BNS

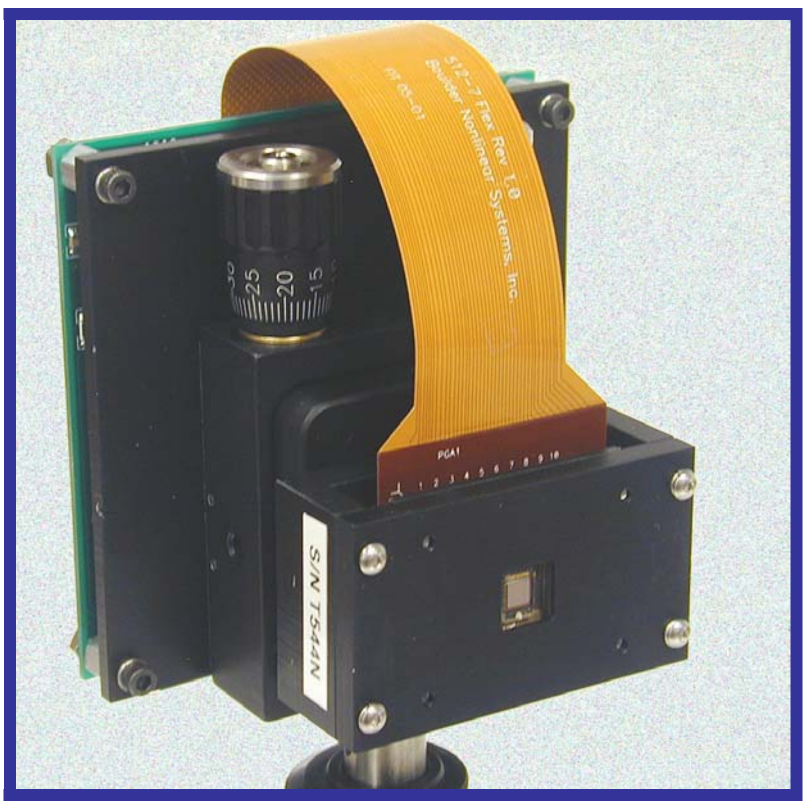
LIQUID CRYSTAL SOLUTIONS

User Manual

XY Phase Series

and

XY PhaseFlat Series
Spatial Light Modulators



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1 Introduction

This User Manual covers the XY Phase Series and XY PhaseFlat Series of liquid crystal on silicon spatial light modulators (SLMs) now available from Boulder Nonlinear Systems, Inc. (BNS). The manual instructs users on how to set up the electronic hardware, optics, and operate the system software. SLM system setup is fairly complex, incorporating optical components, mounting and positioning hardware, custom drive electronics hardware, and a proprietary software interface.

We strongly recommend that all users first read and familiarize themselves with the entire User Manual before initiating the setup and start up procedures.

1.1 Spatial Light Modulator Principles

An SLM is a device that modulates light according to a fixed spatial (pixel) pattern. The XY Phase and PhaseFlat Series SLMs convert digitized data into coherent optical information appropriate for a wide variety of applications, including beam steering, optical tweezers, diffractive optics, and more. These applications require modulators that can easily and rapidly change the wavefront of a coherent beam. By combining the electro-optical performance characteristics of liquid crystal materials with silicon-based digital circuitry, BNS now offers high speed SLMs that are also physically compact and optically efficient.

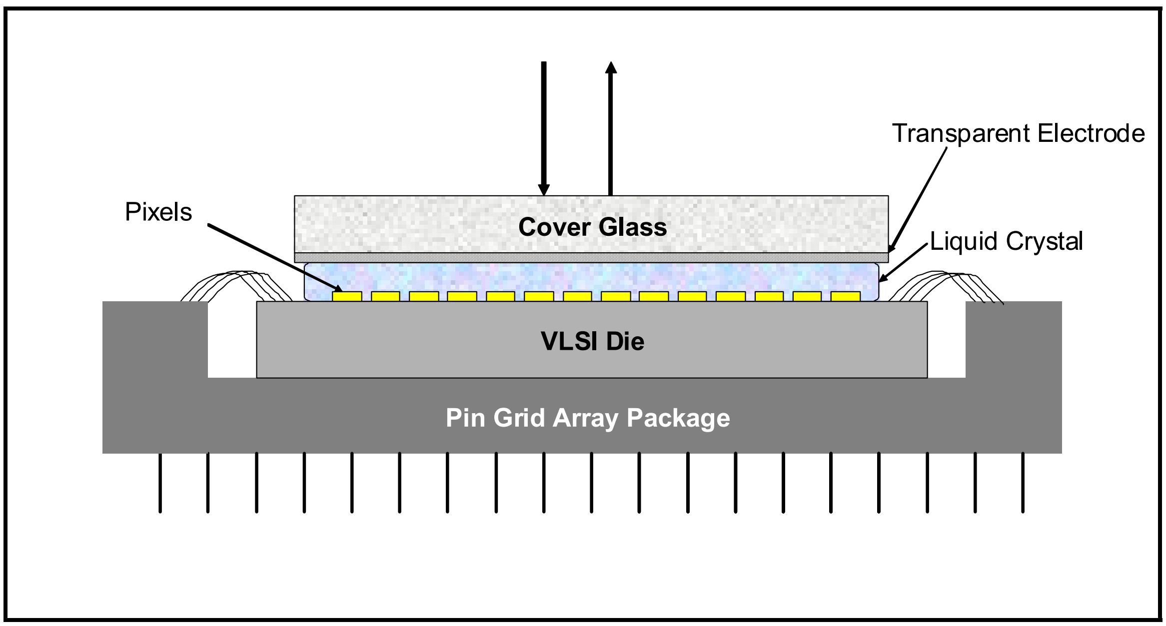


Figure 1 ~ Cross sectional illustration of a liquid crystal spatial light modulator.

Figure 1 shows the cross section of an LC SLM. Polarized light enters the device from the top, passes through the cover glass, transparent electrode and liquid crystal layer, is reflected off the shiny pixel electrodes, and returns on the same path. Drive signals travel through the pins on the bottom of the pin-grid array package, through the bond wires and into the silicon die circuitry. The voltage induced on each electrode (pixel) produces an electric field between that electrode and the cover glass. This field produces a change in the optical properties of the LC layer. Because each pixel is independently controlled, a phase pattern may be generated by loading different voltages onto each pixel.

Each of the SLM pixels is independently programmable to 256 discrete voltage states, all providing phase modulation. These SLM devices exhibit a nonlinear relationship between the modulation level and the pixel voltage. A typical phase SLM provides 50 – 100 levels of linear phase steps, when properly calibrated. Each SLM is shipped with a custom look-up-table (LUT). When this LUT is used during data load, the result will be a linear phase response with at least 50 phase steps.

XY Phase and PhaseFlat Series SLMs operate as programmable waveplates. As pixel voltage changes, so does the retardance of the LC layer, producing a phase shift, or change in the polarization state. With no field present (pixel value of 0) the device has its maximum birefringence, resulting in a maximum phase shift (typically 2π radians, or one wave at the design wavelength). With the maximum field present (pixel value of 255) the phase shift is minimized, though not zero, see Figure 2.

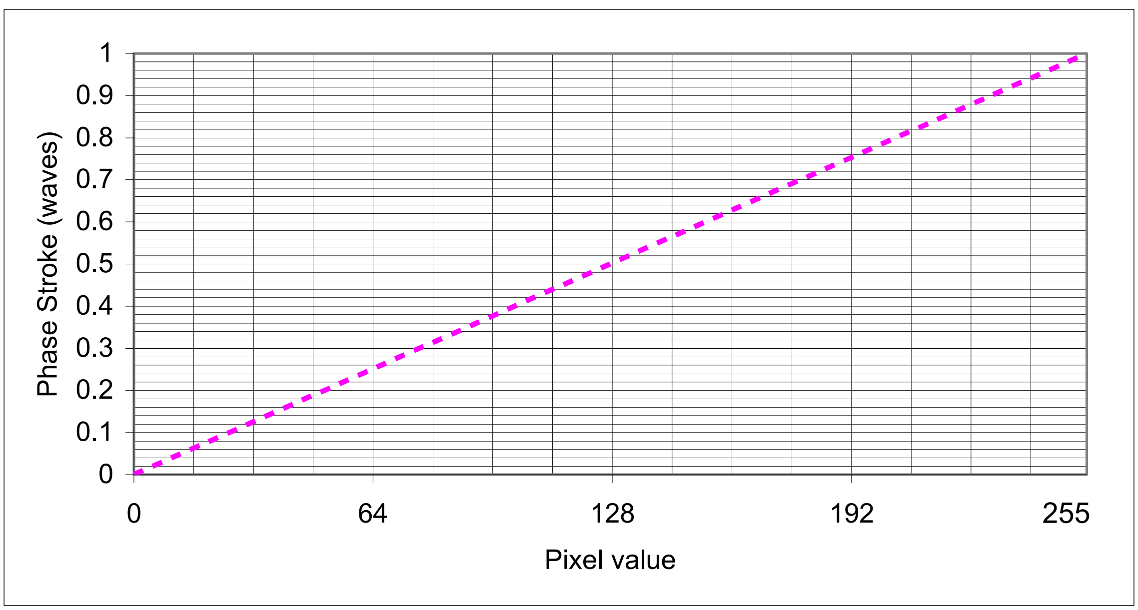


Figure 2 ~ Ideal phase response of an XY Phase or PhaseFlat Series SLM.

1.2 Optical Test Setup

Depending on the application of the XY Phase or PhaseFlat Series SLM, many different optical setups can be used for either combined phase-amplitude mode or phase-only mode. Two examples of phase-only optical test setups are shown below.

The first optical setup, illustrated in Figure 3, is a modification of a Twyman-Green interferometer (Handbook of Optics. Vol. 1, pp. 2.28-2.29). Here, a monochromatic collimated light source (laser beam expanded so it is larger than the diagonal of the SLM) passes through a non-polarizing beamsplitter such that the beam is divided into two beams, with nearly equal intensity. One of these beams illuminates the XY Phase or PhaseFlat Series SLM, while the other illuminates a Reference Mirror. Each of these reflected beams is then recombined at the Image Plane of a Lens. A Camera is placed at the Image Plane in order to magnify the fringes for easier viewing. If the Reference Mirror and the SLM are carefully aligned such that they are nearly coplanar, interference fringes will be visible at the Image Plane. When the XY Phase or PhaseFlat Series SLM is driven with different phase patterns, dynamic interference fringes can be viewed. Analyzing the interference fringes will then provide insight into the phase modulation provided by the XY Phase or PhaseFlat Series SLM.

