconds. This message indicates that the Blanker Control Circuit on the board has failed the calibration. See **Self-Calibration Failure** (page 256) for more information.

**XY DAC Calibration FAILED.** *(Time=X secs)*
- A self-calibration program for the PCI516 board is routinely run to calibrate the board outputs and to check the status of the board. Normally, the XY DAC calibration will successfully complete in 38 seconds. This message indicates that the X and/or Y DAC output on the board has failed the calibration. The failure may be caused by a small problem in the calibration of the outputs and does not necessarily mean that the outputs are unusable for lithography, however, any self-calibration failure should be investigated. See **Self-Calibration Failure** (page 256) for more information.

**No INTERFACE DEVICE DATA available for this GUID instance**
**ERROR: Could not open communication with NPGS PCI516 Board!**
- These messages indicate a problem with the Windows driver for the PCI516 board. See **ERROR: Could not open communication** (page 255) for more information.

**PG(0): memory allocation error**
- The program could not allocate enough memory to function properly.

**PG(1): must supply run file name on command line**
- Correct usage: ‘PG runfile [C or c] [a] [t] [ex]’ where ‘c’, ‘a’, ‘t’, and ‘ex’ are optional. ‘C’ and ‘c’ will make PG run in error checking modes, ‘a’ will cause PG to use the alignment parameters in "Pg_Align.sys", ‘t’ will cause PG to estimate the pattern writing time without calculating the exposure points, and ‘ex’ will scale the exposure times by x (for example, “e1.2” will scale all times by "1.20”).
- Correct usage: ‘AL runfile’.

**PG(2): bad pattern file...no header**
**PG(2): or bad DesignCAD scaling parameter**
- The pattern file does not have the header information stored properly. For use with NPGS, DesignCAD files must have the header information saved with the file. In DesignCAD, go to "Options - Options" and select the "General" tab, then put a check mark on the "Save Parameters with Drawing" prompt.

**PG(3): error opening pattern file: FILENAME**
- The pattern file referenced by the run file being processed does not exist in the current project directory.

**PG(4): not used**

**PG(5): option NAME not implemented**
• The pattern being processed has a entity type that cannot be processed. This error should not occur for any valid pattern.

  option NUMBER nonexistent

• The pattern file has an invalid DesignCAD entity. The pattern data has been corrupted.

**PG(6): error during polyfill()**

• The routine used to calculate the lines for filled polygons was not successful. The filled polygon that caused the error must be modified.
• This error probably results from one of the following:
  1) Vertices that are placed very close together (i.e., less than the "Line Spacing") or when the changes in the perpendicular distance from the original sweep side between successive vertices is less than the "Line Spacing".
  2) Wide lines that have the vertices closer than the designed width of the line. This will typically be caused by vector circles or curves with a large linewidth. Since each segment of a wide line is calculated as a filled polygon (actually a trapezoid) with the ends that match the adjacent segments, the edges of each segment must be distinct. A problem occurs when the curvature of the segmented wide line is such that the inside edge of an individual segment is not distinct. To avoid the problem, use the BasicCAD program CutPoints to set the linewidth and minimum vertex separation.
• 3) When the first and last points of the filled polygons have a small gap. This gap then appears as a very short side, which is often less than the "Line Spacing" parameter, as described above.

**PG(7): too many points for polyfill(): #**

• The routine for filled polygons will accept polygons with up to 1000 vertices. In DesignCAD, the "NPGS - CheckAll" can be used to find any pattern elements that have too many points. The # above is the number of vertices that are in the invalid polygon.

**PG(8): illegal color: # in data file**

• There is an error in the DesignCAD file. In DesignCAD, any RGB colors may be specified, with a maximum of 256 unique colors. If the error message says that "color 0" has been found, this indicates that the RGB color in the pattern does not match any RGB values listed in the run file. Either the pattern file has been corrupted, or it simply needs to be reread by the NPGS Run File Editor. (If the pattern is in the DesignCAD for DOS format, the allowed colors are 1 to 16, inclusive.)

**PG(9): invalid exposure values**

• The exposure time given in the run file is too large or too small.

**PG(10): bad or missing run file parameters**

• Typically this will result from adding layers to a pattern and not updating a previously made run file. If a pattern is changed after a run file has been created, it is necessary to use one of the Run File Editor "File - Reread..." commands. Then the correct parameters should be entered for the new layer(s) and the new run file should be saved.

**PG(11): too many patterns to write: #**

• An invalid run file has been created with too many patterns (#) to write.

**PG(12): too many pattern repeats: #**

• An invalid run file has been created with too many pattern repeats (#) to write.

**PG(13): not used**

**AL(13): too many points needed**

• Too many points are need to draw the alignment window(s) or the alignment overlay(s). This error only results if AL has increased the exposure point spacing by 10x and there still are too many points for the available memory. **Usually, this will only happen if a non-alignment pattern has been given to AL to process.** If the spacing specified in the run file results in too many points, AL will first try increasing the spacing by 1.5x, 2x, 2.5x,...10x, until the number of points is small enough. A warning message will be displayed whenever AL changes the requested spacing.
Error Messages

spacing. If a 10x increase in the point spacing still results in too many points, this error will be issued.
- This error will be displayed if too many points are needed for the window(s), the displayed overlay(s), or the "fit" overlay(s). To evaluate which is the problem, rerun the pattern and pause the display when the number of points calculated for the windows and overlays are displayed. The windows may use a number of points up to the buffer size initially displayed when AL is run, the displayed overlay up to ~8,000 points, and the fit overlay up to the buffer size.
- If the number of points in the windows must be reduced: Increase the "Center-to-Center" and "Line Spacing" or make the window(s) smaller.
- If the number of points for the fit overlay is too large and Auto-Alignment is not being used, then make the overlay without using any closed polygons. The fit overlay will include all points within closed polygons.

PG(14): file 'Pg.sys' not found in current directory
PG(14): or 'Pg.sys' has bad or missing parameters
- The system file "Pg.sys" must exist in the current directory and the parameters must have valid values.
- This file has several parameters that the user may customize. If it has been edited without using the NPGS System File Editor, it is possible that a parameter has been changed to a value outside of the acceptable range or that the format for the data has been altered. Compare the file to the one in the directory "\NPGS\Projects".

PG(15): No longer used.

PG(16): file 'pg_rfe.sys' not found in current directory
- The specified file must exist in the project directory being used.

PG(17): file 'pg_align.sys' not found in current directory
- When PG is instructed to write the pattern using an alignment transformation, the file "Pg_Align.sys" must reside in the current directory. "Pg_Align.sys" is created by the alignment program AL in the directory that is current when AL is run, therefore PG should be run from the same directory.

AL(17): file 'Pg_AL.sys' not found in current directory
AL(17): or 'Pg_AL.sys' has bad or missing values
- The system file must reside in the current directory. If it has been accidentally deleted, simply copy the appropriate file from directory "\NPGS\Projects".
- This file has several parameters that the user may customize. If it has been edited without using the NPGS System File Editor, it is possible that a parameter has been changed to a value outside of the acceptable range or that the format for the data has been altered. Compare the file to the one in the directory "\NPGS\Projects".

PG(18): (Circle or Arc Width)/(Line Spacing) is too large
- The "Line Spacing" parameter is too small for the designed pattern width of a circle or circular arc.

PG(20): an old run file is calling a new pattern file
PG(20): load and resave the run file with the Run File Editor
- Pg.exe has detected that the run file is based on the old DOS color scheme from a DOS version of DesignCAD, but the actual pattern uses the newer RGB color scheme from a Windows version of DesignCAD. The run file should be opened in the Run File Editor, which should prompt to reread the file, since the older version will be detected. In any case, the 'File - Reread All Patterns' option can be selected, which will make the Run File Editor update to the new pattern format. Once the pattern file has been reread, save the run file and it will be updated with the appropriate color scheme.

PG(21): a new run file is calling an old pattern file
PG(21): reread the pattern file in the Run File Editor
Pg.exe has detected that the run file is based on the newer RGB color scheme from a Windows version of DesignCAD, but the actual pattern uses the old DOS color scheme from a DOS version of DesignCAD. The run file should be opened in the Run File Editor and the ‘File - Reread All Patterns’ option should be selected. Once the pattern file has been reread, save the run file and it will be updated with the appropriate color scheme.

AL(30): must have 1, 2, 3, or 4 alignment windows
- Each DesignCAD layer in an alignment pattern is considered to be a separate window. Layers in a pattern are grouped by using the "Start New Set" option in the Run File Editor. For example, if the pattern has eight windows (in layers 1 through 8), then the "Start New Set" option should be set in the Run File Editor for the 5th layer if they are to be grouped into two sets of four. Similarly, using "Start New Set" on the 3rd and 6th layers will group the windows into sets of two, three, and three.

AL(31): windows AND overlays must exist in each layer
- In an alignment pattern, each DesignCAD layer must contain at least one filled polygon, which will become the window, and at least one solid line with width=0, which will become the alignment overlay. Typically, a filled box will be used for the window and lines of width=0 that trace the edge of the registration mark will be used for the alignment overlay.
- Note that circles and circular arcs may be included as part of an overlay for manual alignment, however, there must also be at least one vector as part of the overlay.

