meadowlark optics
polarization solutions

SPATIAL LIGHT MODULATORS

—Reflective XY Series

Phase and Amplitude — 512x512 and 256x256

A spatial light modulator (SLM) is an electrically programmable device that modulates light according to a fixed spatial (pixel) pattern. SLMs have an expanding role in several optical areas where light control on a pixel-by-pixel basis is critical for optimum system performance. SLMs are typically used to control incident light in amplitude, phase, or the combination of both (phase-amplitude).

Meadowlark Optics, Inc. (Meadowlark) manufactures and sells both reflective liquid crystal on silicon (LCoS) and Transmissive spatial light modulators (SLMs) for a variety of photonics applications. The XY SLM is based on our reflective LCoS technology. Instead of using off-the-shelf displays, Meadowlark has designed multiple SLMs specifically for these applications. This custom design approach allows us to offer products that are optimized for use in photonics applications. Our manufacturing processes have been developed to yield optically flat devices tuned to maximize performance at a variety of nominal wavelengths from the visible through the near infrared (NIR).

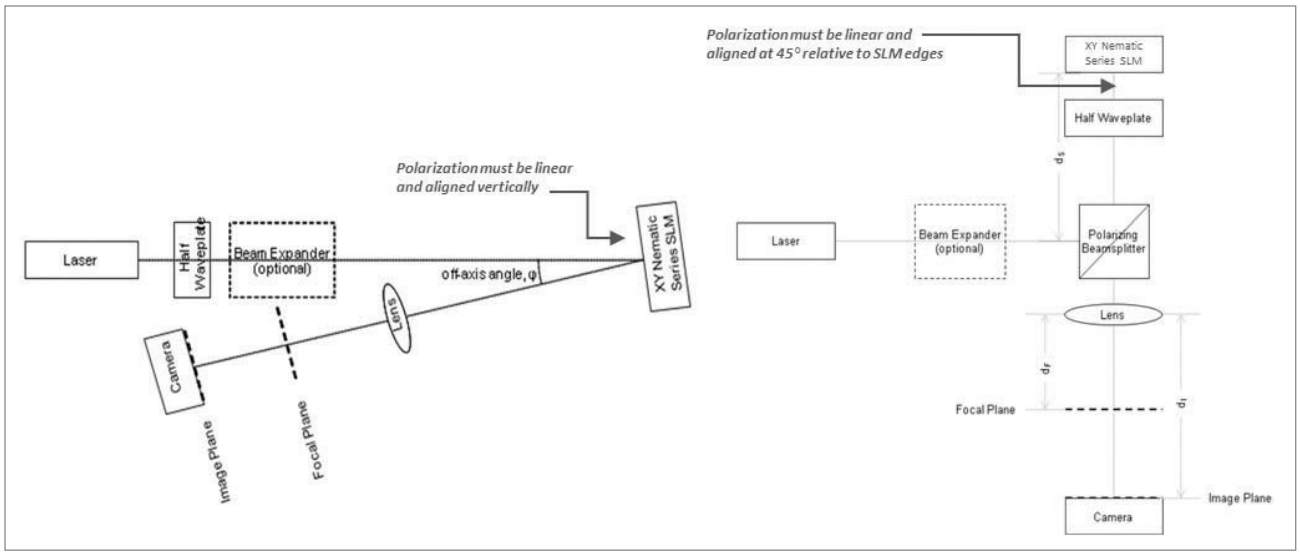
Prototype SLMs can also be purchased for ultraviolet (UV), short-wave infrared (SWIR), mid-wave infrared (MWIR), and long-wave infrared (LWIR).

Key Features

- Phase / Amplitude / Combined
- High Speed Phase Modulation (up to 500 Hz)
- High Efficiency (up to 95%)
- Low Phase Ripple
- Minimal Crosstalk
- High Optical resolution

XY NEMATIC SERIES SLMS – PHASE, AMPLITUDE OR BOTH

The Meadowlark XY Nematic Series Spatial Light Modulators (SLMs) are designed for versatility and ease of use in typical optical laboratory environments. The XY Nematic Series SLMs are optimized to provide a full wave (2π) of phase stroke upon reflection at one of several nominal design wavelengths. These SLMs provide phase modulation when the input light source is linearly polarized in the vertical axis. Amplitude modulation, with some phase-coupling, can also be achieved by simply rotating the input polarization by 45°.