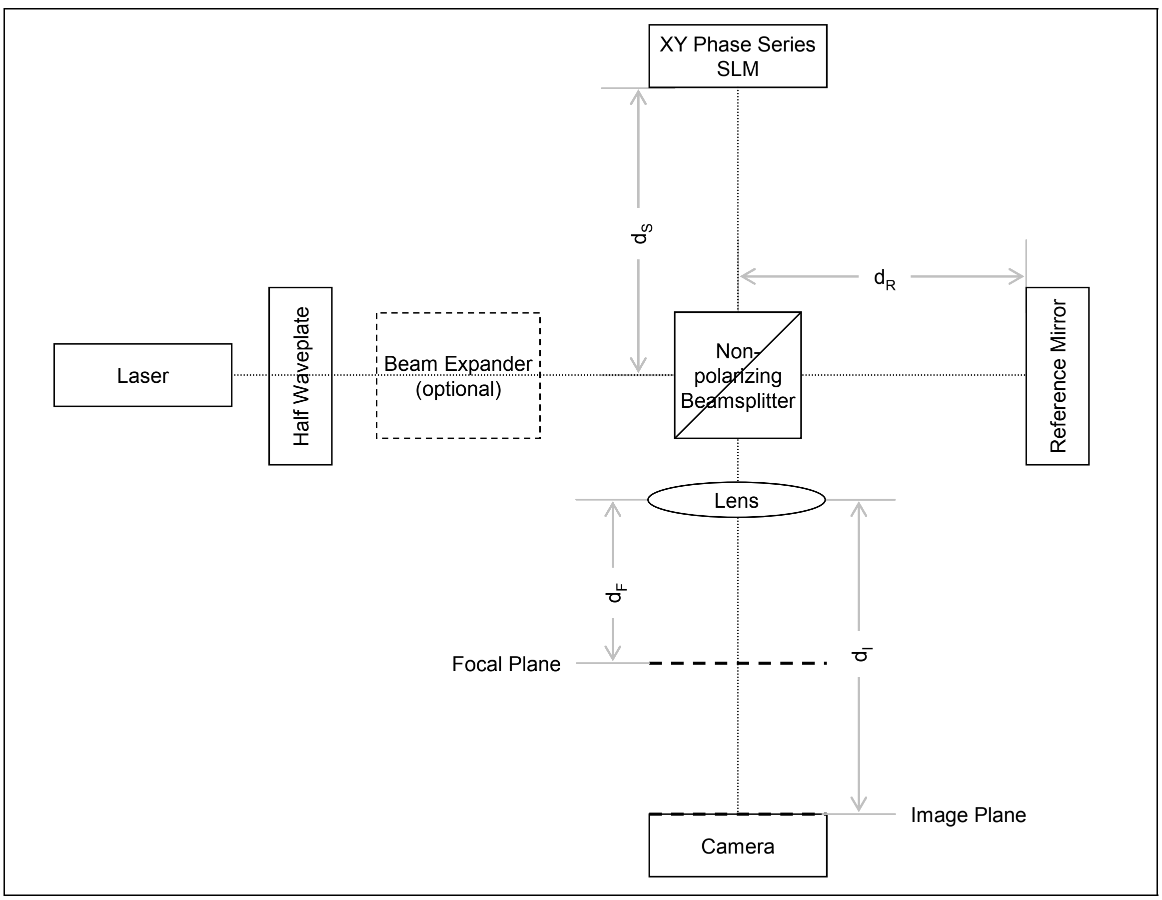


Figure 3 ~ A Twyman-Green interferometer for testing a XY Phase or PhaseFlat Series SLM.

In order to ease the alignment of the Reference Mirror and the XY Phase or PhaseFlat Series SLM in the Twyman-Green interferometer, place the Camera, or a card into the beam path, at the Focal Plane of the Lens. There should be two spots visible, one from the Reference Mirror, and one from the SLM (there may also be very faint high-order diffraction spots from the SLM). If utilizing a beamsplitter cube, there are likely to be additional spots that are ghost images from the beamsplitter. When adjusting the tip/tilt of either the Reference Mirror or the SLM the ghost spots will not move, but the true spots from the Reference Mirror and the SLM will move. Once the correct two spots are located, adjust the tip and tilt of the Reference Mirror and/or the SLM until these two spots are aligned on top of one another. Place the Camera back in the Image Plane, or remove the card, and interference fringes should be visible in the Image Plane. By slowly adjusting the tip and/or tilt of just the Reference Mirror or SLM, the desired interference fringes should be readily obtained.

If working with a laser diode it is important to note that the coherence length of laser diodes are typically much shorter than the coherence length of a gas-discharge laser. With a Twyman-Green interferometer it is critical that both the SLM leg and the Reference Mirror leg have the same optical path length, ensuring that the short coherence length of a laser diode does not significantly reduce the visibility of the interference fringes. In order to ensure equal path lengths, set the Camera such that it is focused onto the SLM – distinct features of the silicon backplane, such as individual pixels or the edge of the active area, should become sharp. Blocking the reference leg beam will likely be necessary in order to prevent crosstalk in the Camera. Then move the block from the reference leg to the SLM leg and move the Reference Mirror closer to, or further from, the beam splitter until it is also in sharp focus on the camera. Since the Reference Mirror will likely not have any features with which to see the best focal point, look for focus of dust particles, or perhaps very carefully place a card onto the Reference Mirror such that it covers about half of the beam. The card edge can then be used as a guide to find the best focal position of the Reference Mirror.

There are a few important issues to remember whenever working with an SLM.

1. Polarization – The SLM is basically a variable single-order retardation plate, or waveplate. Like all waveplates, there is a fast axis and a slow axis. However with the XY Phase and PhaseFlat Series SLMs the index of refraction along the slow axis can be decreased electronically. When the light source is linearly polarized and parallel to the slow axis of the SLM, the result is phase-only modulation of the light source. If instead the light source were linearly polarized perpendicular to the slow axis, there would be no modulation. The use of a passive half waveplate will greatly facilitate achieving the desired polarization alignment.

2. Diffraction – The SLM has discrete, reflective pixel pads in order to isolate the electrical signals and allow phase patterns to be written into the SLM. As a result of these discrete pixel pads, there will be diffraction. This diffraction can easily be seen in the Focal Plane of the Lens. There will be a very bright center spot (0^{th}-order), surrounded by a grid of spots becoming progressively dimmer as they get further from the 0^{th}-order. In order to

attain the maximum throughput, it is suggested to use as many of the diffracted spots, or orders, as possible. However, some applications do not allow the use of more than one order (typically the 0^{th}-order).

3. Dispersion – Liquid crystal waveplates are not very achromatic because the index of refraction varies as a function of wavelength. This dispersion means that a device designed to provide a 2π Phase Stroke at one wavelength, will provide less than 2π Phase Stroke at a longer wavelength, and more than 2π Phase Stroke at a shorter wavelength.

4. Optical quality – Due to the very small pixel pitch of the SLM, it is important to use high quality optics. A single element lens will generally have too much spherical aberration to provide a good, sharp focus across the entire clear aperture of the SLM. As a result, it is recommended to always use at least a doublet lens. For the same reason, the longer the focal length of the Lens, the better the resulting image at the Image Plane. In addition, the Transmitted Wavefront Distortion of most beamsplitter cubes is typically ~λ/4, contributing to unacceptable wavefront distortion at the Image Plane. The use of a beamsplitter plate in place of a beamsplitter cube could improve the wavefront distortion, but using a beamsplitter plate requires the use of a compensating plate in the reference leg of the Twyman-Green interferometer.

An off-axis setup, shown in Figure 4, is designed to maximize throughput by eliminating the non-polarizing beam splitter. A laser beam is incident on the SLM at a slight angle, reflects off of the reflective pixel pads, and then is imaged with a Lens onto a Camera. Please note that since this optical setup is not an interferometer, the actual phase modulation will not be visible on the Camera. This optical setup is only shown to illustrate the concept of an off-axis system. The setup should be modified to meet the exact application requirements. The off-axis angle should be kept to a minimum in order to reduce crosstalk effects due to the beam traveling through more than one pixel region. Minimizing the off-axis angle also keeps the Phase Stroke closer to the designed value.

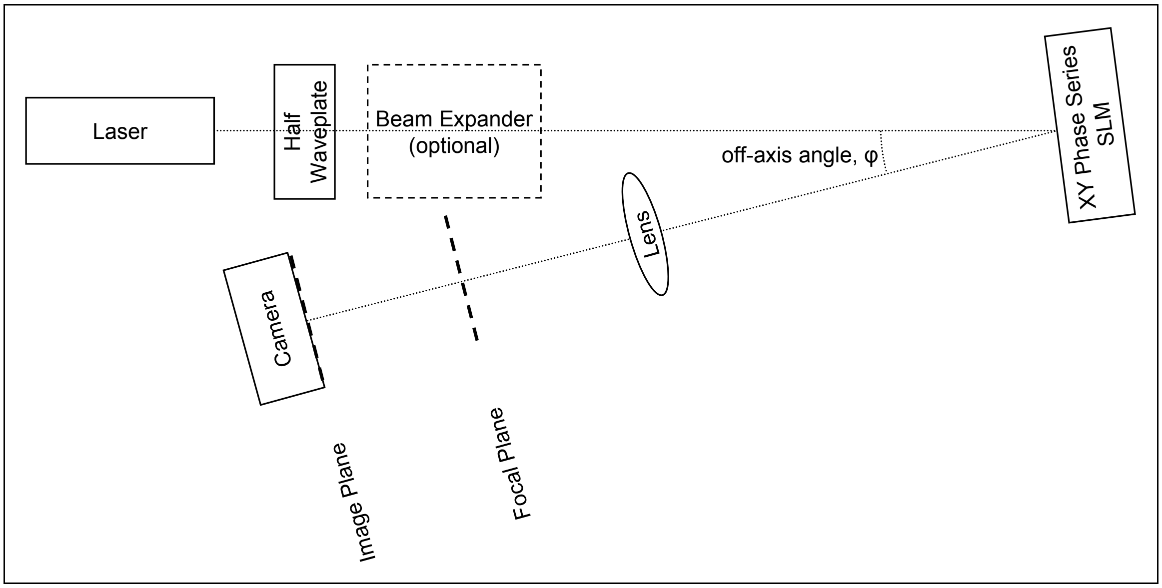


Figure 4 ~ Off-axis optical setup for the XY Phase and PhaseFlat Series SLMs.

2 Spatial Light Modulator System Shipping Contents

Your system contains the following components:

- PCI Memory Board
- DAC Board
- SLM Optical Head
- User Guide
- Software CD
- Cables:
    - 3 ft 80-pin ribbon cable.
    - 3 ft SCSI cable.
    - 3 ft DAC power cable (DB9 ends)

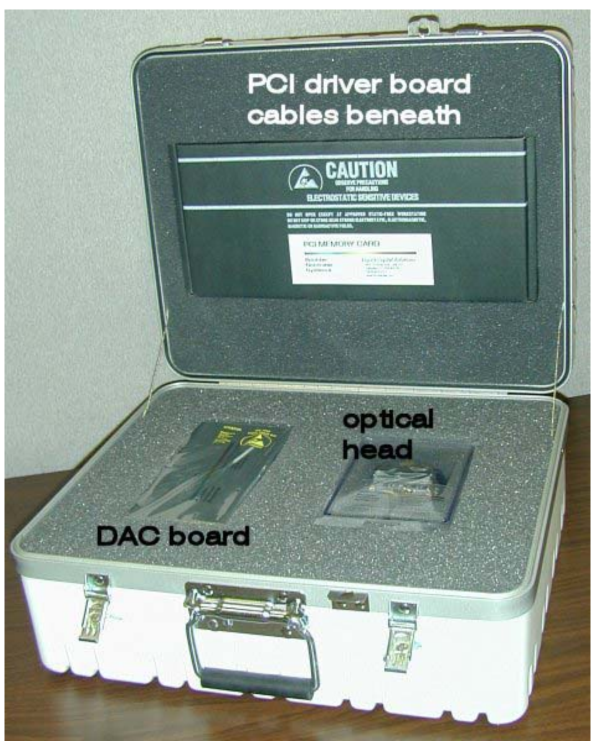


Figure 5 ~ SLM system components.