AL(32): image not properly fitting into display area,
AL(32): be sure that multiple windows are designed in
AL(32): separate drawing layers
- When only one window is being displayed, the overlay is checked to make sure that at least 50% of its points show up on the PC screen. If the overlay does not fit on the screen when the initial pixel size is set to two, it will be set to 1 and the display will be regenerated. If the overlay does not fit when the pixel size is set to one, this error message will be displayed.
- The typical cause for this error will be if multiple window/overlay pairs were incorrectly designed in one drawing layer, instead of having each window/overlay pair in a different drawing layer.

AL(40): file 'pg_aa?.sys' not found in current directory
AL(40): or 'pg_aa?.sys' has bad or missing values
AL(40): use PG_EDIT to check values
- The system file must reside in the current directory. If it has been accidentally deleted, simply copy the appropriate file from directory "\NPGS\Projects".
- 'pg_aa?.sys' refers to the system file being used, i.e., "Pg_AA1.sys", "Pg_AA2.sys", or "Pg_AA3.sys". The system file to use is selected in the Run File Editor program by setting the "Alignment Mode" to "AutoAlign1", "AutoAlign2", or "AutoAlign3", respectively.
- This file has several parameters that the user may customize. If it has been edited without using the NPGS System File Editor, it is possible that a parameter has been changed to a value outside of the acceptable range or that the format for the data has been altered. Compare the file to the one in the directory "\NPGS\Projects".

AL(41): Auto-Aligned position outside window too many times
- When the 'Edge: Mode' parameter in "Pg_AA?.sys" is set to check if the overlay is near the window edge, the 'Edge: # of times...' parameter tells how many times the overlay positions can hit the edge before displaying this error message.
- If the ideal position of the overlay is very near the edge of the window, then it may be best to disable the edge checking by setting the 'Edge: Mode' to -1.
- 'pg_aa?.sys' refers to the system file being used, i.e., "Pg_AA1.sys", "Pg_AA2.sys", or "Pg_AA3.sys". The system file to use is selected in the Run File Editor program by setting the "Alignment Mode" to "AutoAlign1", "AutoAlign2", or "AutoAlign3", respectively.

PG(42): stage driver must be defined in 'pg_stg.sys'
- The "Move Auto-Stage to Faraday Cup to Make Reading" parameter in "Pg_Beam.sys" is set to 1. This specifies that the a stage should be moved to the location of a Faraday cup before reading the beam current and requires that a stage driver be used to communicate with the...
automated stage. From within the NPGS Menu program, use "Options - System Files - Pg_Stg.sys" to enter the stage interface program on line #1 in the file "Pg_Stg.sys. Alternately, if the beam reading mode is not desired, set the "Beam Current Checking" parameter in "Pg_Beam.sys" to 0.

AL(42): stage driver must be defined in 'pg_stg.sys'
- The 'Stage: Mode' parameter in "Pg_AA?.sys" specifies that the coarse correction for the position should be passed to the stage driver, however, the stage driver is not given in the file "Pg_Stg.sys". From within the NPGS Menu program, use "Options System Files - Pg_Stg.sys" to enter the stage interface program on line #1 in the file "Pg_Stg.sys.

AL(43): Auto-Aligned position produced invalid matrix
- The matrix that was calculated using the overlay positions found by the Auto-Alignment routine produced a correction matrix that was invalid.
- This may result from: poor overlay positioning caused by insufficient quality of the image, an initial alignment that was too far off, or from an alignment pattern that has the windows too close to the edge of the alignment field of view. For example, if the windows are 5 μm wide, then they should be at least 5 μm from the edge of the field of view. The field of view size is determined by the magnification setting used for the pattern alignment.

AL(44): error creating temporary file
AL(44): check available space on hard disk
AL(44): do not use DOS 'share' or 'append' commands
- This error may result from a virus infection of the system, bad clusters on the hard disk, or insufficient space on the hard disk.

AL(45): error writing to temporary file
AL(45): check available space on hard disk
- see AL(44).

AL(46): error opening temporary file for reading
AL(46): check hard disk for a virus
- see AL(44).

AL(47): error reading temporary file
AL(47): check hard disk for a virus
- see AL(44).

PG(48): 'pg_stg.sys' has bad or missing values
PG(48): use PG_EDIT to check values
- The system file must reside in the current directory if an automated stage is to be used. If it has been accidentally deleted, simply copy the appropriate file from directory "\NPGS\Projects".
- This file has several parameters that the user may customize. If it has been edited without using the NPGS System File Editor, it is possible that a parameter has been changed to a value outside of the acceptable range or that the format for the data has been altered. Compare the file to the one in the directory "\NPGS\Projects".

PG(50): cannot read runfile with aRray, Fraction, Global, or Previous option
PG(50): use NPGS to process runfile
- Run files with these options must be processed by NPGS.exe and cannot be processed with the "Write Only" or "Align Only" options in the NPGS Menu program.

NPGS(52): error creating file: 'pg_angle.sys'
NPGS(52): or error creating: 'pg_focus.sys'
NPGS(52): check available space on hard disk
- The file "pg_angle.sys" contains the results from the Global Correction mode initialization and the file "pg_focus.sys" contains the results from the X-Y-Focus mode initialization. Check that
the NPGS executable has not been damaged, the PC is free from viruses, and that the hard disk is not full.

**PG(60): beam current has dropped below threshold**

- When the beam current reading mode is being used, subsequent readings are compared to the first reading. If the ratio between a subsequent reading and the first reading falls below the value specified as the 'Error Threshold', pattern writing will terminate with this error message. For example, if the value is 0.5, the beam current could drop to one half of the original reading before an error message would be issued. This feature allows the user to set an acceptable level for beam drift before pattern writing is stopped. It also can be used to terminate pattern writing if the filament fails during writing.

**PG(61): file 'pg_stg.sys' not found in current directory**

- The system file must reside in the current directory if an automated stage is to be used. If it has been accidentally deleted, simply copy the appropriate file from directory "\NPGS\Projects".
- This file has several parameters that the user may customize. If it has been edited without using the NPGS System File Editor, it is possible that a parameter has been changed to a value outside of the acceptable range or that the format for the data has been altered. Compare the file to the one in the directory "\NPGS\Projects".

**PG(62): 'pg_beam.sys' has bad or missing values**

- The system file must reside in the current directory. If it has been accidentally deleted, simply copy the appropriate file from directory "\NPGS\Projects".
- This file has several parameters that the user may customize. If it has been edited without using the NPGS System File Editor, it is possible that a parameter has been changed to a value outside of the acceptable range or that the format for the data has been altered. Compare the file to the one in the directory "\NPGS\Projects".

**PG(63): error reading beam current in '%pg_io.tmp'**

- When an external program is used to read the beam current, it should output the beam current to the temporary file "%pg_io.tmp". This error results when the temporary file could not be opened for reading or the file does not contain valid data.
- Possible explanations for this error are:
  1) The external program is not creating the temporary file that is required.
  2) The external program is not returning the correct format. The first value should simply be the measured beam current (in pA, if using the Absolute mode), while any comment string may follow.
  3) The PC may have a virus that is interfering with the creation of the temporary file.
  4) The hard disk may have a bad cluster or may be completely full.

**PG(64): error reading stage location in '%pg_io.tmp'**

- Before the stage is moved to the location of the Faraday cup, the stage driver is prompted to return the present location of the stage to the temporary file "%pg_io.tmp". This error results when the temporary file could not be opened for reading or the file does not contain valid data.
- For more information on the communication between PG and the stage driver, see Interfacing to an Automated Stage (page 160).
- Possible explanations for this error are:
  1) The driver program is not returning the correct format or is not creating "%pg_io.tmp". The first line should have the X position followed by any comment string, and the second line should have the Y position followed by any comment string.
  2) The PC may have a virus that is interfering with the creation of the temporary file.
  3) The hard disk may have a bad cluster or may be completely full.

**PG(65): relative mode beam reading error**

- This error message indicates that the beam current reading routine was about to divide by zero. In normal operation, this error message should never be encountered. Check that the
PG executable has not been damaged, the PC is free from viruses, and that the hard disk is not full.

PG(66):  beam current <=0 in '%pg_beam.tmp'
- This error message indicates that a beam current reading of zero has been saved in the temporary file listed, or that the temporary file was not read correctly. In normal operation, this error message should never be encountered. Check that the PG executable has not been damaged, the PC is free from viruses, and that the hard disk is not full.

PG(67):  error writing to '%pg_beam.tmp'
- When the beam current reading mode is active, PG will create a temporary file containing the details of the last reading before terminating. The next time PG is called by NPGS, it will then read the temporary file and continue with the beam reading mode as desired. This error message indicates that the temporary file could not be created. In normal operation, this error message should never be encountered. Check that the PG executable has not been damaged, the PC is free from viruses, and that the hard disk is not full.

NPGS(100):  could not open temporary files for fracturing
NPGS(100):  check available space on hard disk
- When a pattern is fractured, each sub-field is saved in a separate, temporary *.dc2 file. To maximize the speed of the fracturing, the software will open as many temporary files as it can. This error will result when not even one temporary file can be opened.