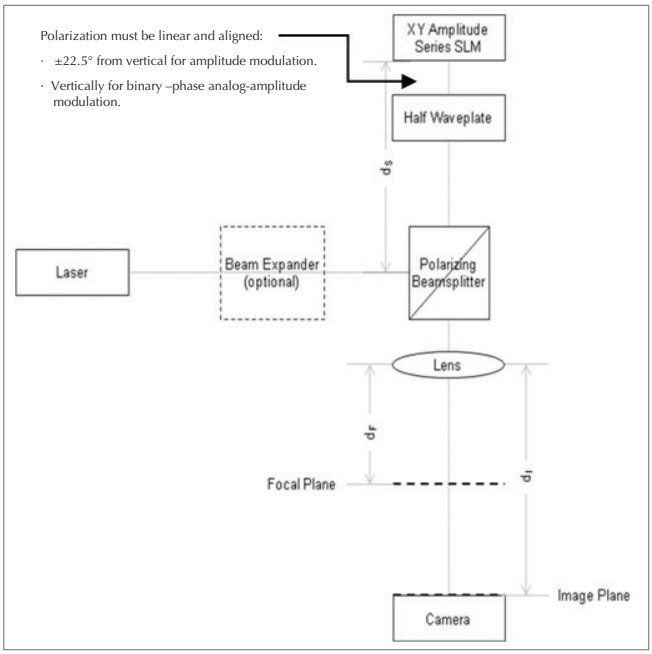
Nematic SLM used for Phase Modulation

Nematic SLM used for Amplitude Modulation

XY FERROELECTRIC SERIES SLMS – AMPLITUDE, OR POLARIZATION ROTATION

Meadowlark's XY Ferroelectric Series Spatial Light Modulators are designed to provide amplitude modulation via an analog polarization rotation of up to 90°.

These SLMs are optimized to provide very fast frame rates (up to 1 kHz). However, as with all ferroelectric liquid crystal devices, the duty cycle is limited to a maximum of 50:50 (drive requirements force the use of the true image for half of the cycle and an inverse image for the other half).



Ferroelectric SLM used for Amplitude Modulation

MEADOWLARK UNIQUE FEATURES

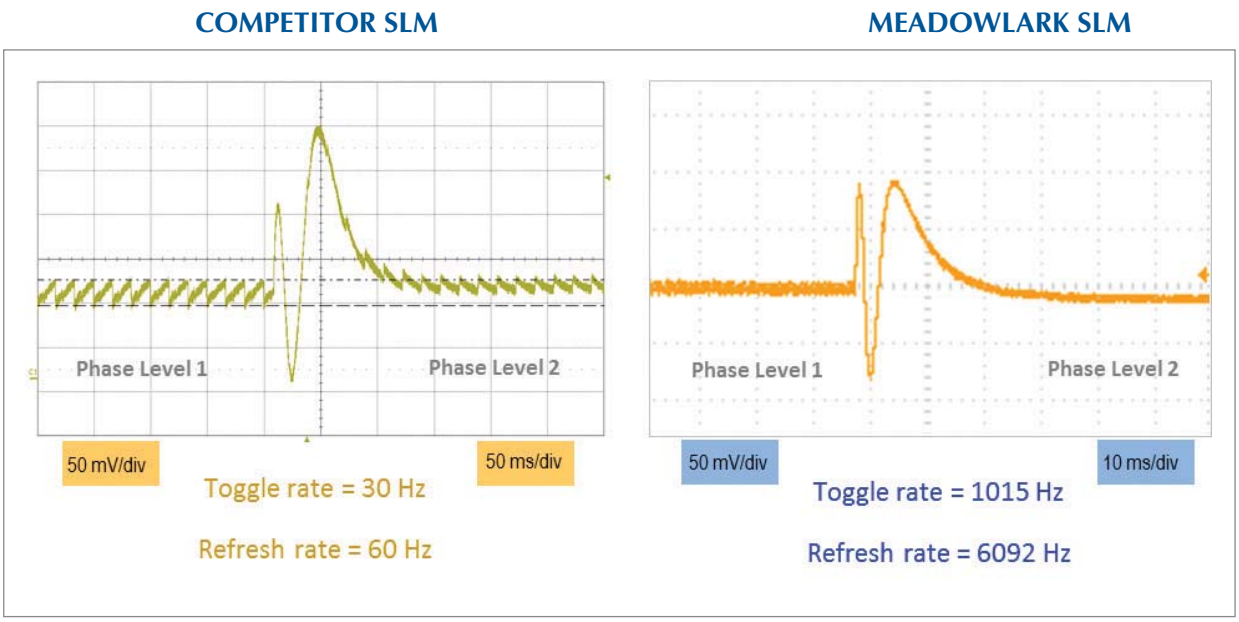
Meadowlark has developed many unique liquid crystal spatial light modulators over the past two decades. Through this development process there has been an advancement of SLM performance unmatched by any other company.