3 System Setup

CAUTION

To minimize potential installation issues do not install any hardware until after the software has been fully installed.

The diagram in Figure 6 shows the SLM system hardware. The PCI board provided with the system plugs into a standard PCI bus slot on an IBM-compatible personal computer (PC). This board provides timing synchronization and control logic for the LC-SLM system. This board also has on-board memory storage of 1024 patterns for the 512 x 512 SLM, and 4096 patterns for the 256 x 256 SLM. The on board memory enables rapid sequential display on the LC-SLM. When the system is running, digital image data is sent from the PCI board to the DAC board through the SCSI cable, where it is converted to an analog data signal. The analog data signals are then transferred to the Op-Amp board (on the SLM head assembly) where they are amplified to appropriate levels. A flex circuit is then used to transfer data from the Op-Amp Board to the SLM itself.

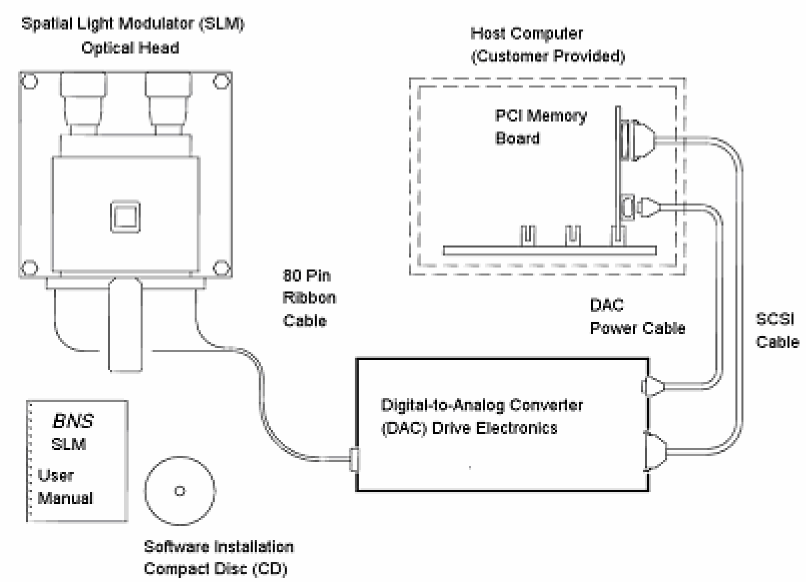


Figure 6 ~ Top level diagram illustrating major components of the BNS SLM systems contents.

3.1 Software Installation

3.1.1 Minimum System Requirements

In order to effectively utilize your SLM system some basic computing hardware is required. The following components are essential to properly achieve the full performance of your SLM system.

- IBM-compatible personal computer (PC), Pentium® -based (100 MHz minimum) system.
- Compact disk (CD) drive.
- Available full-length PCI slot.
- Windows®-based computer operating system (Windows 2000 or XP Professional).
- Mouse or other pointing device.
- Display monitor with 800 x 600 pixel format (minimum) and 256 colors (or more).
- 32 megabytes (MB) of available hard disk space is required for the BLINK basic software installation.
- 32 MB of available random access memory (RAM) to store and manage user-selected frames.

3.1.2 Software Installation Instructions

The Blink software on the CD-ROM contains the executable code necessary to operate the SLM, as well as sample pattern files, sequence files, and various other support files. Please follow these steps to install the software prior to installing the hardware.

1. Insert the CD-ROM that came with your SLM system into the CD-ROM drive.
2. This is an "auto-run" CD-ROM meaning that Windows should detect the presence of the CD and automatically start up the BLINK Setup program.
3. When the BLINK Install shield appears, follow the onscreen instructions to complete the installation.
4. When the installation is complete, eject the CD from the drive and store it away carefully.
5. Shut down the computer and install the hardware as shown in the step by step pictures in the Hardware Installation section of the guide.
6. After the hardware is installed, boot the computer and install the device driver as shown in the step by step pictures in section 3.2.1 of the guide.

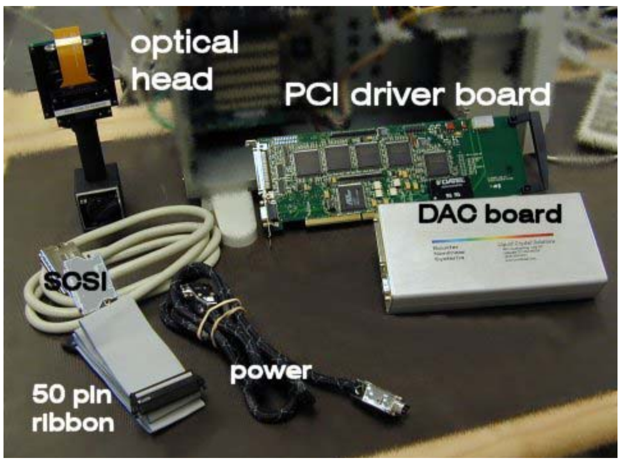
NOTE: If the Autorun program does not start after you insert the CD-ROM, you can start the program by opening "My Computer" or Windows Explorer to navigate to the CD-ROM contents, and then double-clicking the file Setup.exe.

3.2 Hardware Installation

CAUTION

Ensure that your computer is completely powered off prior to installing any hardware.

Do not power the computer on until ALL cables included with your SLM system have been properly connected.

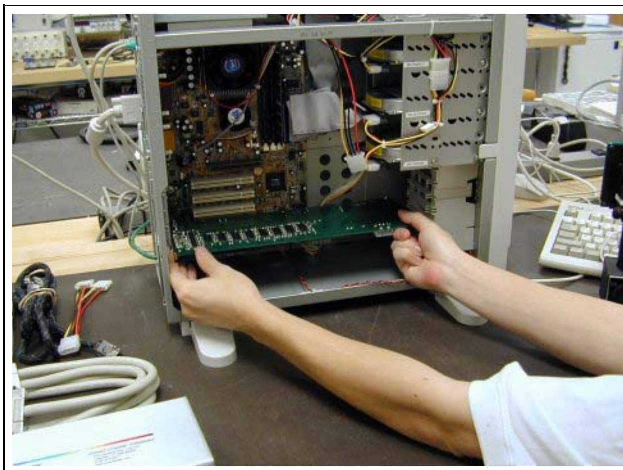


Unpack and locate the items shown in the picture. The optical head is not shipped with a post holder.

You will need a small flathead and Phillips head screwdriver.

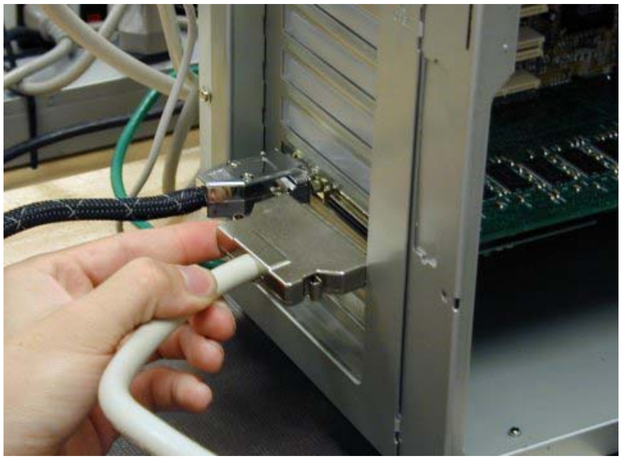
Follow static safe procedures. Attach a wrist strap and ground it to the computer case or a grounded static dissipative mat.

Figure 7 ~ SLM systems contents.



Remove the outside cover of your computer. Insert the PCI Board into any unused slot. Ensure the card edge is lined up properly with the PC connector, do not force the board into place. Screw the mounting bracket of the PCI board to the back panel of the computer. This will prevent the board from coming loose, such as when connecting or disconnecting cables.

Figure 8 ~ PCI Board installation.



Attach the DAC power cable (DB-9, black sheath) to the PCI board. Secure with the attached screws.

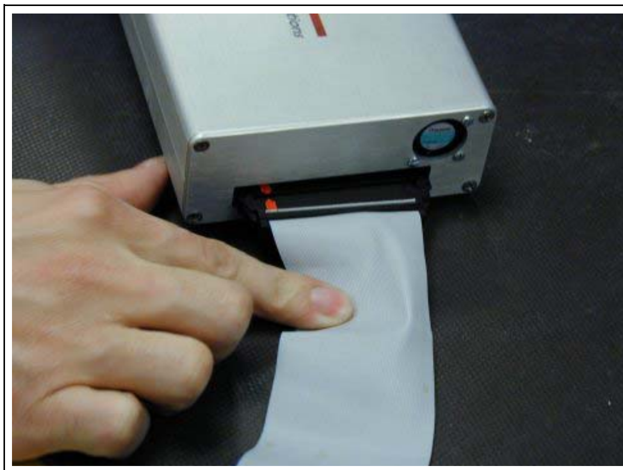
Attach the SCSI cable to the PCI board. Ensure proper orientation to avoid damage. Listen for an audible "click" to ensure proper mating.

Figure 9 ~ PCI Board cable attachment.

Attach the other ends of these cables to the DAC Board box, ensuring proper orientation to avoid damage.

Secure the power cable to the DAC Board box with the attached screws.

Figure 10 ~ DAC Board cable attachment.



Attach the 80-pin ribbon cable to the DAC board box.

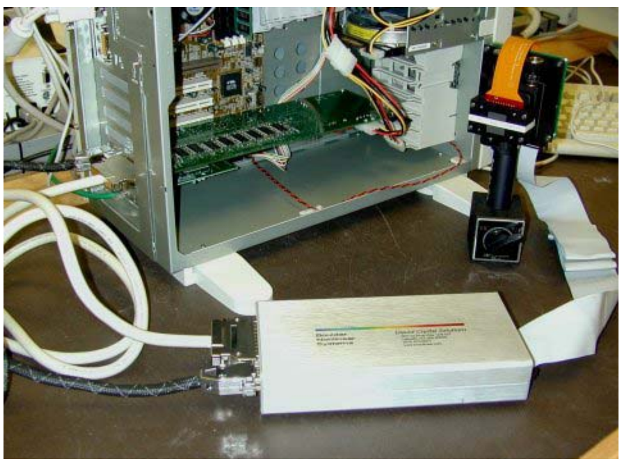
Ensure proper orientation to avoid damage.

Figure 11 ~ 80-pin ribbon cable to DAC Board.