NPGS(101):  too many vertices needed during fracturing
NPGS(101):  simplify filled polygons with many vertices
- During the fracturing process, when a side of a filled polygon crosses out of the current sub-field, an additional vertex is added to the polygon at the point it crosses the sub-field edge. If the polygon crosses in and out many times, too many additional vertices may be required. In this case, the polygon must be simplified or split into two or more polygons.

NPGS(102):  invalid field number during fracturing
NPGS(102):  check validity of pattern elements
- A pattern element was found that did not fall within a valid sub-field. If the sub-fields have been defined by the user, check that all pattern elements fall within the user-defined sub-fields and check that the sub-field size entered in the run file matches the placement of the center markers in the pattern.

NPGS(103):  error fracturing pattern entity
NPGS(103):  crossing point not found
NPGS(103):  check validity of pattern elements
- The point at which a pattern entity crosses out of a sub-field could not be determined. Explanations could be that the pattern entity is invalid, the value for the "border" option is too large, or the sub-field size entered in the run file does not match the placement of the center markers in the pattern.

NPGS(104):  error fracturing pattern entity
NPGS(104):  undetermined crossing point
NPGS(104):  check validity of pattern elements
- The point at which a pattern entity crosses out of a sub-field could not be determined. Explanations could be that the pattern entity is invalid, the value for the "border" option is too large, or the sub-field size entered in the run file does not match the placement of the center markers in the pattern.

NPGS(105):  error fracturing wide line
NPGS(105):  check validity of pattern elements
- Each segment of a wide line is converted to a filled trapezoid, and then the trapezoid is fractured. An error has occurred during the processing and the wide line must be modified.

NPGS(106):  error checking ordering of polygon vertices
NPGS(106): check validity of pattern elements
- For each filled polygon, the software must determine if the points are ordered clockwise or counter-clockwise. An error has occurred during this procedure and the pattern element must be modified.

NPGS(110): bitmap not allowed in pattern ‘Fracture’ mode
- The exposure of a bitmap is not supported by the Fracture entity mode.

NPGS(150): infinite loop in run file nesting
- The nested run files create an infinite calling sequence, such as RunFileA ➔ RunFileB ➔ RunFileC ➔ RunFileA. This sequence must be modified.

NPGS(151): too many nested run files
- Up to a total of 100 nested run files may be processed within the top level run file.

NPGS(152): error opening nested run file: ‘filename’
- A nested run file does not exist in the current project. This may result when files have been copied between projects and a file was accidentally not copied or when a nested run file has been deleted or renamed.

PG(200): stage error: stage_driver: error_message
- Whenever a call is made to the “stage_driver” specified in Pg_Stg.sys, NPGS.exe, Pg.exe, and Al.exe will check if the stage_driver has created the text file “NPGS\Projects\%pg_stg.err”. If this file exists when the stage driver terminates, the first line of the file will be displayed as the “error_message”, and the file will be deleted. In this way, any stage driver called by NPGS can return an error message if the stage move is unsuccessful.

PG(-1): round() argument error
- This is usually caused by pattern elements that have points that fall outside of the microscope field of view at the magnification selected in the run file. This can happen when the transformation matrix produced by AL causes the subsequent pattern to fall outside of the field of view when written by PG. For example, if a pattern fills the writing field of view to within 5 μm, then a 6 μm alignment shift would cause this error.
  - Also, this can result when run files created away from the main NPGS PC are copied to the NPGS PC for processing, if the “mag scale” value in Pg.sys at the remote PC doesn’t match the value at the main NPGS PC. It can also happen between any two NPGS projects, if the “mag scale” in Pg.sys in each project do not match. Using the Run File Editor on the main NPGS PC to reread the supplied patterns and then saving the updated run file will eliminate the problem (in the Run File Editor, use “File – Reread All Patterns”).

PG(-2): <<<SYSTEM ERROR>>>
PG(-2): error in PCI516 operations: #.##
- Error number #.## occurred in the operation of the PCI516 board.
- Check the system for a virus and reinstall the program from the backup copy or the original distribution media.

PG(-3): <<<SYSTEM ERROR>>>
PG(-3): cannot initialize output buffer
- Check the system for a virus and reinstall the program from the backup copy or the original distribution media.

PG(-4): PCI516 XY Range Error
PG(-4): board settings do not match Pg.sys range values
PG(-4): use 'Commands - Calibrate DACs' to recalibrate
- This error message typically means that different Project directories have different calibration values. If NPGS is connected to only one microscope, typically all Projects should have the same calibration values, and the Project with the incorrect values should be modified (use “Options - System Files - Pg.sys”). If NPGS is connected to more than one microscope, then
the Autocalibration for the PCI516 board must be run whenever changing between the two microscopes.

**PG(-5): PCI516 Buffer Clocking Bit Error**

- This is a low level error that should never be seen when the PCI516 board is running properly.
- Check that the PCI516 board is properly seated in the PCI slot and that the PC cooling fans are all working properly.

**PG(-6): PCI516 DMA Transfer Error**

- This is a low level error that should never be seen when the PCI516 board is running properly.
- Check that the PCI516 board is properly seated in the PCI slot and that the PC cooling fans are all working properly.

**PG(?): <<SYSTEM ERROR>> (error # nonexistent)**

- Check the system for a virus and reinstall the program from the backup copy or the original distribution media.
Solutions to Problems

If you have a problem that is not discussed in the following cases or elsewhere in the manual, please call, fax, or send e-mail with a description of the problem so that a solution can be worked out. Also, you can check the "User Notices" page of the NPGS web site to see the most recent "Solutions to Problems" listing.

Pattern Exposures

Astigmatism

- When I write fine lines, the exposure varies for lines at different angles.
- When I expose single dots, the dots are elongated rather than round.
- When I write fine circles, the linewidth varies between wide and thin every 90 degrees.

All of these problems are almost always caused by astigmatism in the beam. The astigmatism either is present when the samples are being viewed or was present when they were being written. If the pattern contains circles or radial spokes (see Sample0.dc2) the exposure is especially revealing. When the linewidth changes between wide and thin every 90 degrees it is a sure sign that there is/was astigmatism in the beam. In fact, a circle exposed by a single pass of the beam should be incorporated into every test pattern in order to detect astigmatism. Unfortunately, the results are not known until the sample is processed, but it still provides an excellent gauge of how well the microscope was set up for the pattern writing. With a little practice, most people can consistently set up the microscope to minimize the astigmatism well enough for very fine lithography.

For images showing the results of astigmatism during the exposure, please visit the "Guide to Common SEM Lithography Exposure Problems" on the "Sample Pictures" page of the NPGS web site.

Missing Pattern Elements: Curves, Ellipses, Text, Etc.

- When I use Curves, Ellipses, Text, or Dimensions in my pattern they are not written.

Curves, Ellipses, and Text must be designed as Vector entities in order to be written as part of a pattern. The DesignCAD command "Vector Convert" or the NPGS BasicCAD program "ToVector" may be used to convert these entities to vectors that will be written. Dimensions may only be used as comments in a pattern. For more information, see Ignored Pattern Elements (page 75).

Pattern Aspect Ratio

- When I write circles they do no turn out round and squares turn out as rectangles.

This may mean that the aspect ratio for pattern writing must be adjusted. For more information, see PCI516 DAC Outputs (page 212) and the section in the "NPGS Installation Guide" on "System Calibration". Normally, once the aspect ratio for the PCI516 outputs have been calibrated, no further adjustments will be needed, unless the microscope itself changes.

If patterns only occasionally have a distorted aspect ratio, the cause may be that a "tilt correction" mode of the SEM was enabled during the pattern writing. For lithography, any tilt correction mode of the SEM should be disabled. For distortions on the order of a few percent, it is quite possible that the microscope's aspect ratio for the XY inputs changes as the magnification has changed, but errors on this level are typically within spec for an SEM. Another possibility is that the "scan rotation" option of many microscopes may introduce aspect ratio errors on the order of a few percent.
Pattern Distortion from Charging

- When I write a large pattern on a low conductivity substrate some parts of the pattern turn out distorted while other parts are fine.

The sample is probably charging during the pattern writing enough to deflect the beam in some areas. Please see the "Charging (during writing)" diagnostic image on the "Sample Pictures" page of the NPGS web site for more information.

One solution is to evaporate ~100 Angstroms of aluminum on top of the resist before writing and etch it off in NaOH or KOH after the writing and before developing. One recipe is to use several pellets of NaOH in ~100 ml of DI water and etch for about 30 seconds. (You can coat some test samples and try various concentrations and times to optimize the process, if necessary.) Note that NaOH may permeate the PMMA and chemically interact with some substrates. Other metals such as Au, AuPd, or Cr can also be used with the appropriate etch after exposure. Also, non-metallic conductive layers can be used.

Another solution when an ‘Environmental’ or ‘Variable Pressure’ SEM is being used is to introduce a low pressure of gas (typically water vapor, N₂, Ar, or He) to avoid charging effects during lithography.

Pattern Noise from Environment

- My patterns have a significant noise problem (either line frequency or even a square wave at some other frequency) even though the PC chassis is grounded directly to the microscope chassis.