Such performance enhancement includes:

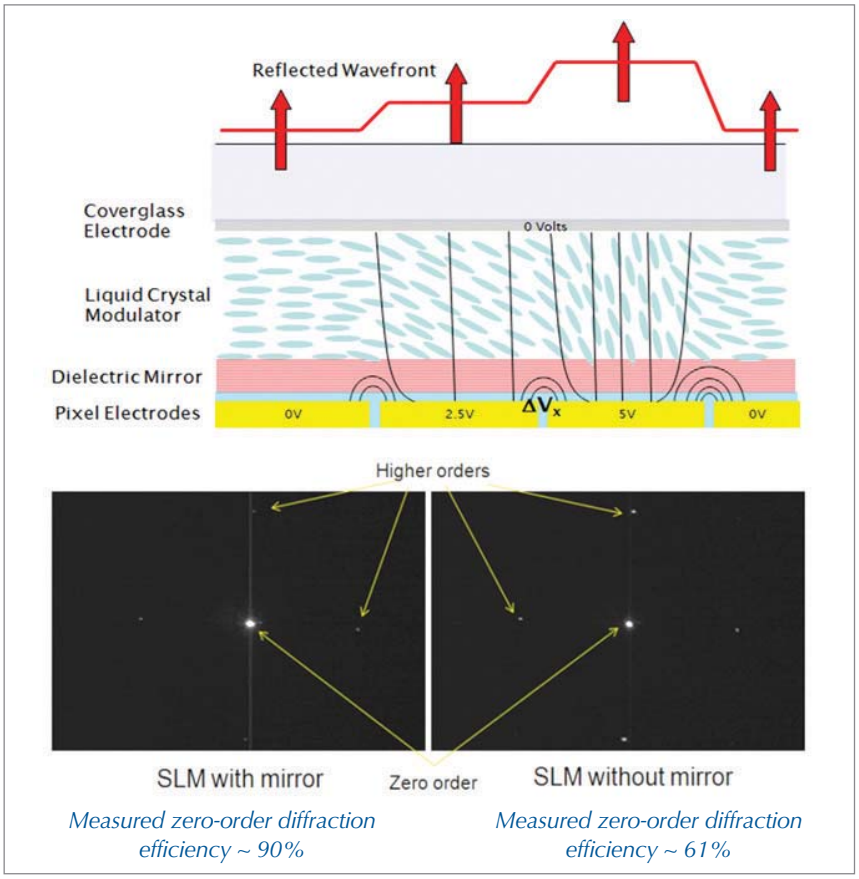
- Sub-millisecond frame loading to prevent phase droop and addressing latency
- 100% fill factor to reduce higher-order diffraction
- Intra-pixel-pair modulo-2π phase transitions to maximize bandwidth space
- Customized manufacturing processes to achieve optically flat performance
- Phase liquid crystal response times — up to 500 Hz

HIGH SPEED ADDRESSING

Meadowlark loads every pixel with an 8-bit or 16-bit data several times per millisecond. This high speed addressing scheme eliminates phase ripple as demonstrated in the figure below. There is significant data-dependent ripple caused by slowly addressing the modulator (left trace). That is, the rate used to toggle the field driving the modulator is slower than the liquid crystal's free relaxation response. The ripple represents a phase error when the modulator is used in its phase mode (input polarization aligned with modulator's optic axis). To eliminate the ripple, the toggle rate needs to be several times faster than the modulator's response (right trace). This requires active matrix backplanes and drive electronics capable of sub-millisecond load rates such as the Meadowlark XY Nematic Series SLMs.