Attach the other end of the 80-pin ribbon cable to the optical head.

Ensure proper orientation to avoid damage.

Figure 12 ~ 80-pin ribbon cable to optical head.



Your system should look like this.

DO NOT TURN ON THE COMPUTER POWER UNLESS ALL CONNECTIONS ARE COMPLETE. IRREPARABLE DAMAGE TO THE SLM COULD OCCUR.

Figure 13 ~ Assembled system.

Replace the computer cover. When you re-boot your computer, the "Add/Remove Hardware" wizard will appear detecting new hardware. At this point you will need to help Windows locate the correct driver for the new hardware.

If your computer operating system is Windows 2000, continue on with section 3.2.1. If your computer operating system is Windows XP Professional, skip to section 3.2.2. Other operating systems are not currently supported.

3.2.1 Windows 2000 Device Driver Installation

1. When the "Found New Hardware Wizard" window appears, click the "Next" button (see Figure 14).

Figure 14 ~ New hardware wizard.

2. Select the option labeled "Search for a suitable driver for my device", click the "Next" button (see Figure 15).

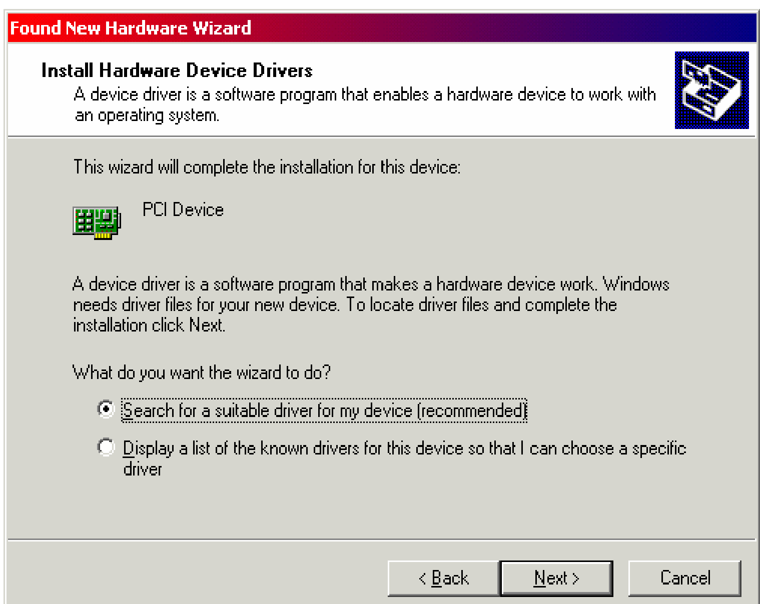


Figure 15 ~ Search for driver.

3. Select the option labeled "Specify a location", deselect all other options, click the "Next" button (see Figure 16).

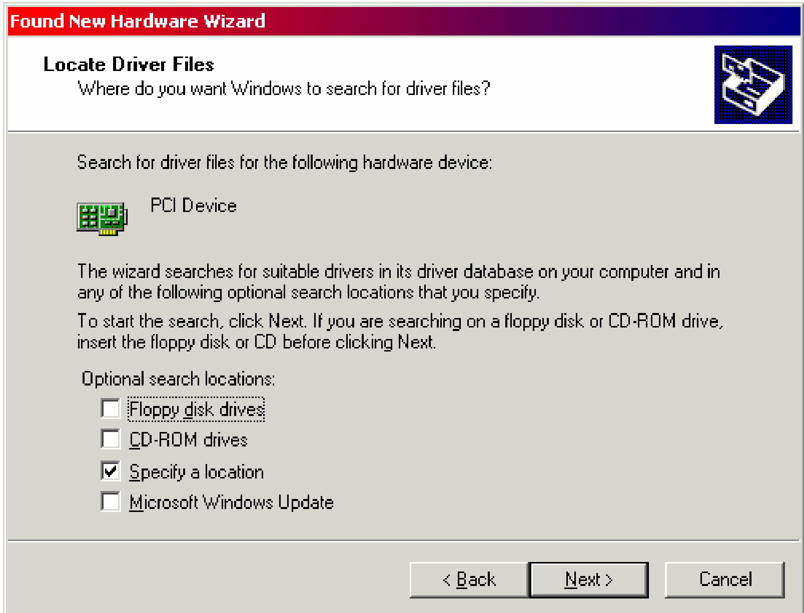


Figure 16 ~ Specify a location.

4. Click the "Browse" button, then select the folder "C:\Blink" (see Figure 17).

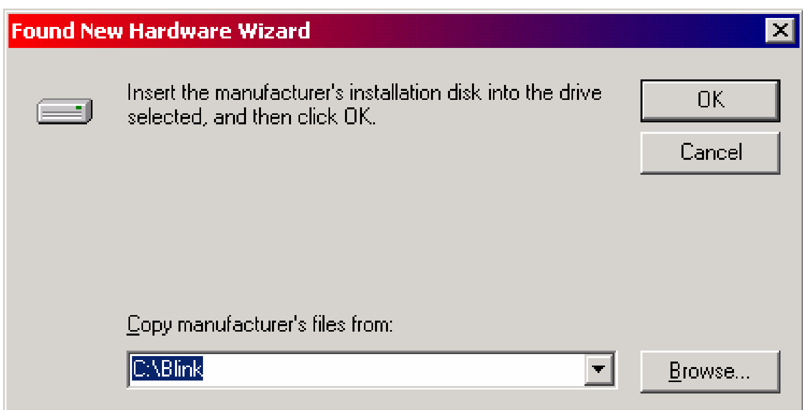


Figure 17 ~ Blink software.

5. At this point the display should now show that the wizard found a driver for the PCI Device, click the "Next" button (see Figure 18).

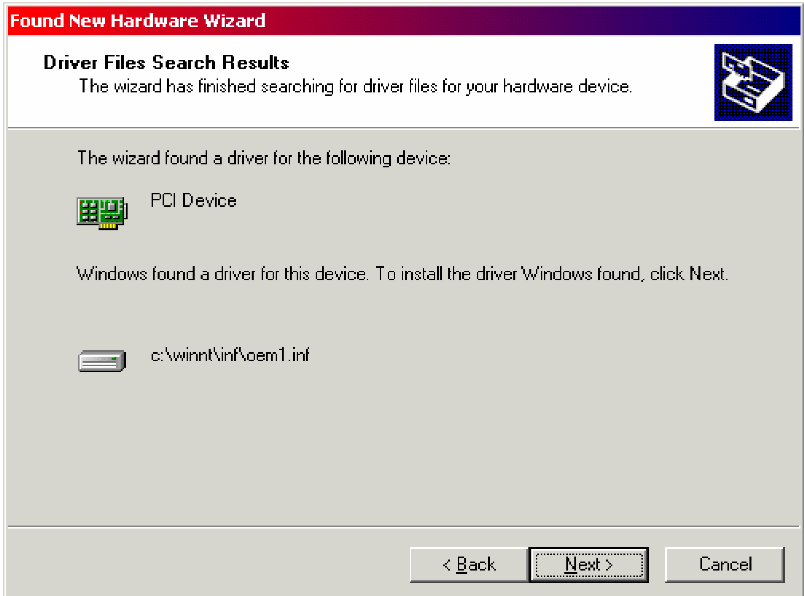


Figure 18 ~ Confirm device found.

6. The display should now show that Windows has finished installing the software for this device, click the "Finish" button (see Figure 19).

7. To verify proper installation open the Device Manager. Right click on "My Computer" on the Windows desktop and select properties. Select the Hardware Tab and click on the button labeled Device Manager. A screen should appear that looks like Figure 20. Verify that under the Jungo device both PLX_9050 and WinDriver exist. Right click on PLX_9050 and select "Properties", then click on the Driver tab, and verify that the Driver version is 6.0.2.0. Next right click on WinDriver and select "Properties", click on the Driver Tab, and click on the Driver Details button. Verify that the Driver File is C:\WINNT\System32\Drivers\windrvr6.sys and that the File Version is 6.0

Figure 19 ~ Confirm successful installation.

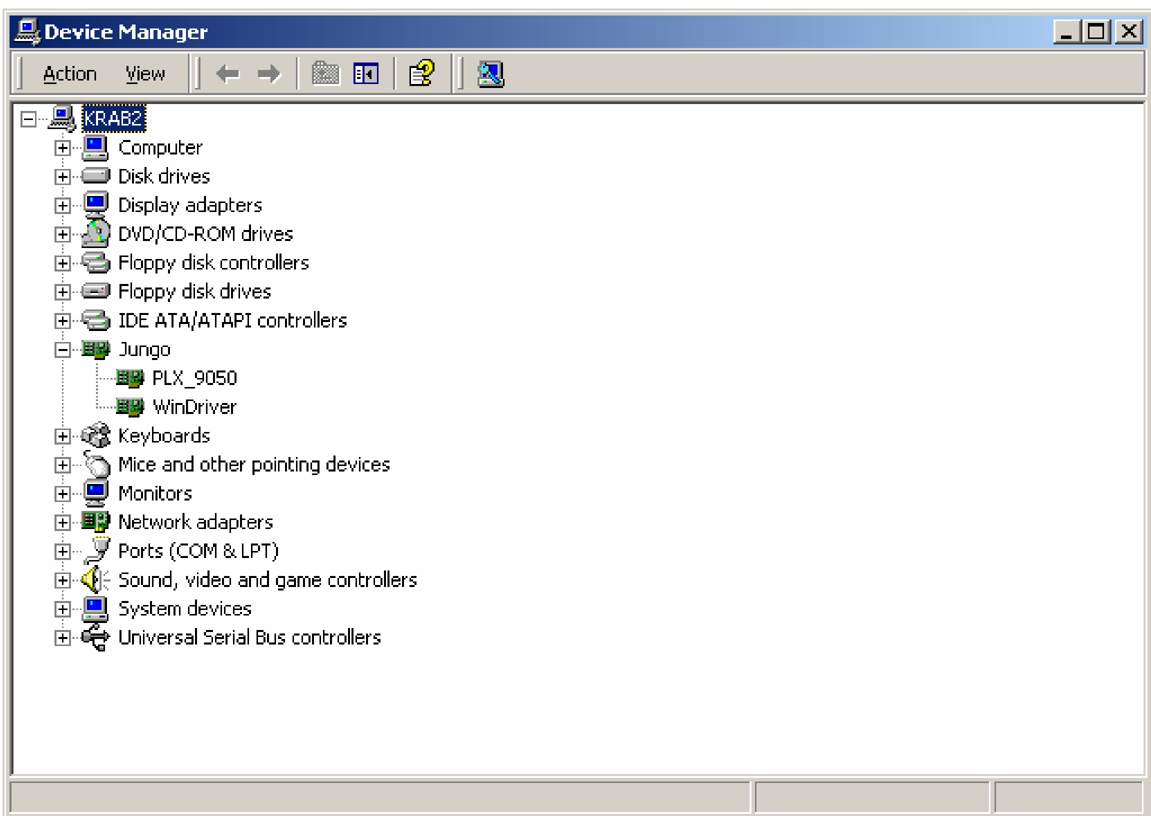


Figure 20 ~ Device Manager window.