The most common source of noise is magnetic pickup at line frequency. Please see the "Line Frequency Noise" diagnostic image on the "Sample Pictures" page of the NPGS web site for more information.

Three possible solutions are:

1. Identify the source of the noise and prevent the interference from reaching the microscope by shielding the source or turning it off.

2. Shielding the microscope sample chamber with mu-metal.

3. Installing a magnetic field canceling system in the microscope room. These systems typically have large loops of cable around the room and a detector placed near the microscope column. They can cancel magnetic fields from DC up to a kilohertz or higher.

These image show severe cases of 60 cycle pickup from a nearby power bus. Mu-metal shielding around the SEM chamber significantly reduced the noise. The lines were written with a single pass of the beam and the lineweights in both images are about 150 nm.
In general, the appearance of line frequency noise pickup may range from the "choppy" interference shown here to almost perfectly smooth sinusoidal oscillations. The identifying characteristic is that the period will correspond to the local line frequency. To determine the frequency of the interference from a micrograph:

1. Measure the period of the noise in nanometers.

2. Divide the period by the "Center-to-Center" distance (nanometers) used when the pattern was written. This will yield the number of exposure points in one cycle.

3. Multiply the result from (2) by the exposure time per point (μsec), as listed in the run file.

4. The result will be the period in μsec. To get the frequency in Hz, multiply by 10^-6 and take the reciprocal.

Also, some old SEMs will have internal pickup on the xy scan lines depending on the SEM scan mode and magnification that is used for the pattern writing. In theory, the SEM scan mode should have no effect on the pattern writing because the microscope is under external control, but in some cases it does matter. For example, on some JEOL SEMs, interference from the internal scan generator may be superimposed on the pattern if the microscope is in the SR (Super Rapid) or TV mode during writing, while a Slow Scan mode will appear fine.

The magnification used for pattern writing can also affect the interference that is seen in the patterns. SEMs have different circuits that are used for different ranges of magnification and the low end of each range will have the best signal to noise, and consequently, the least sensitivity to internal interference from the microscope. Typically, when the SEM changes from one magnification range to another, an audible click may be heard and/or a glitch may be seen on the SEM image. For more information, see Pattern Noise from SEM (page 241) and System Installation: Summary - Check List (page 13).

**Pattern Noise from SEM**

- My patterns were writing perfectly at 1000x, but now have a noise problem at 800x.
- My patterns were writing perfectly at 100x, but now have a noise problem at 80x.

The typical design of the scan coil amplifier circuits in SEMs is such that the signal to noise for pattern writing will vary as the SEM magnification is changed. For example, in older JEOL microscopes (models 6400 and earlier), patterns over a field of view of 900 microns square may be conveniently written at a magnification of 100x, however, slightly larger patterns should not be written at 90x or the noise level will be about ten times worse. Typically, for older JEOL microscopes, the best signal to noise will be found from 10x to 30x, 100x to 300x, and 1000x to 3000x. **Other brands will typically have the same effect, but at different values in magnification.** For example, on an FEI XL30 SEM, the signal to noise changes significantly around 750x, with the exact value depending on the direction of the last change in the magnification and on the working distance and accelerating voltage being used. A clue to where the range is divided is that the SEM image will often shift and/or an audible click will be heard as the SEM is changed across the range boundary. **The best signal to noise will be found just above the magnification value where the image shift and/or audible click is observed. For more information, see System Installation: Summary - Check List (page 13).**

- My patterns exhibit periodic noise on fine lines and/or small gaps in filled polygons, while other people in the group do not have these problems.

A typical cause for this is that some old microscopes (JEOL 6000 series, Leica/LEO S440, and probably others) will have internal noise that distorts the external scan signals when the microscope scan setting is left on TV or Super Rapid, etc. Ideally, when the microscope is in external scan mode, the internal scanning should not have any affect on the beam, however, that is not the case. The solution is to put the microscope in a Slow scan mode when doing lithography. Some new models will
completely turn off the internal scan generator when the SEM is in external mode, which eliminates this problem.

**Pattern Position Offset**

- When I write a pattern using different magnifications and/or beam currents, there is an unexpected offset between different parts of the pattern.

When the magnification and/or beam current is changed, virtually every SEM will have a shift of the image area and of the pattern writing area which may range from less than a micron to over 50 microns in some cases. This unwanted offset is caused by the basic design and/or miscalibration of the microscope's circuitry. Fortunately, this shift will typically be repeatable from one day to the next, although it may change when the column parameters have been adjusted significantly or after a major servicing of the column.

In the “Samples” project of NPGS v8.0 and higher, a run file called “Chk_Off1” can be used to easily measure the offset between any two combinations of magnifications and beam currents. Complete instructions are provided in the run file in the Comment entity. Once the shift has been measured for the parameters to be used for the pattern writing, the compensating shift can be entered into the “Origin Offset” parameter in the NPGS run file for the pattern. (The origin offset values entered into the run file will have the same sign as the values read from the screen when Chk_Off1 is processed.) This approach will typically allow the net offset to easily be reduced to much less than a micron. If this approach does not produce a consistent correction for the offset, the cause is typically that the substrate is charging during the writing and is dynamically shifting the beam position or that the stage is drifting.

Once origin offset values are determined that compensate for the shift when the microscope parameters are changed, the Chk_Off1 run file can simply be processed before subsequent writing sessions to see if the microscope’s offset has changed or not. If the Chk_Off1 run file has the last good offset values, the alignment will be good without any adjustments as long as the microscope’s offset has not changed.

- When I write a pattern without changing the magnification or beam current, there is an unexpected offset between different parts of the pattern.

The following causes for this type of problem have been reported:

1. A nearby freight elevator would cause a distortion in the Earth's magnetic field and consequently affect the position of the beam in the microscope. Other than disabling the elevator or working at night when the elevator is not in use, the only approach to solving this problem is to use an active magnetic field canceling system. These systems have coils around the room and a sensor near the SEM chamber. The coils are driven to null the magnetic field at the sensor. Such systems can cancel fields from DC to a kHz or so.

2. A small particle in the column would collect a charge during dynamic point to point blanking of the beam during the pattern writing with NPGS v8.0 and earlier and would cause a consistent offset. Since the beam is not dynamically blanked during the normal mode alignment procedure, this offset would appear even after a careful alignment to the registration marks. The offset was so consistent that initially, the user simply designed a compensating offset into the pattern. This approach worked until the column was cleaned and the particle was removed, which eliminated the original offset.

3. A related problem was also seen where different layers of the pattern had up to a 1 micron offset. The offset was again caused by charging related to the dynamic blanking of the beam (with NPGS v8.0 and earlier). In this case, the user had designed a pattern with two very different exposure times on the two layers of the pattern. This effectively caused a different blanking frequency for each layer, which resulted in a different steady state charging and corresponding beam offset. The quick solution was to keep the exposure times in the different layers more similar and the long term solution was to clean the blanker/column to remove the contamination that was charging.
Pattern Size

- My patterns are not exposed at the size I designed them to be.

The "mag scale" parameter in "Pg.sys" tells the NPGS software what the microscope field of view is at each magnification. See the section in the "NPGS Installation Guide" on "System Calibration" to adjust the "mag scale" parameter. If the calibration has been successfully completed at one magnification, but the patterns are not correct when written at a different magnification, then the microscope may need to be serviced. Each type of scope will have a different specification on how accurate the magnification is at different settings. A high performance SEM should be accurate on the order of 1 to 3%.

An alternate cause may be that the microscope magnification was not set at the value entered in the run file. This is the typical cause for size scaling errors that are the same in both the X and Y directions.

Other possibilities are that a microscope setting has been changed that affects the scaling of the XY inputs when in external control. Examples of such settings may include the scan speed (the TV mode on older Hitachi SEMs has been observed to do this), tilt correction (this SEM feature can be used to intentionally distort the XY aspect ratio and should normally not be used during lithography), or a magnification calibration mode (on PC based SEMs, this adjusts the displayed magnification value so that it may match the output when viewed on the monitor or when the image is printed on a video printer, or reproduced on a Polaroid - in each case, the "magnification" value is adjusted so that it corresponds to the viewing size of the image).

When the problem is caused by the tilt correction setting of the microscope, the pattern scaling will be correct in one direction and will be too small in the other direction.

When the problem is caused by the ‘magnification calibration mode’ of the microscope, the size scaling error for both X and Y will be the same and may be either too small or too large. If the microscope magnification was set to the correct magnification during the writing, then the most likely cause for an overall writing size error will be that the magnification calibration mode has been changed. This issue applies primarily to Zeiss/LEO models and older FEI/Philips models that allow the mag calibration mode to be set between choices such as Display, Polaroid, VideoPrinter, or File/Printer. Any of these choices can be used with NPGS, however, the same choice that was used when the ‘mag scale’ in Pg.sys was determined should be used for all subsequent pattern writing.

NPGS v9 Software

NPGS Menu program does not launch properly

- I am running under Windows XP/Vista/Win7 and when I double click the NPGS Menu icon, an error message about “Read/Write file access” is displayed. (For older versions of NPGS, the error messages “Menu(13)” and “Run time error 75” are displayed.)