Two parallel-aligned nematic LC modulators addressed at different rates. The left trace shows a strong data-dependent ripple that is synchronous with the video-rate addressing period. The right trace shows complete suppression of the ripple with sub-millisecond addressing – the standard for all Meadowlark SLMs.



Measured zero-order diffraction efficiency ~ 90%

Measured zero-order diffraction efficiency ~ 61%

100% FILL FACTOR

All of the light reflecting off of the spatial light modulator is modulated – including the light between the aluminum pixel electrodes. The reflective pixel structure associated with a Liquid Crystal on Silicon SLM backplane acts as an amplitude grating that diffracts some light into higher orders. To eliminate this loss of light, Meadowlark has developed a process for removing the grating effects due to the pixel structure. Optically, the active area of the backplane is converted into a flat dielectric mirror by depositing planar dielectric layers to eliminate the amplitude and optical path variations associated with the underlying aluminum pixel structure. The dielectric stack is kept thin to minimize any drop in electric field across the Liquid Crystal layer as shown in the figure to the right. In other words, there are no abrupt changes in phase modulation (such as dead zones) between pixels due to the smoothing (low pass spatial filtering) which results from separating the LC modulator from the driving electrodes.

HIGH OPTICAL RESOLUTION

The optical resolution of a modulo-2π (one-wave) phase modulator is related to its ability to produce phase wraps (i.e. a transition of 2π radians) over a small distance — preferably within a pixel pair. That is, the full resolution capability of the SLM is realized by producing phase wraps within the line-pair resolution of the LCoS backplane. Ideally this transition width is zero, but in reality will always have some width that is directly related to the thickness of the various layers in the modulator and the voltage potential between adjacent pixel electrodes, and between the coverglass electrode. This dielectric mirror stack eliminates inter-pixel dead zones, but it increases pixel-to-pixel influence. Therefore, the distance from pixel pad to coverglass electrode needs to be small in relation to the LCoS pixel pitch to maximize spatial resolution.

LCoS SLM CONTROLLER INTERFACE OPTIONS

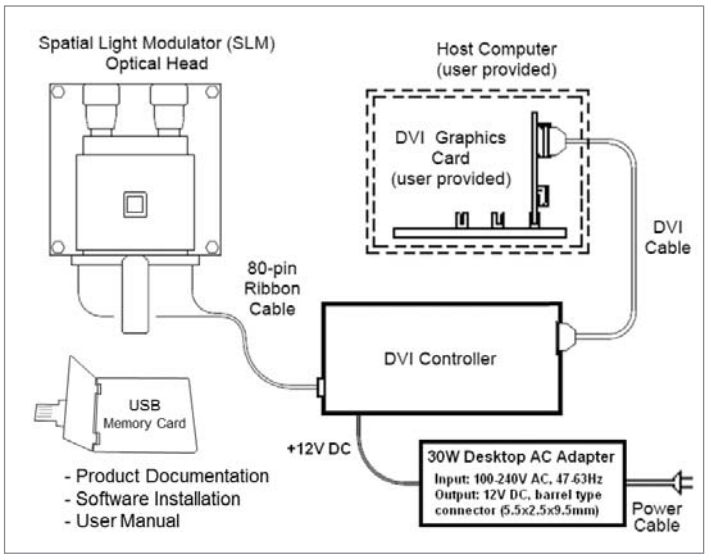
Introduction

Meadowlark offers three electronic hardware interface options for our LCoS SLMs: PCI Express (PCIe) 8 and 16-bit, or DVI 16-bit offering added flexibility to meet the most demanding customer applications.

DVI

For applications that are not concerned with latency or exact timing, but that desire a standard video interface to the SLM, this is an appropriate hardware choice. This controller provides 16-bit pixel data to the SLM. Calibrations of the nonlinear optical response of the liquid crystal to voltage can be loaded to the hardware, thus reducing system latency, and minimizing the need for the customer to understand the procedure to apply the calibration.