3.2.2 Windows XP Professional Device Driver Installation

When the "Found New Hardware Wizard" screen appears, select the option labeled "Install the software automatically" and click the "Next" button (see Figure 21). This will automatically install the device driver, after which, the Blink program can be started by double-clicking on the Blink icon located on the desktop.

Figure 21 ~ Windows XP Professional software install.

4 Software Operation

To start the software, double click the "Blink" shortcut located on your desktop, or click on the Windows "Start" button, select, "Run…", type "C:\Blink\Blink.exe", then click "OK". If your system includes only the basic software (Blink - Compact) the screen shown in Figure 22 should now be visible. However, if you have purchased any of the optional packages (XY PhaseFlat Series SLM system, Blink – Plus software, or Blink – Full software), the screen shown in Figure 23 should now be visible.

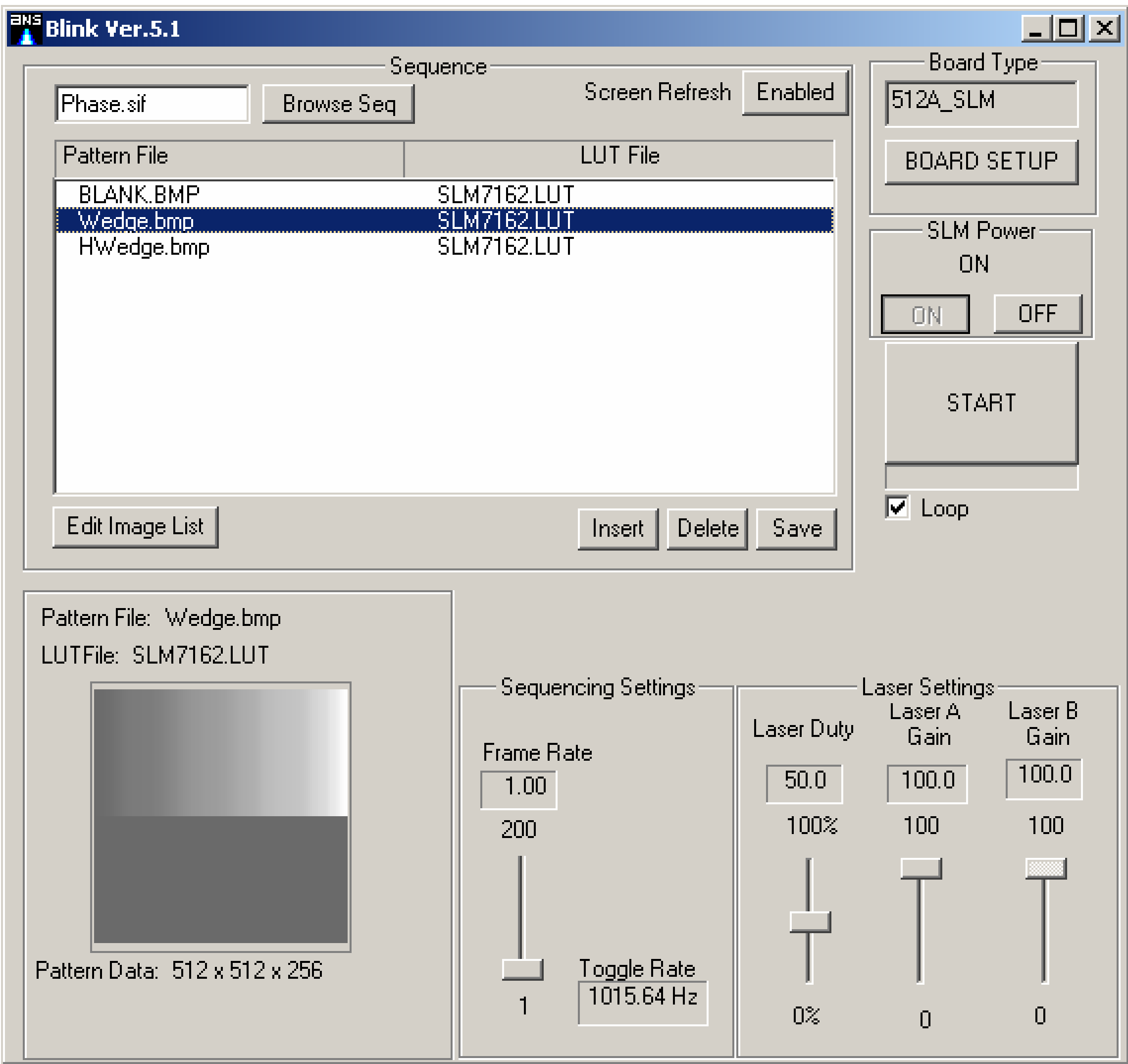


Figure 22 ~ Main window for the XY Phase Series SLM and the basic software Blink - Compact.

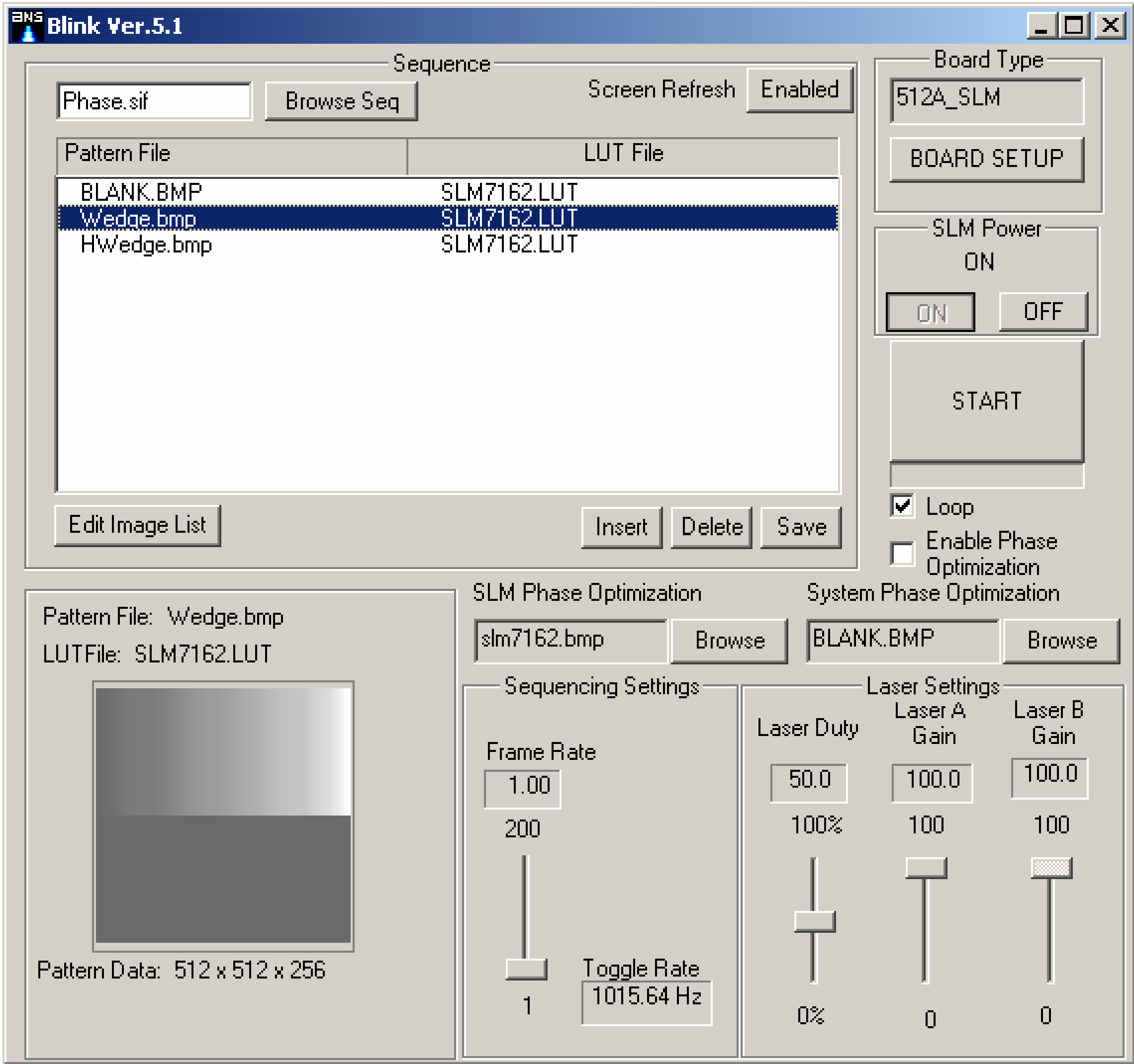


Figure 23 ~ Main window for the XY PhaseFlat Series SLM system and for the advanced software packages Blink - Plus and Blink - Full.

The XY PhaseFlat Series SLM systems, and the advanced software packages, Blink – Plus and Blink – Full, include the added functionality for compensating phase distortion due to either the SLM or your specific optical system, or simply for adding a spatially variant phase offset to all pattern files loaded into the SLM. With the Phase Optimization enabled it is possible to obtain flatter phase profiles across the entire SLM aperture than may be possible with the basic software, Blink - Compact. Each system purchased with one of the advanced software packages will include a phase optimization pattern file (in bitmap format) based on wavefront data measured at the factory using a Twyman-Green interferometer at the specified wavelength of operation.

When the software first starts the SLM is powered off. The power status can be seen on the right side of the Main screen, in the SLM Power section. This should read “OFF” at startup. In addition, the Pattern File display in the lower left of the Main screen should read “SLM POWER OFF”.

To turn the SLM power on, click on the "ON" button located in the SLM Power section of the Main screen. The status should change from "OFF" to "ON". The Pattern File display should now be showing the first Pattern File in the Sequence List located in the upper left area of the Main screen. This Pattern File should also be visible on the SLM.

Note: The Pattern File display on the Main screen is a gray-scale representation of the data in the Pattern File. Pixel values of 0 (0 λ phase stroke with slmXXXX.lut) are displayed as dark, while pixel values of 255 (1 λ phase stroke with slm XXXX.lut) are displayed as light (the exact intensity displayed is dependant upon the values in the look-up table). Values in between are represented by a linear gray-scale ramp. Depending on your optical setup, this may not look the same as the pattern visible on the SLM, see Section 1.2 for details on the optical setup.

To change the Pattern File currently loaded into the SLM, simply point the mouse at a different Pattern File in the Sequence List and click. This new Pattern File should now be highlighted, and be immediately loaded into the SLM. The cursor key (↑ and ↓) can also be used to select different Pattern Files in the Sequence list.

The Pattern Files can be changed repetitively by clicking on the "START" button located on the right side of the Main window (see Figure 22). Once the "START" button has been pressed the button is relabeled to "STOP", and the system will be sequencing through the Pattern Files in the Sequence List. Click the "STOP" button to halt the automatic sequencing.

The rate at which sequencing occurs is called the Frame Rate. The Frame Rate can be set using the "Frame Rate" slider bar located near the bottom of the Main window in the Sequencing Settings section. The units for the Frame Rate are in Hertz (Hz).