When running NPGS under Windows XP/Vista/Win7, the user’s login must have file access privileges so that the files in the “\NPGS” directory structure can be modified. The error messages listed above are seen when the user has not logged into Windows and does not have permission to modify the NPGS files.

In order to run NPGS in a non-Administrator login, you must set the file permissions for the NPGS directory to allow other users to have full access to the files. Using Windows Explorer, select the NPGS directory, right click, then select "Properties". On the "Security" tab, set the file permissions to give Full Access to Power Users, which will allow anyone with Power User accounts to run NPGS. If the Security tab is not present, from Control Panel - Folder Options - View tab, remove the check from "Use simple file sharing" (at the bottom of the list).
If the problem persists when logged in as the Administrator, then it may mean that an old version of NPGS is being used. In this case, downloading and installing the latest update to NPGS v9 may solve the problem.

- Everything had been working fine and NPGS would start in the last project which was used, but now an error message is displayed and the Menu program terminates.

This problem has been observed when one or more critical files in the starting project have become corrupted, usually by a user overwriting their current NPGS system files with outdated backup files from a previous version. In this case, the first issue is to launch NPGS so that other users can continue to use the system. To do this, first delete the \NPGS\Program\Pg_StartPrj.sys file. This will cause a list of all projects to be displayed when the Menu program is launched. The first project on the list will be the corrupted project, but any uncorrupted project will launch correctly.

The second issue is to copy the valid system file(s) into the corrupted project. It is always recommended to have periodic backups of all NPGS files, but if a recent backup does not exist, the corrupted file(s) can be copied from another working project. In this case, the Pg_Menu.sys file is most likely the one that is causing the Menu program to fail to launch, but others may be corrupted as well. Note that if Pg_Menu.sys is replaced, any unique custom commands defined in the corrupted version will be lost.

- I am running NPGS with a non-US version of Windows and the NPGS Menu program will not launch and/or the Run File Editor does not work.

The problem is caused by the decimal place symbol used in many non-US configurations of Windows. NPGS automatically identifies this character under Windows 2000/98/95 and runs properly, however, non-US versions of XP operate differently than the US version. Consequently, when using a non-US version of XP, the decimal place symbol must be set to a period. The decimal symbol can be changed to a “.” (period) through the Windows Control Panel using the “Regional and Language Options” choice.

Running NPGS under Win7

- Our IT department supplied a PC with Windows Win7 for NPGS, but when we installed the ‘Microscope Installation’ of NPGS, it did not work.

The original board driver supplied with NPGS only worked with Windows 2000 or XP, however, an updated driver which works with 32 bit Windows 2000/XP/Vista/Win7 (all Professional versions) is available. Send e-mail for details. Note that a driver to allow the NPGS hardware to work under 64 bit Windows may be available in the future.

- When running the NPGS ‘Office Installation’ under Win7, a ‘run-time’ error is encountered when I try to start the NPGS Menu program or the Run File Editor.

The typical problem that has been observed when launching the Run File Editor under Win7 is the same as what is seen when running NPGS under Windows XP.

In order to run NPGS in a non-Administrator login under Windows, you must set the file permissions for the NPGS directory to allow other users to have full access to the files. Using Windows Explorer, select the NPGS directory, right click, then select "Properties". On the "Security" tab, set the file permissions to allow "Full Control" to each user that will run NPGS. Alternately, in some Windows versions, you can give "Full Access" to "Power Users", which will allow anyone with Power User accounts to run NPGS. If the Security tab is not present, go to "Tools" on the Windows Explorer menu, select "Folder Options" then the "View" tab and remove the check from "Use simple file sharing" (at the bottom of the list). After completing this step, the "Security" tab should be modified as described above (hit "View – Refresh" on Windows Explorer, if the Security tab is not initially displayed). An alternate sequence to enable the Security tab is from the Control Panel (Classic View) - Folder Options - View tab or Control Panel (Category View) – Appearance and Themes – Folder Options – View tab. Also, if using a non-US version of Windows, set the decimal character to a period.
If the problem persists when logged in as the Administrator, then it may mean that an old version of NPGS is being used. In this case, downloading and installing the latest update to NPGS v9 may solve the problem.

- When running the NPGS ‘Office Installation’ under Win7, the ‘Arrow Question Mark’ popup help displays an error message.

An issue unique to Vista/Win7 is that Microsoft decided not to include the software to support the popup help that is so useful in the NPGS Run File Editor (through the “Arrow - Question Mark” icon in the lower right corner). However, Microsoft does allow the support software to be downloaded at no cost.

The following web sites have a free download from Microsoft which will add the WinHelp support under Vista and Windows 7:

[http://support.microsoft.com/kb/917607](http://support.microsoft.com/kb/917607)  - Info and Download Links

To download WinHlp32.exe for Win 7:
[http://go.microsoft.com/fwlink/?LinkId=166421](http://go.microsoft.com/fwlink/?LinkId=166421)

To download WinHlp32.exe for Vista:
[http://go.microsoft.com/fwlink/?LinkID=82148](http://go.microsoft.com/fwlink/?LinkID=82148)

If the link doesn't work, you can find the appropriate download on the Microsoft site by searching for WinHlp32.exe. Also, Microsoft does not allow other companies to include this update with non-Microsoft software, which is why it is not already included with NPGS.

Note that this file allows the very useful popup help to work in NPGS, but it is not required for the overall operation of NPGS.

- When running the NPGS ‘Office Installation’ under Win7, I get errors or crashes when using DesignCAD LT 2000.

Another file not found in Vista/Win7 which may be needed is "d3drm.dll". This is used for some graphics functions and may affect the performance of DesignCAD. It can be found online or in C:\WINDOWS\system32 on a system with XP.

The latest release of NPGS supports DesignCAD v21.2, DesignCAD v16.2 and the older DesignCAD LT 2000 (all versions can be installed simultaneously, if desired). The versions 21.2 and 16.2 work fine under Vista/Win7, however, some random problems may be encountered when using the older DesignCAD LT 2000. It has been reported that the problems will stop if a ‘classic’ Windows theme is used instead of one of the newer themes. If this does not resolve the problem, a newer version of DesignCAD should be installed.

The ‘NPGS’ menu is not in DesignCAD

- In DesignCAD, the menu entry labeled ‘NPGS’ is not present.

This problem typically means that one or more of the files NPGS uses to initialize DesignCAD has been corrupted. For DesignCAD v21, deleting the file ‘NPGS_DC21E_RefreshFiles.txt’ in the NPGS project where the problem occurs and then leaving and reentering the project will force NPGS to restore the DesignCAD files to the default copies from the \NPGS\Projects directory. For DesignCAD v16, delete the file ‘NPGS_DC16E_RefreshFiles.txt’.
Copying Custom Commands Between Projects

- I have created a new project and I would like to copy all of the custom commands from my other project.

To copy all of the NPGS custom command definitions from an old project to a new project, do the following steps. Be aware that all user defined settings for the project will be copied.

1. Set the "Current Project Directory" to the NEW Project (where the custom commands will be copied to).
2. Select "File - Update System Files".
3. Use the "Browse" button to set the "Source" directory to the OLD project (where the custom commands will be copied from).
4. Select "Pg_Menu.sys - Project Buttons/Colors" from the first column of files and click "Yes" at the warning.
5. Click "Copy Files" at the bottom of the window and then "Yes".

To copy individual Custom Commands between projects, use the Cut/Copy/Paste buttons on the Custom Command dialog box.

The “Update System Files” dialog box can also be used to copy any of the NPGS system files between projects or to and from the “Master” set of system files.

Unexpected Color Order in Run File Editor

- When I manually define a number of colors in my pattern, the order of the colors as displayed in the Run File Editor is not what I expected.

The issue regarding the ‘pure white’ color as discussed below has been eliminated in the current release of NPGS. Now, a pattern will only be ordered using the original DOS 16 color scheme if only those colors are used in the pattern.

NPGS includes a backwards compatibility feature for old patterns that are based on the DOS color scheme. This feature is very useful when users with old NPGS versions have updated to the latest version and want to continue to use their old patterns. This feature will correctly order the old patterns using the original DOS color scheme, if the pattern includes one entity that is pure white, i.e., RGB = (255,255,255). Since nearly all old patterns will contain pure white, most old patterns will automatically be interpreted correctly by default. One consequence of this feature is that new patterns should avoid using pure white, otherwise, the old ordering mode will be activated. Since pure white is not listed in the color palette, it should be easy to avoid using it in new patterns. Note that using RGB = (254,254,254) or anything similar, but not pure white, will work fine in the new ordering scheme.

Failure to launch DesignCAD

- The button in the NPGS Menu program for running DesignCAD is active, however, when clicked, it fails to launch the program.

The problem has only been seen when the Windows username for the Administrator has been changed and NPGS is running under the new username. The solution is to avoid changing the Administrator username or to only run NPGS from other Windows user logins.

This problem has been eliminated in the latest version of NPGS.
Virus Alert

- My Symantec anti-virus software has issued a ‘SONAR’ alert regarding the Al.exe program (or any other NPGS executable).