Note: The Frame Rate supported by the Blink software is considerably faster than the XY Phase Series SLM is able to support. Please contact BNS to determine the maximum Frame Rate of your SLM. As the Blink Frame Rate increases beyond the maximum Frame Rate supported by the SLM, the Phase Stroke of the SLM will decrease. This effect is only temporary. The full Phase Stroke will return once the Blink Frame Rate is slowed to be equal to or less than the maximum Frame Rate of the SLM.

4.1 Phase Optimization

This option is only available for the XY PhaseFlat Series SLM systems, Blink – Plus software, and Blink – Full software.

To enable phase optimization the Enable Phase Optimization checkbox must be selected. In addition, the SLM Phase Optimization pattern file should contain the name of the bitmap file for optimizing SLM specific phase distortion. By default this file will be "SLMxxxx.bmp", where xxxx is the serial number of the SLM. The System Phase Optimization is set to "BLANK.BMP" by default. This pattern file contains pixel values of zero for all pixels, i.e. there will be no phase optimization changes when this pattern file is selected.

The phase optimization files can be set to any valid BMP file, or a ZRN file, which is a text file defining a set of 20 Zernike coefficients (note that these are not the first 20 Zernike coefficients). A sample ZRN file with only X astigmatism is shown below, followed by the equations used to convert the Zernike polynomials into Cartesian coordinates, shown in Table 1. These ZRN files are simple text files that can be viewed or modified with any text editor.

```
Piston = 0.000000
XTilt = 0.000
YTilt = 0.000000
Power = 0.000000
AstigX = -5.0000000
AstigY = 0.000000
ComaX = 0.000000
ComaY = 0.000000
PrimarySpherical = 0.000000
TrefoilX = 0.000000
TrefoilY = 0.000000
SecondaryAstigX = 0.000000
SecondaryAstigY = 0.000000
SecondaryComaX = 0.000000
SecondaryComaY = 0.000000
SecondarySpherical = 0.000000
TetrafoilX = 0.000000
TetrafoilY = 0.000000
TertiarySpherical = 0.000000
QuaternarySpherical = 0.000000
```

Table 1 ~ The equations used to convert the Zernike polynomials to Cartesian coordinates. Note that these equations are normalized such that entering a coefficient of one will result in exactly one wave of phase error.

Name	Equation
Piston	1
XTilt	x
YTilt	y
Power	$-1+2(x^2+y^2)$
AstigX	x^2-y^2
AstigY	$2xy$
ComaX	$-2x+3x(x^2+y^2)$
ComaY	$-2y+3y(x^2+y^2)$
PrimarySpherical	$1-6(x^2+y^2)+6(x^2+y^2)$
TrefoilX	x^3-3xy^2

Name	Equation
TrefoilY	$3x^2y-y^3$
SecondaryAstigX	$-3x^2+3y^2+4x^2(x^2+y^2)-4y^2(x^2+y^2)$
SecondaryAstigY	$-6xy+8xy(x^2+y^2)$
SecondaryComaX	$3x-12x(x^2+y^2)+10x(x^2+y^2)^2$
SecondaryComaY	$3y-12y(x^2+y^2)+10y(x^2+y^2)^2$
SecondarySpherical	$-1+12(x^2+y^2)-30(x^2+y^2)^2+20(x^2+y^2)^3$
TetrafoilX	$x^4-6x^2y^2+y^4$
TetrafoilY	$4x^3y-4xy^3$
TertiarySpherical	$1-20(x^2+y^2)+90(x^2+y^2)^2-140(x^2+y^2)^3+70(x^2+y^2)^4$
QuaternarySpherical	$-1+30(x^2+y^2)-210(x^2+y^2)^2+560(x^2+y^2)^3-630(x^2+y^2)^4+252(x^2+y^2)^5$

4.2 Sequences

The Sequence List is a predefined list of Pattern Files that will be loaded into the SLM (top to bottom). The file name of the current Sequence List is shown in the upper left corner of the Main window (Figure 22). If the sequence file name is followed by an asterisk (*), the current Sequence List has been modified and no longer matches the Sequence List defined in the sequence file name. To prevent losing the modifications, save the sequence file by clicking on the “Save” button in the lower right of the Sequence area.

The Sequence List defined in this file is displayed in the left center of the Main window. Each line represents a sequence record, describing one of the Pattern Files to be loaded, and the Look-Up Table (LUT) through which the Pattern File is processed. If the Pattern File is preceded by an exclamation point (**!**), an error occurred when reading that sequence record. The following conditions can cause an error: the Pattern File or LUT File could not be opened, the Pattern File or LUT File could not be found, the Pattern File is not a properly formatted Windows Bitmap file (.bmp), or the Pattern File is not a 128x128, a 256x256, a 512x512, or a 1024x1024 image. Refer to Section 7 for troubleshooting information.

To change the Pattern File currently loaded into the SLM, simply point the mouse at a different Pattern File in the Sequence List and click. This new Pattern File should now be highlighted, and be immediately loaded into the SLM. The cursor key (↑ and ↓) can also be used to select different Pattern Files in the Sequence list.

4.2.1 Running a sequence

Clicking on the “START” button will cause the SLM to automatically cycle through the Sequence List from top to bottom. Once the “START” button has been pressed the button is relabeled to “STOP”, and the system will be sequencing through the Pattern Files in the Sequence List. Click the “STOP” button to halt the automatic sequencing.

The Frame Rate can be set using the “Frame Rate” slider bar located near the bottom of the Main window (see Figure 22) in the Sequencing Settings section. The units for the Frame Rate are in Hertz (Hz).

If the program is sequencing at a fast rate the selected line in the sequence list may begin to jump. This does not mean that images are being skipped. It simply means that the user interface cannot update as fast as the hardware is sequencing. The user can disable screen updates by clicking on the button in the bottom left corner of the dialog underneath “Refresh”. If the button reads “Disabled” the screen updates are disabled. If the button reads “Enabled” the screen updates are enabled.

In order to continuously loop on the Sequence List enable the “Loop” checkbox. To run through the Sequence List only once, deselect the “Loop” checkbox.

4.2.2 Opening new sequence files

To open a new sequence file move the cursor over the “Browse Seq” button and click. This opens the standard Windows wizard for opening a file. The user is asked to locate the file on the hard disk. Once located, the new sequence is automatically loaded into the system.

There are three sequence files (SIFs) shipped with the SLM system. These SIFs are text files that can be viewed or modified with any text editor.

1. Intensity.sif – This is a good sequence for demonstrating basic functionality of the SLM while viewing the SLM with just a polarizer and room lights. This SIF utilizes linear.lut and two pattern files. Both pattern files contain a background with pixel values of zero, and a foreground with pixel values ranging from 255 on the left side down to zero on the right side of the pattern. This “wedged” foreground should result in a color shift when viewing with room lights and a polarizer. These pattern files are shown in Figure 24.

Note: For the XY PhaseFlat Series SLM system and the advanced software packages (Blink – Plus and Blink – Full) Phase Compensation should be DISABLED when viewing the SLM in an amplitude mode.

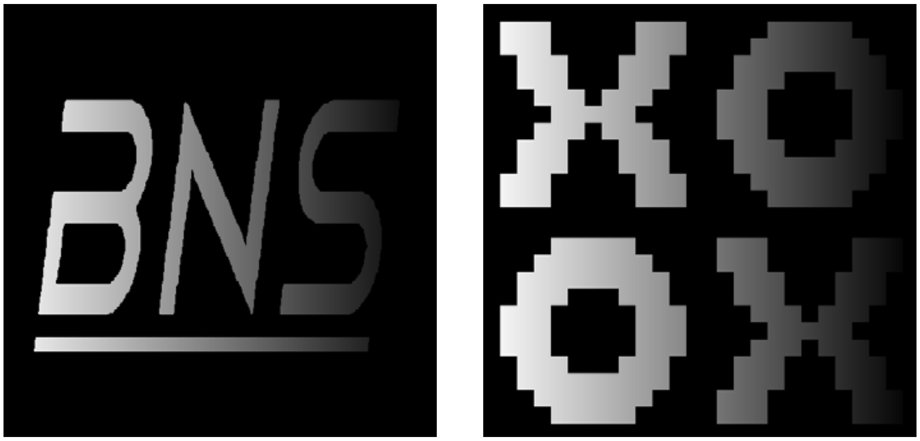


Figure 24 ~ Pattern files utilized in the default SIF, Intensity.sif.

2. Phase.sif – This sequence demonstrates basic phase modulation performance when the SLM is properly installed in an interferometer (see Section 1.2 for optical configuration). This sequence includes three pattern files and demonstrates the use of the custom LUT shipped with each SLM system for linearizing the phase modulation as a function of pixel value.

3. Zernike.sif – This sequence demonstrate the use of bitmap (BMP) pattern files versus Zernike (ZRN) files. This sequence works best when operated with the SLM as part of an interferometer (see Section 1.2 for optical configuration). The first six Zernike polynomials are demonstrated both as BMP pattern files and as ZRN files. Both should result in equivalent patterns displayed on the SLM.

4.2.3 Modifying a sequence record

To modify a sequence record within the current Sequence List, move the cursor over the desired sequence record and click to select it. Double-click the desired sequence record, or alternatively click the “Edit Image List” button located in the lower left of the Sequence area. This will open the Edit Sequence Record window, see Figure 25. Use the “Browse Pattern” button to select a new Pattern File. Use the “Browse LUT” button to select a new LUT file.

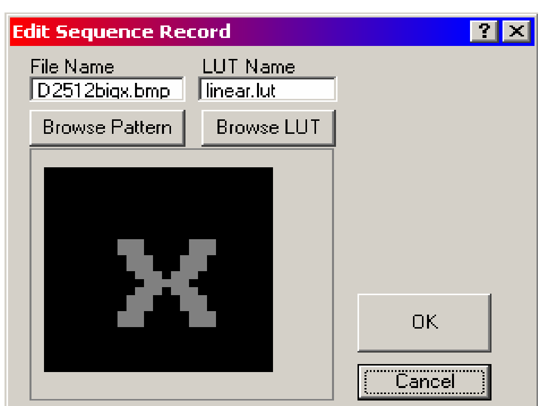


Figure 25 ~ Edit Sequence Record window.

A LUT is a look up table used to map the original input data to a set of new output values when the Pattern Files are loaded into the hardware. The LUT provides greater control by allowing the user to quickly change the response of a large set of Pattern Files without having to modify the Pattern Files themselves. Typically this is used to provide an approximately linear phase response to a linear set of pixel values. The LUT file is a text file with two columns of numbers. The first column is the input pixel value of your Pattern File. The second column contains the corresponding output pixel values that are loaded into the SLM hardware when a particular input pixel value is encountered in the Pattern File.

Each SLM system is shipped with a custom LUT designed to enable a linear phase stroke versus pixel value. This LUT will be named "slmXXXX.lut", where XXXX corresponds to the serial number of your SLM. When using this LUT, a pixel value of 0 will correspond to the minimum, or 0 λ phase stroke, a pixel value of 63 corresponds to ¼ λ of phase stroke, 127 corresponds to ½ λ of phase stroke, 191 corresponds to ¾ λ phase stroke, and 255 corresponds to 1 λ, or one wave, of phase stroke.

Another LUT, named "linear.lut", is also shipped with each SLM. This LUT is not to be confused with the custom LUT shipped with each SLM. This LUT provides a linear mapping of input pixel value to output pixel value, eg. 128 in the data file will be loaded into the SLM as 128.

4.2.4 Insert a new sequence record

A new sequence record can be added to the Sequence List by clicking the "Insert" button located at the bottom of the Sequence area. The new sequence record will be inserted above the currently selected sequence record. The currently selected sequence record will be copied, and then the Edit Sequence Record screen will be displayed.

4.2.5 Deleting a sequence record

To delete a sequence record from the Sequence List select the sequence record to delete, then click the "Delete" button. Note that the program will not allow you to delete all the records in the list. If the user attempts to delete the last record the Edit Sequence Record window will be displayed.

4.2.6 Saving a Sequence List

To save a Sequence List click the "Save" button located at the bottom of the Sequence area. The standard Save window will be displayed, allowing the user to replace the existing sequence file, or change the file name to create a new sequence file.

4.3 Sequencing Settings

The Sequencing Settings area contains one adjustable slide bar for modifying the Frame Rate, plus a display box for the Toggle Rate. The Frame Rate is the rate (in Hz) at which the system will change from one Pattern File to the next, as defined in the Sequence List. The Toggle Rate is the rate at which the data loaded into the SLM is inverted between true and inverse to maintain proper electrical balance. This is for informational purposes only. The Toggle Rate can be modified via the BOARD SETUP button (see Section 4.5).

4.4 Laser Settings

The Laser Settings area contains three adjustable slide bars. These are Laser Duty, Laser A Gain, and Laser B Gain. To fully understand how these sliders control the system it is necessary to read Section 9, which provides background information on the system timing for SLMs. Note that for the XY Phase and PhaseFlat Series SLMs the Laser A Gain and Laser B Gain are always equal. For this reason the Laser B Gain slide bar is “read-only” and is controlled by the Laser A Gain slide bar.

4.5 Board Type

The Board Type section located in the top right corner of the Main window (see Figure 22) displays the driver board type detected by the software at startup. This should read 512A_SLM for an XY Phase or PhaseFlat Series (P512 or PF512) system or 256A_SLM for an XY Phase or PhaseFlat Series (P256 or PF256) system. Please contact BNS immediately if the displayed board type does not match your hardware.

Clicking the “BOARD SETUP” button will open the Driver Board Setup window, see Figure 26. This window displays version information for the hardware and software, along with information on the Modulator type, Toggle Rate, and Detector Sync signal. Most of the information on this screen is read-only.

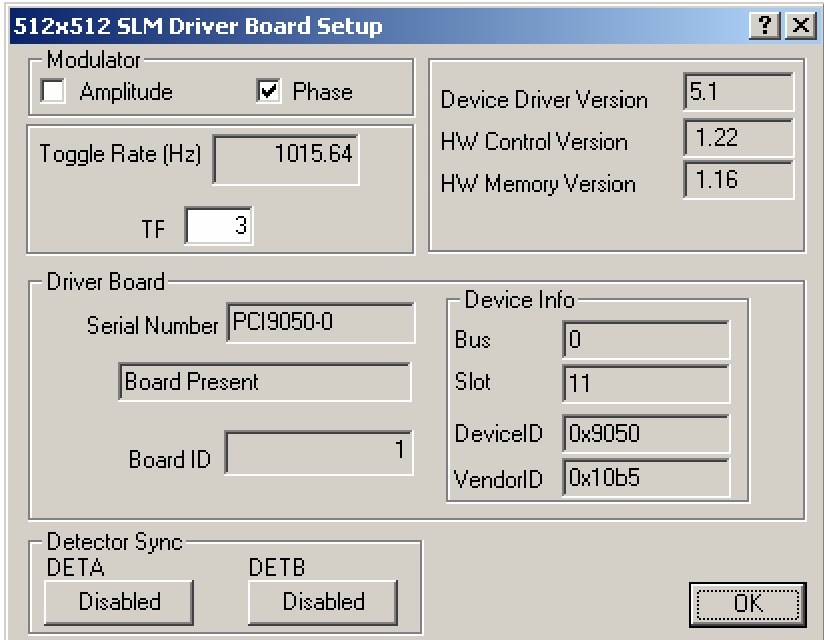


Figure 26 ~ Driver board setup screen.

1. Modulator

   The Modulator check box indicates what type of SLM is being utilized. For an XY Phase or PhaseFlat Series SLM the Modulator should always be set to "Phase". If the user changes this selection, a warning will be displayed about the potential effects.

2. Toggle Rate

   Toggle Rate is the rate at which the hardware changes the pattern file between the true pattern data and the inverse of the pattern data, see Section 9 for additional information. Toggling between true and inverse patterns is required to prevent permanent damage to the LC. The Toggle Rate is determined by the value of TF (True Frames), see Equation 1 for a 512 x 512 SLM system and Equation 2 for a 256 x 256 SLM system. The Toggle Rate has been configured at the factory to optimize performance for your SLM. Please contact BNS should you need additional information concerning the Toggle Rate.

$$ToggleRate = \frac{1}{TF * 328.32\mu \sec}$$

Equation 1 ~ Toggle Rate calculation for the 512 x 512 SLM system.

$$ToggleRate = \frac{1}{TF * 82.56\mu \sec}$$

Equation 2 ~ Toggle Rate calculation for the 256 x 256 SLM system.

The Toggle Rate also impacts the maximum Frame Rate in the Sequencing Settings section. The software will not allow a Frame Rate that exceeds the Toggle Rate.

3. Device Driver Version

   This is the version number of the device driver. This value is queried from the device driver.

4. Hardware Control Version

   The Hardware Control version indicates the firmware version number of the Timing and Control FPGA on the PCI board. A valid number here indicates that the device driver is installed, and is talking to the PCI board properly.

5. Memory Control Version

   The Memory Control version indicates the firmware version number of the SDRAM controller FPGA on the PCI Board. A valid number here indicates that the device driver is installed, and is talking to the PCI board properly.

6. Serial Number / Board Present

   The Serial Number refers to which BNS Driver Board is being used, if multiple boards exist. The Status indicator below the Serial number indicates the board was found in the system, and is able to communicate. Note that this is not a hardware serial number, but rather a serial number assigned by the operating system when the hardware is detected at boot-up.

7. Board ID

   The Board ID is used to tell the software if the hardware is 256 or 512 hardware, and what firmware revision is on that hardware.

8. Device Info

   The four parameters listed in this box describe the PCI characteristics. The Device and Vendor ID are programmed into the PCI board's firmware at our factory. The Bus and Slot ID's are where the operating system found the PCI board.

9. Detector Sync

   There are two buttons in this part of the dialog. The DETA button will enable the detector sync pin to pulse high at the end of the display of the True pattern. The DETB button will enable the detector sync pin to pulse high at the end of the display of the Inverse pattern. Refer to Section 9 for additional information.

5 Mechanical Housing

The SLM Housing has vertical and horizontal micrometers for adjusting the tip and tilt up to ± 3°. The housing also allows the user to rotate the SLM about the optical axis by ~15°. A set screw (located beneath the flex, between the knobs) locks the rotation about the optical axis.

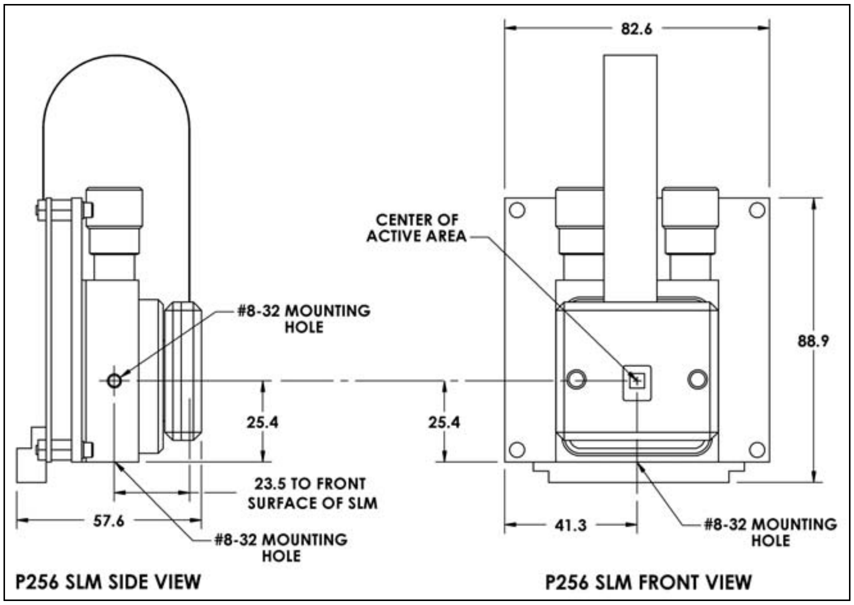


Figure 27 ~ Outline drawing showing front and side views of 256 SLM Optical Head. Dimensions in millimeters.

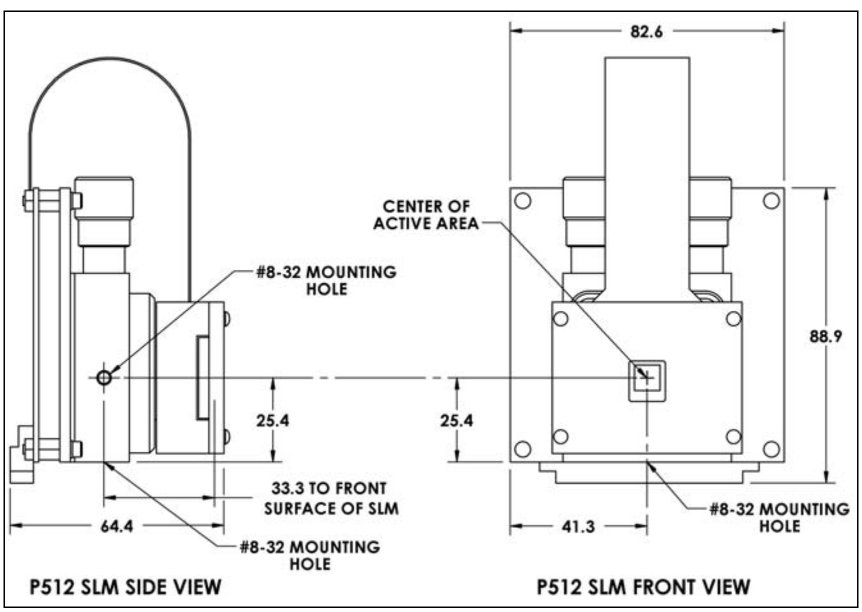


Figure 28 ~ Outline drawing showing front and side views of 512 SLM Optical Head. Dimensions in millimeters.

6 SLM care and cleaning

CAUTION

Failure to follow the recommendations included in this document may violate your warranty. Always ensure all personnel involved in the handling of your SLMs have appropriate tools, equipment, and training prior to cleaning any SLM.