SONAR is an abbreviation for Symantec Online Network for Advanced Response which is intended to provide real-time protection by examining the behavior of applications in order to decide if they are malicious. This means that some action of the executable is being flagged as suspicious by the SONAR algorithm. If the executable has the same file size as on the original NPGS CD or has been downloaded from the NPGS web site, the alert is a false positive and the program should be placed on an ‘exclusion’ list within the Symantec software. Otherwise, delete the file and run the most recent NPGS update.

According to the Symantec web site: “SONAR might inject some code into the applications that run in Windows user mode to monitor them for suspicious activity. In some cases, the injection might affect the application performance or cause problems with running the application. You can create an exception to exclude the file, folder, or application from this type of monitoring.”

Missing Project Directories

- I previously had several NPGS Projects defined, but now one (or more) do not show up in the pull down project list in the NPGS Menu program.

NPGS maintains the file "\NPGS\Program\Pg_PrjDir.sys" that contains the list of active projects. In some cases, this file has become corrupted, thus resulting in missing projects within the NPGS Menu program. If only one or two projects are missing, the easiest approach is to run "Projects - Create New Project" and typ a name of a missing project, and hit "Create". The NPGS software will then see that the project already exists and will give you the option of using it without any changes (as long as the full list of system files exists in the project). If many projects have disappeared from the list, the easiest approach is to replace the corrupted "Pg_PrjDir.sys" file with a good version from the most recent backup of the system and in the NPGS Menu program automatically create a backup of the project list in "\NPGS\Program\Pg_PrjSav.sys", which will automatically be used if NPGS detects that the original list has been corrupted.

Pattern Design with DesignCAD

Design Units

- What are the units displayed in DesignCAD?

Within DesignCAD, the units should be set to "inches", however, they will be interpreted as "microns" by NPGS. Consequently, the user can simply consider all dimensions displayed in DesignCAD as microns. (When the units are properly set, DesignCAD will interpret 1.0 as 1 foot, while NPGS will interpret the same value as 1 micron.)

- When I write the same pattern at two different magnifications, why are the structures written at the same size? I had expected the sizes to scale with the magnification when I change it on the SEM and in the NPGS run file.

In some simplistic SEM lithography systems, the pattern size (and doses) vary as the SEM magnification is changed. However, NPGS has always been designed to write the patterns at an absolute size which is defined in the pattern itself. This approach makes it unnecessary to make calculations for the pattern size, while instead the user knows that a pattern element designed to be 10 microns in DesignCAD will be 10 microns when exposed (as long as the magnification listed in the NPGS run file matches the magnification of the SEM when the pattern is written). Of course, if NPGS is not properly calibrated or if the SEM magnification does not match the value in the run file, the
patterns will be written at an incorrect size. See the printed NPGS Installation Guide that was provided with the system for information on calibrating the pattern size for NPGS.

**Filled Polygon Display**

- When I use the BasicCAD program "PolyFill" to make a filled polygon, the dashes (or dots) of the lines defining the polygon are smaller than I would like them to be.
- I have imported patterns from other CAD formats and the dashes of the filled polygons are too small or too large.

Filled polygons are denoted by dashed (line type=1) or dotted (line type=5) lines. The "Line Scale" parameter determines the size of the dashes or dots. If the display of the line appears slow and solid, then the Line Scale parameter is too small. Note that this parameter only alters the display in DesignCAD and has no effect on the pattern writing.

Within DesignCAD, you can click on a drawing element and hit "Ctrl I" to bring up the Info Box. From there, you can select the dashed (1st choice below solid) or dotted (5th choice after solid) line types to change between the serpentine sweep mode and the one-sided sweep mode, respectively. You can also change the Line Scale parameter to any desired value. Note that for filled polygons, the Linewidth should be zero.

To change the Line Type, Line Scale, and/or Linewidth for all lines in a drawing layer, use the layer options window. This window is accessed by hitting "L" or using the menu command "Options - Layer". Once there, the "Assign Line Style" prompt will allow any desired changes to be made for all lines in the selected layer.

**Errors with Filled Polygons**

- I have made Filled Polygons in DesignCAD, however, the patterns generate errors when I try to write them.

When problems are encountered with Filled Polygons, the reason is almost always that the "NPGS - PolyFill" command in DesignCAD was not used to create the structures. When Filled Polygons are designed manually or are converted from other pattern formats, it is possible that invalid structures can result. In DesignCAD, the command "NPGS - CheckAll" can be used to check the entire pattern for elements that will be ignored when the pattern is written, as well as for invalid or questionable Filled Polygons.

**Off-Site Pattern Design**

- I would like to be able to design patterns in my office or at home, rather than in the microscope room.
- I have a collaborator who would like to design patterns at another location for us to write on the microscope here.

If patterns are to be designed on a PC other than the one connected to the SEM, the "Office Installation" mode can be selected when running the NPGS Installation program which will then install the appropriate NPGS files so that patterns and run files can be created just as on the original PC that is connected to the microscope.

*After installing the "Office Installation" of NPGS, a licensed copy of DesignCAD v21.2, v16.2, or LT2000 should be installed.* For information on obtaining additional DesignCAD licenses, send e-mail to Info@jcnabity.com. Only DesignCAD Express v21.2, DesignCAD Express v16.2, or DesignCAD LT2000 should be used with NPGS.
Missing Tool Menus

- I was using DesignCAD and the NPGS ToolBox icons on the left side of the screen were completely removed from the display.

This can happen when a toolbox is disabled or when DesignCAD is restarted after the program has encountered a serious error. In either case, use “Options – Options” then the “Toolbox” tab, then the “Load Toolbox” button to load “NPGS_Tools1.dct” and/or “NPGS_Tools2.dct” In DesignCAD v21, these files will be located in “My Documents\DesignCAD 21”. In DesignCAD v16, these files will be in “\NPGS\DC16Exp\”.

- I was using DesignCAD and the image for the zoom icons in the lower right part of the window became blank (or the ToolBox icons on the left of the screen), however, the commands actually function when I click where the icons are normally displayed.

The icons will be displayed properly if you minimize and then restore the DesignCAD window.

Running DesignCAD from a Desktop Icon

- When I start DesignCAD, it sometimes uses my project directory, but other times it uses the projects of other users.

This will happen when either the DesignCAD icon on the Windows desktop or the DesignCAD entry in the “Start - Program…” menu is used to run DesignCAD. **It is recommended that any desktop icon and/or the entry in the Start menu for DesignCAD be deleted to prevent this from happening.**

**DesignCAD should only be run from within the NPGS Menu program!** The NPGS Menu program makes sure that DesignCAD uses the correct project and that any changes in DesignCAD are uniquely saved for each project.

BasicCAD Programs

- An error message is displayed which says an NPGS BasicCAD program cannot read “ProjFile$”.

This can be caused by anti-virus software that prevents access to the file “\NPGS\Temp\current_project.tmp” which is referenced as ProjFile$ in some NPGS BasicCAD programs. In some cases, the anti-virus software may not give any obvious indication that it is preventing the access. The solution will depend on the specific anti-virus program. Typically, anti-virus programs will have an ‘exclusion’ list for programs that should not be checked or restricted. The BasicCAD programs are processed by the main DesignCAD executable, so excluding that file should solve the problem.

- The OrderEntities and OrderGroups functions in the “NPGS” menu within DesignCAD sometimes do not finish properly. What should I do?

These functions are BasicCAD programs that must save and reload the file to reorder the pattern entities. Sometimes, the reload function will not work successfully. In that case, the original file can be copied from “\NPGS\Temp\pg_back.dc2”

However, on some PCs with fast graphics adapters, the software occasionally gets confused and a message window from the BasicCAD program will be displayed behind the main DesignCAD window. In this case, minimizing and restoring the main DesignCAD window forces the BasicCAD window to the front and allows the function to finish successfully. Also, see the patch discussed below.

- The Save function in the “NPGS” menu within DesignCAD sometimes does not display the final confirmation that the file was saved successfully. What should I do?
On some PCs with fast graphics adapters, the software occasionally gets confused and a message window from the BasicCAD program will be displayed behind the main DesignCAD window. In this case, minimizing and restoring the main DesignCAD window forces the BasicCAD window to the front and allows the function to finish successfully.

There is also a patch that allows an extra time delay to be added, which can eliminate this problem. The file "\NPGS\Temp\dc_order_delay.tmp" can be created with a single line consisting of an integer number of milliseconds, which will indicate how much extra delay should be added. A value of 200 or higher should take care of the problem.

**Virus Warning**

- **My anti-virus software has identified "W95.CIH.remnants" in the file "encrypt.exe". Should I be concerned?**

**This issue only applies to DesignCAD LT 2000.**

Many years ago, that file apparently had the "W95.CIH" virus, but the virus was removed. However, the file still contains some bits from the virus code and starting in October 2004 some virus scanners started treating the "remnants" of the virus as an active virus, even though it cannot do anything under Windows.

You can either quarantine or delete the file, since it is not used with NPGS.

- **My anti-virus software has identified "W95.CIH.remnants" during the installation of DesignCAD LT2000 and has prevented the installation from being successful. What should I do?**

**This issue only applies to DesignCAD LT 2000.**

As explained above, the "remnants" cannot do any harm in Windows. Consequently, you should: 1) Disable the active virus checking; 2) Install DesignCAD LT2000; 3) Enable the active virus checking. This will allow the installation to be successful, and the "encrypt.exe" file can be deleted later, if desired.

**Setting a Small Snap Grid Size**

- **When I set the Snap Grid Size to a small value, it instead snaps to a grid of a larger spacing than what I have specified.**

**This issue only applies to DesignCAD LT 2000.**

Unfortunately, in DesignCAD LT2000, the Small Step Size interacts with the Snap Grid Size, however, there is an easy fix. If you go to the menu command "Options - Options..." in DesignCAD, then select the "Cursor" tab and set the "Small Step Size" to be equal to or smaller than your desired snap size, the Snap Grid Size you have defined will be used.

Note that the "Large Step Size" defines the displacement when the arrow keys are used and the "Small Step Size" defines the displacement when the "Shift" key is held down while the arrow keys are used. If you never use the Shift-Arrow combination, then you can simply set the "Small Step Size" to a very small value, and the "Snap Grid Size" will always work as expected.

**Beam Blanker**

**Reversed Beam ON/OFF**

- **The blanker had been working properly, however, now the blanking states have become reversed, i.e., "Beam On" blanks and "Beam Off" turns it on.**
This problem has been seen with blankers that are installed near the gun when the user has left the blanker in the “Beam Off” state and then proceeded to optimize the microscope. Initially, no beam current will be observed, however, the gun alignment gets adjusted by the user such that the deflection from the blanker is compensated for by a misalignment of the gun. The net result is that when the blanker enters the “Beam On” state, the gun is so badly aligned that the beam is effectively blanked. The solution is to always make sure that the blanker is in the “Beam On” state when the microscope is optimized.

**Exposed Dot at Origin**

- The SEM has a fast blanker, however, after writing a pattern or just doing an alignment, there is an exposed spot in the middle of the field of view.

This has been seen when a blanker is “leaky”. Instead of completely blanking the beam, enough current hits the sample to cause the extra exposure. The extra exposure appears as a dot at or near the center of the field, because that is where the scan coils are normally set after writing when the system has a fast blanker. The best solution is to fix the blanker. A less desirable solution is to set a dump point in all patterns so that the beam is never "parked" in an important area of the writing field.

When a blanker is not working correctly, the two most common causes are that the blanker electronics have malfunctioned or that the blanker plates are dirty. In some cases, the voltage going to the plates can easily be measured to check if the electronics are working properly. *Be careful, since some blankers use high voltages.*

In some blankers, the blanking plates can be removed by the user and cleaned according to instructions provided with the blanker. Note that the orientation of the blanker within the column may be critical. If the blanker has two or four-fold symmetry in its position, be sure to mark the original position before removing the blanker plates.

Also, when the blanking electronics have an adjustable blanking voltage, another possibility is that the blanking voltage is just not set high enough. The best blanking voltage is usually 1.5 to 2x higher than the threshold voltage where the beam just starts to be blanked. The blanking threshold voltage may change depending on the beam alignment in the column, so the ideal blanking voltage may also vary over time.

**Pattern Writing Time with a High Beam Current**

- When I use a very high beam current, the required exposure times are longer than they should be (i.e., it appears to take more dose at higher beam currents!).

When using a JEOL magnetic blanker, the rise time for turning on the beam will depend on the beam current, if the blanker is not installed properly. To check for this problem, connect a two channel oscilloscope to the Secondary Electron Detector Photomultiplier Tube (PMT) output and to the Blanking Control Circuit (BCC) output. Then write a pattern consisting of a single large filled rectangle with the exposure time per point set to about 50 usec. If the blanker is working properly, the PMT signal should lag the BCC signal by about the same amount independent of the beam current. Magnetic blankers typically have about a 1 usec rise time, while electrostatic blankers typically have rise times of 100 ns or less.

**Alignment**

**Invalid Matrix Calculation**

- The alignment program responds with "Invalid Matrix Calculation" or "Invalid Mag. And Offset" when I recalculate the alignment matrix
This error message results when the calculated alignment matrix* would cause the alignment windows to be scanned outside of the allowed field of view. For example, if the alignment windows are positioned only 3 um away from the edge of the field of view, then an overlay offset of >3 um would require the windows to move outside of the field of view, thus causing this error. (*The “Mag and Offset” message is the same as the “Matrix” issue, but is displayed when a full 2x2 matrix is not being used.)

When the run file is being created, an easy way to check how much room is available for moving the windows during the alignment is to look at the limit that is displayed on the status bar at the bottom of the Run File Editor window when the "Origin Offset" entry is highlighted. For both alignment patterns and writing patterns, the value displayed on the status bar will be the maximum amount that the pattern can be moved in X and Y during the alignment that guarantees that the pattern will not "hit" the edge of the writing field.

Note that the magnification used for the final alignment must be the same as the magnification used for the subsequent pattern writing and that adequate space must be left for moving the alignment windows, as well as the pattern(s) to be written. The best approach is to ensure that the "Origin Offset" limit for the subsequent patterns is equal to or greater than the limit for the alignment windows, and that the alignment window limit is large enough to accommodate the uncertainty of the initial stage position when the alignment windows are first scanned.

Another cause for this message is when four alignment windows are open and the user recalculates the matrix after only one window has been aligned. In some cases, this partial alignment will result in an invalid matrix. For the best results, when four windows are open, all overlays should be aligned before recalculating the alignment matrix.

**No Alignment Image**

- When I use the AL program, I do not see an image on the PC screen and the "DATA" values just slowly drift or are constant with a 1 or 2 point difference.

Check that a cable is connected between the "Input" connector on the NPGS hardware at the back of the PC and an image intensity signal on the microscope. The image intensity signal should change as the beam hits areas on the sample of different "brightness". The signal can be from a secondary or backscattered electron detector as long as the maximum signal is within +/-10 volts. Ideally, as the beam goes from bright to dark, the signal will change by 0.5 volts or more. In AL, the "DATA" values correspond to the 16 bits of the ADC. Consequently, a 1000 point range in the "DATA" indicates a 0.3 volt data range, when the input voltage range of the ADC is +/-10 volts. It can be quite informative to connect an oscilloscope to the signal to observe its response to the contrast and brightness settings, as well as to the structure on the sample.

**Pattern Alignment when using the Global Rotation Mode**

- After using the Global Rotation mode to compensate for a ~90 degree rotation of my sample, the alignment windows are also rotation by 90 degrees.

The alignment feature expects that the scan axes of the microscope will initially be at least nominally aligned with the axes of the sample. If the sample is rotated by some large angle, the "Scan Rotation" feature of the microscope should be used to make the scan axes nominally align with the sample rotation. If the microscope does not provide a "Scan Rotation" feature, or if the "Scan Rotation" feature distorts the pattern writing and cannot be used, you should use the stage rotation to nominally align the sample with the scan axes.
External Control (Stage/SEM/Etc)

SEM/Stage Interface not Working

- When I try to have NPGS control the SEM and/or the automated stage, the SEM/stage driver reports an error.

For many models of SEMs, NPGS communicates with the SEM by calling a batch file with specific commands that control the microscope and/or stage. When using NPGS version 8.0 or newer, i.e., with a Windows user interface, any batch files called by NPGS must have a full path specified when calling other programs. It is recommended that any non-standard programs used with NPGS be placed in the "\NPGS\Projects" directory.

Another issue can be that the programs used within NPGS to communicate with the SEM and/or stage will typically have a "system" file that contains parameters for the communication. (See the documentation behind the divider in the NPGS Installation Guide for the specifics on the files used to communicate with your SEM and/or stage.) Each NPGS Project subdirectory will have a unique copy of the system file, as well as the \NPGS\Projects directory. Consequently, if you are testing the communication from a command line prompt in the \NPGS\Projects directory (which is where the communication program executable will be located), the system file to modify will be in the same directory. Also, if any changes are made to the system file in the \NPGS\Projects directory during the initial setup, the working file should also be copied to all other NPGS projects. (This can be done through the NPGS Menu System File Editor using the ‘File - Load Defaults’ function.)

When using NPGS under Windows 2000, XP Vista, or Win7, a 32 bit interface program is required. Updated versions of the drivers for common SEMs and stages are available for use with NPGS v9 at no charge.

- The SEM/Stage interface had been working fine, however, now NPGS is not able to control the SEM/Stage.

The first thing to check is that the SEM and/or stage control has not been disabled within the Advanced Modes of the run file being used. Also, check that the Ethernet or serial cable between the NPGS PC and the SEM has not been disconnected.

Alternately, newer PC based microscopes typically have separate programs that enable the external control of the SEM and/or stage. Ideally, the control program will automatically load when the microscope PC is rebooted, however, that is often not the case. Also, even when the correct program is automatically loaded on a reboot, another user may accidentally terminate or disable the external control interface while using the microscope.

For LEO/Zeiss SEMs, including the 440, 1400 series, 1500 series, Evo, Supra, and Ultra series, be sure that the "RemCon.exe" or "RemCon32.exe" program is running and enabled on the SEM PC.

For FEI (Philips) XL30 and Sirion SEMs, be sure that the "SCS.exe" program is running and enabled on the SEM PC.