Never use acetone to clean your SLM. Acetone will cause irreparable damage to your SLM.

Never use pressurized air or nitrogen to clean your SLM. Pressurized air or nitrogen will destroy the bond wires that provide the electrical interface to the SLM.

The SLM is shipped with a piece of black paperboard covering the SLM aperture. This aperture, or a similar aperture, should be kept in place while the SLM is not is use to reduce the buildup of dust and debris on the SLM coverglass. When removing the aperture cover, or while the SLM coverglass is exposed, care should be taken to avoid any contact with the coverglass.

If dust or debris does contaminate the coverglass, gently remove then with a methanol soaked lens tissue. Take a small lens tissue or cleanroom wipe and soak a corner of it with methanol. Let the methanol evaporate until the lens tissue is just damp then gently wipe off the particles with the corner of the wipe. For more stubborn debris the methanol drag can be used. Fold a lens tissue several times until it is just small enough to fit inside of the SLM aperture. Soak the folded edge with methanol and let it evaporate until just damp. Line up the folded edge of the lens tissue with the edge of the glass, and drag the tissue straight across the glass. Never wipe the glass more than once with the same lens tissue as it will merely transfer dirt back onto the coverglass. Repeat as necessary.

If there is any dirt or contamination that cannot be removed, please contact the factory for additional cleaning instructions.

7 Troubleshooting

7.1 Error: Cannot find the PCI board

Verify that the PCI board is in the machine and that the device driver is installed. To verify the device driver open the device manager and expand the Jungo key. Under the Jungo key both "WinDriver", and "PLX_9050" should be listed. If not refer to the device driver installation section or call BNS support.

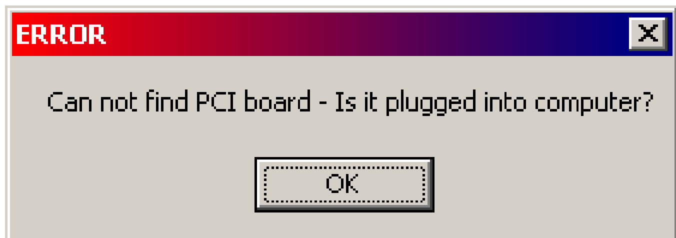


Figure 29 ~ PCI Board error message.

7.2 Error: Could not open the DAC board.

Verify that the DAC board is connected to the PCI board through both the DAC power cable and the SCSI cable.

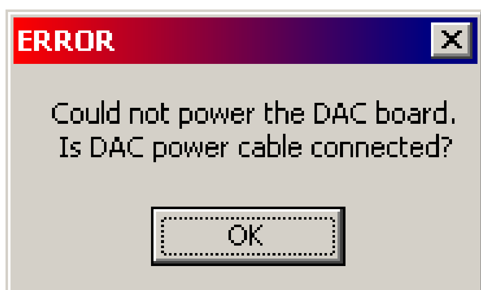


Figure 30 ~ DAC Board error message.

7.3 Invalid Sequence

If an exclamation point (!) appears in front of a Sequence Record in the Sequence List check the following items:

1. Open the sequence file using Notepad, or equivalent, and verify that the paths to the image files and LUT files are valid, and that the files exist.

2. Verify that the image file name ends in .bmp

3. Verify that the image size is either 1024x1024, 512x512, 256x256 or 128x128.

7.4 Error: "Could not read the SIF"

If "Could not read the SIF" appears in the dialog when first opening the program, that means there was a problem reading the sequence file. Check the following items:

1. Verify that the sequence file name ends in .sif.

2. Verify that the file exists, and that the path to the file is valid.

Note: When this error occurs, Blink should still open, and you should be able to browse to a new SIF. When Blink is restarted it will always attempt to open the SIF that was in used when Blink was last closed.

7.5 Error: "Could not load Sequence"

If "Could not load Sequence" appears there is likely a hardware failure. You should contact Boulder Nonlinear Systems for customer support.

7.6 Error: "Could not fill array of Images"

If "Could not fill array of Images" appears in the dialog when first opening the program, there was a problem allocating memory to the array used to store the pattern files defined in the current sequence file. This typically means that the computer has run out of working memory. You will either need to free some memory by closing other applications, use a smaller sequence file, or add physical or virtual memory to your computer.

8 System Specifications

	Phase Series Model P256	Phase Series Model P512	PhaseFlat Series Model PF256	PhaseFlat Series Model PF512
Array Size	4.61 x 4.61 mm	7.68 x 7.68 mm	4.61 x 4.61 mm	7.68 x 7.68 mm
Design Wavelength (nominal)	532, 635, 785, 1064, or 1550 nm			
Diffraction Efficiency (zero-order)	63.9% (maximum)	61.5% (maximum)	63.9% (maximum)	61.5% (maximum)
Duty Cycle	Up to 100%			
External Window[1]	Broadband antireflection coated for $R_{avg} < 1\%$ (over 450 – 850 nm or 850 – 1650 nm).			
Fill Factor	85.0%	83.4%	85.0%	83.4%
Format	256 x 256 (65,536 active pixels)	512 x 512 (262,144 active pixels)	256 x 256 (65,536 active pixels)	512 x 512 (262,144 active pixels)
Mode	Reflective			
Modulation	Controllable index of refraction			
Phase Levels (resolvable)	50 linear levels (minimum) for 2π phase stroke			
Phase Stroke (double-pass)	Typically 2π at user-specified laser line			
Pixel Pitch	18 x 18 µm	15 x 15 µm	18 x 18 µm	15 x 15 µm
Reflected Wavefront Distortion (rms)[2]	$\lambda/4 - \lambda/10$	$\lambda/3 - \lambda/8$	TBD	$\lambda/12 - \lambda/20$
Response Time[3]	33 – 100 ms			
Spatial Resolution	27 lp/mm	33 lp/mm	27 lp/mm	33 lp/mm
Switching Frequency[3]	10 – 30 Hz			

1. Custom antireflection coating options are also available, including V-type for optimum optical efficiency at a single laser wavelength.
2. At nominal wavelength.
3. Phase stroke, temperature, and wavelength dependent.

Above specifications are subject to change without notice. Please contact Boulder Nonlinear Systems for additional updates, and or wavelength-specific data.

9 Appendix – System Timing

The liquid crystal requires the drive signal to have no dc bias over time. The XY Phase and PhaseFlat Series SLM systems automatically provide a zero dc bias drive signal by sending a combination of "true" patterns and "inverse" patterns to the SLM. The true patterns are the Pattern Files as described in the Sequence List. The inverse patterns result in the liquid crystal experiencing the opposite voltage that was experienced during the true pattern for each and every pixel. Since the system also forces the SLM to utilize both the true and inverse patterns for the same period of time, the net result is a zero dc bias.

The liquid crystal utilized in the XY Phase and PhaseFlat Series SLM systems does not respond to the polarity of the drive signal. Therefore the SLM gives the same optical response whether the true pattern or the inverse pattern is loaded into the SLM. The rate at which the true and inverse patterns are written to the SLM is called the Toggle Rate. For the XY Phase and PhaseFlat Series the optimum Toggle Rate varies, but is typically in the range of 150 – 1500 Hz, much faster than the response time of the liquid crystal. The default Toggle Rate is defined for your system in the default configuration files. Generally it is not recommended to alter the Toggle Rate of your SLM system. Please contact BNS support if you need help determining the default Toggle Rate for your SLM system.

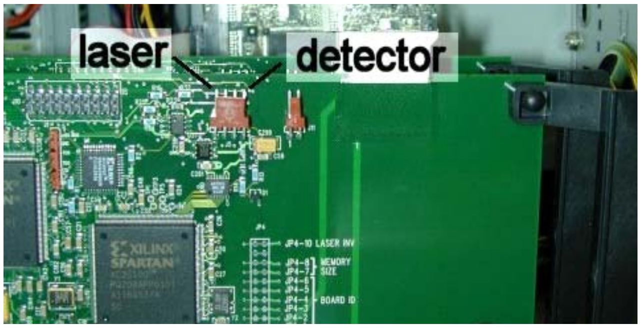
Timing for the SLM system is based on a Load Period. The Load Period is the amount of time it takes to completely refresh the SLM with a pattern. Each pixel can be thought of as a capacitor that requires the charge to be continually refreshed. Therefore the SLM system continually loads the current pattern, even when the Pattern File remains constant. The Refresh Rate is the rate at which the SLM is loaded, or refreshed stated in units of Hz. See Table 2 to determine the Load Period and Refresh Rate for your SLM system.

SLM Model	*Load Period*	*Refresh Rate*
P512 and PF512	164.16 μs	6091 Hz
P256 and PF256	41.28 μs	24,224 Hz

Table 2 ~ Load Periods for the different models of XY Phase and PhaseFlat Series SLM systems.

The Pattern Period is the length of time the SLM system spends on one Pattern File before changing to the next Pattern File. The Frame Rate is the rate, in Hz, of the Pattern Period. The Pattern Period and Frame Rate are controlled in the Blink software by the Frame Rate slide bar, see Figure 22. For the XY Phase and PhaseFlat Series SLM systems the Toggle Rate should always be at least 10 times faster than the Frame Rate.

The SLM system also includes a hardware signal that is often useful for integrating the SLM system into a larger system. This signal is referred to as the Laser Modulation signal, and is physically located on the PCI Board, see Figure 31 for details.



Pin Number	*Signal*
1	Laser Modulation
2	Ground
3	No Connect
4	Detector Sync

Figure 31 ~ The Laser Modulation and Detector Sync connector on the PCI Board.

The Laser Modulation signal can be utilized for driving the modulation input signal on many commercial laser diode drivers. The Blink software allows the user to control both the laser gain and the laser duty cycle. The laser gain is controlled through the “Laser Gain A” and “Laser Gain B” slide bars in the Main window (see Figure 22). For the XY Phase Series and the XY PhaseFlat Series the Laser Gain B setting is fixed to be equivalent to the Laser Gain A setting. Therefore the Laser Gain B setting cannot be modified by the user. The range on these slide bars is 0 – 100%. When the slide bar is set to 0%, the Laser Modulation signal will output 0 V at the designated time. When the slide bar is set to 100% the Laser Modulation signal will output 5 V at the designated time.

CAUTION

Check the compatibility of the Laser Modulation signal with your laser diode driver manufacturer prior to connecting this signal. Failure to do so could result in permanent damage to your laser diode.

Note: Some laser diode drivers are designed to utilize a different voltage range and/or a different polarity for the laser modulation input signal. Please be sure to check the detailed requirements of your laser diode driver with the manufacturer prior to attempting to utilize the Laser Modulation signal from your SLM system.

The Laser Modulation signal changes to 0 V at the end of the Pattern Period, unless the laser duty cycle is set to 100%. That way, if the Laser Modulation Signal is on, it will be on at the end of the Pattern Period, which is the time that the liquid crystal is most likely to have fully responded and therefore be at a steady state. This means that modifying the laser duty cycle has the effect of modifying the start of the Laser Modulation signal, the event when the signal changes from 0 V to the value determined by the laser gain setting.