For FEI Quanta, NanoSEM, NanoLab, and Helios microscopes**, be sure that the DCOM Ethernet interface is properly installed and that the same user name and password is used to log into both the SEM PC and the NPGS PC.

For the JEOL Ethernet Interface** on the 5600, 5900, 6060, 6360, 6460, 6380, 6480, 6390, and 6490 models be sure that the "EDSI.exe" program is running and enabled on the SEM PC.

For the JEOL EIK Ethernet Interface** (used on the 6500F/7000F/7400F/7500F and similar), a JEOL technician must configure the NPGS PC in order for it to communicate with the JEOL SEM.
**Another possible explanation is that some anti-virus software may block or quarantine NPGS programs that communicate with the SEM through an Ethernet connection. If this happens, the NPGS program should be marked as safe or set to be ignored within the anti-virus software.**

*Note that often when you buy an SEM with an external control option (typically serial or Ethernet), the SEM vendors will NOT include the documentation that describes how to run it!* You are encouraged to contact your SEM vendor and request that the complete documentation on the external control interface be provided. The documentation should describe how to enable the external control and it should also include a complete list of the available commands for external control of the SEM and/or stage.

**Sharing Connections with EDS/WDS Systems**

- NPGS has been working fine, but now we want to add an x-ray system to the microscope. What do we do?

  The main issue is that other microscope accessories such as EDS/WDS systems will typically need access to the same connectors as NPGS. Some SEMs will have multiple sets of inputs for the analog voltages, however, most microscopes only have one XY input connector (or a pair of connectors when BNCs are used). In this case, either the cable(s) from NPGS and the other system must be physically changed before each system is used or a switch box can be installed that allows one system or the other to access the SEM XY input. The video signal output from the microscope can typically be connected to both NPGS and the other system simultaneously.

  Some microscopes will have a serial input that allows external systems to control the microscope parameters such as magnification and focus. If the driver for NPGS is set to use the same serial communication settings as the other system, the simplest approach is to install a standard serial A/B switch box that will allow one system or the other to access the serial input to the microscope.

  *For all inputs to the microscope, such as XY, blanker, enable, and serial connections, you should never "tee" the cables from NPGS and the other system together.*

  Related Topic: SEM Input Connectors (page 211)

**USB Remote Enable Switch not Working**

- I am using the NPGS USB Remote Enable Switch and after it was accidentally unplugged, Windows is now telling me to insert the “Compact Disk labeled ‘FTDI USB Drivers Disk’ into the CD-ROM Drive. What should I do?

  When the NPGS Remote Enable Switch is shipped with NPGS, the drivers for the switch will be in the directory “Pg_USB_Driver” on the NPGS Installation CD. Inserting the NPGS Installation Disk and clicking the OK prompt should allow Windows to find the necessary driver. If not, browse to the specific directory on the disk.

**SEM Input Relay Adapter not Working**

- I have the optional SEM Input Relay Adapter that was supplied with NPGS and it no longer switches to the mode for external control of the SEM.

  When the adapter is without power, the default condition is to stay in the internal SEM mode. The newer style of Input Relay Adapter is powered through the NPGS USB Remote Enable Switch. In this case, check that the Remote Enable Switch is connected and is working properly. Documentation on the Remote Enable Switch is located in at the back of the printed NPGS Installation Guide.

  For older versions of the Input Relay Adapter, the most likely explanation for not switching the external mode is that the 5v power plug has come loose from the adapter or that the power supply itself has been unplugged from the wall socket. There should be a cable tie securing the power plug
so that it is not accidentally pulled out. In one case, the power supply itself had failed and was promptly replaced at no charge.

**Skipped Commands**

- The interface between NPGS and the SEM typically works fine, however, during some very long writing sessions, it appears that the some of the SEM commands sent by NPGS are skipped.

This problem had been observed on overnight exposures and it was subsequently determined that a Task Scheduler program on the LEO SEM was running a disk defragmenter and/or a virus checker in the middle of the night during the pattern writing. The result was that the SEM was not receiving some of the serial commands being sent by NPGS, i.e., stage moves and/or changes of the magnification. The solution was to disable the Task Scheduler during overnight exposures.

**Delay Before Each Pattern is Written**

- When I start PG or AL there is about a 15 second delay when the program is loading, but the delay only occurs for some run files.

If a run file includes a command for an automated stage and a stage driver name is listed on line #1 of "Pg_Stg.sys" or a microscope driver name is listed on line #9 of "Pg_Cmdn.sys", an attempt to pass a command to the stage controller or microscope will be made when PG or AL begin. If a stage controller or microscope interface does not properly accept the command, the program will pause while the communication is attempted. In some cases, the driver will wait indefinitely and the computer will appear to have crashed. If the stage controller is already turned on, check that the cable between the NPGS PC and the controller is properly attached. Also, for newer microscopes where the stage is interfaced through the SEM PC, be sure that the interface program is running on the SEM PC. If no stage control is desired, either blank out line #1 of "Pg_Stg.sys" or disable the stage control using the "Advanced Modes" in the Run File Editor (for older versions, enter a "/" in the run file for the stage command).

**PCI516 Board**

**ERROR: Could not open communication**

- When the NPGS PC is booted, the following error message is displayed:

```
No SP_INTERFACE_DEVICE_DATA available for this GUID instance
ERROR: Could not open communication with NPGS PCI516 Board!
```

When the NPGS software is installed properly, but the actual PCI516 board is not in the PC, this message is displayed whenever the NPGS software attempts to access the board. If the board has been removed for repair, this message can be ignored and other NPGS functions can be used.

If this message is seen when the NPGS PCI516 board is properly installed, then it suggests that the board is not functioning properly or that the Windows driver for the board is no longer installed. In this case, follow the diagnostic steps in the 'Self-Calibration Failure' section below.

- The "Menu(220) Integrity Check" message is displayed when I load the NPGS Menu program.

For older installations of NPGS v9, this error indicated that the HASP security plug was not found. For NPGS v9.1 and higher, the HASP security plug has been replaced by other security measures and the error indicates that the NPGS PCI516 board cannot be accessed.
Self-Calibration Failure

- During the self-calibration of the PCI516 board, an error message is displayed saying that the calibration has failed.

The NPGS PCI516 board must run a self-calibration each time the PC reboots, and by default, the NPGS Menu program will run the board's self-calibration when Menu is started, if the calibration has not been done in the last 10 hours. The user can also manually start the self-calibration using the NPGS Menu command: “Commands - Calibrate DACs”.

The self-calibration process first calibrates the blanker control voltages, as specified in Pg.sys, then it sweeps through the full X and Y voltage ranges to create a lookup table to improve the linearity of the XY outputs. An error message will be displayed if either calibration fails. In that case, the following diagnostic steps can be performed:

Use anti-static precautions, such as an anti-static wrist strap, to avoid damaging the PCI516 board by static electricity during any handling of the board or cables attached to the board.

1. Reboot the PC. It is always possible that Windows can develop some problem that is cleared by rebooting the PC. For some unusual problems in Windows, the PC must be turned completely off and not restarted for ~5 minutes. Even though rebooting is not typically a solution for problems with the PCI516 board, in general, this can be a good first step for any problem seen in a Windows based system. If rebooting initially fixes the problem, but the problem reappears, check to make sure the PC is not entering a Standby, Suspend, Sleep, or Hibernate mode. These modes should be disabled in Windows on the NPGS PC, since they are not compatible with the PCI516 board.

2. Check for a virus or spyware on the NPGS PC. One PC virus has been seen that caused the PCI516 self-calibration to fail.

3. Confirm that the NPGS516A driver is installed in Windows. From the Control Panel, go to System, Hardware, then Device Manager. The NPGS PCI516 Multifunction Board should be installed under ‘Other devices’ (the yellow question mark displayed in some versions of Windows is normal). When the Properties are checked, the status should be that the device is working properly. If the driver needs to be reinstalled, it can be found on the original NPGS Installation CD.

4. Use "Commands - Digital Imaging" to check if an image can be captured from the microscope. If so, it means that the basic X, Y, and Imaging functions are working, and the board may still be useable for lithography. This may be the case if a minor problem exists that is causing the self-calibration to fail, even though the problem is too small to be seen in any patterns.

5. Disconnect all cables to the PCI516 board and retry the calibration. It is possible that noise, a short circuit, or some other electrical problem in the microscope can affect the XY voltages during the self-calibration, such that the calibration will fail. If the board passes the calibration when disconnected from the microscope, the problem in the microscope should be fixed before reconnecting the cables to the PCI516 board.

6. Reseat the board. Be sure to use measures such as an anti-static wrist strap to avoid damaging the PCI516 board by static electricity during any handling. The board does not need to be removed, but just pull it slightly out of the PCI slot and securely reinsert it. It is possible that the self-calibration failure can result when the PCI516 board is not properly inserted into the PCI slot. This is most likely to happen during the initial shipment of NPGS when the board is shipped preinstalled in the PC, but it can also happen if the PC has been moved or if the NPGS cables are stressed.
If the calibration failure is not resolved by these diagnostic steps, then the board will need to be returned for repair.
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