16-bit 512x512 images can be transferred across the DVI interface at a rate limited by the graphics card used. If a custom graphics card is used, the hardware supports up to 200 Hz frame rates. However, standard graphics cards are typically limited to 60 - 75 Hz refresh rates. The actual achieved frame rate is variable, with dependence on the computer and the software interface used. The achieved frame rate steps in increments of the monitor refresh, i.e. for a 75 Hz refresh and a C++ interface the image will sometimes update in 13.3 ms, but could update in 26.6 ms. In some system configurations the DVI interface may be slower than the liquid crystal response time.



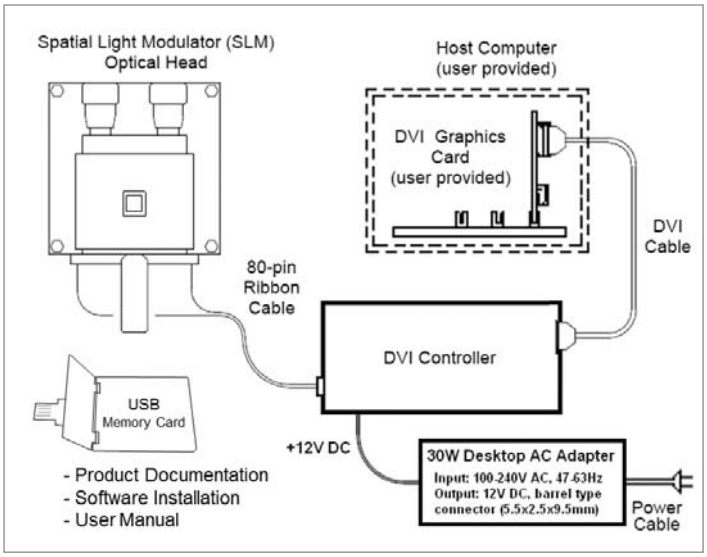
DVI Controller Hardware for LCoS SLM

The standard product software reads in the contents of a folder, and allows the user to either manually select an image to display on the SLM, or to load the images to the SLM sequentially using software timers. The software timers used to update the SLM are not highly accurate, so it is not possible to transfer images on a precise interval. The standard software uses a dualview mode, allowing the user to maintain full control over the primary monitor while actively driving the SLM.

LCoS SLM CONTROLLER INTERFACE OPTIONS

DVI continued…

In order to support 16-bit operation, 24-bit images are used, where 8-bits are blue, 8-bits are green, and 8-bits are red. The blue bits are ignored by the hardware, the green bits are the 8 most significant bits, and the red bits are the 8 least significant bits. If 8-bit images are loaded to the SLM through the Meadowlark software interface, the 8-bits are assigned to the 8 most significant bits. These images will appear green in the user interface. Images are transferred through the graphics card, meaning that the graphics card settings are critical to the operation of the SLM. Specifically, using the nVidia NVS 290 256MB dual DVI Graphics card, gamma must be set to 50% to get the expected mapping of input values to output values after passing through the graphics card, and for the Meadowlark supplied LUT calibration to function properly. Meadowlark cannot guarantee identical operation for all graphics cards. If a different graphics card is used it is recommended that the SLM calibrations be verified prior to use.



DVI Controller Hardware for LCoS SLM

PCIe 8- and 16-bit

For applications that require minimal latency such as atmospheric turbulence simulation/correction the PCIe interface is an appropriate choice.

This controller provides 8- or 16-bit pixel data to the SLM. Calibrations of the nonlinear optical response of the liquid crystal to voltage can be loaded to the hardware, thus reducing system latency, and minimizing the need for the customer to understand the procedure to apply the calibration.

8-bit 512x512 images can be transferred across the PCIe bus in approximately 600 µs using a x4, or larger PCIe slot. 16-bit 512x512 images can be transferred at the same rate but requires a x8, or x16 PCIe slot.

The standard product software reads in the contents of a folder, and allows the user to either manually select an image to display on the SLM, or to load the images to the SLM sequentially using software timers. Software timers are not highly accurate, so it is not possible to transfer images on a precise interval. However, if synchronizing into a larger system, triggers can be used to determine when a new image is on the SLM.

HOST COMPUTER REQUIREMENTS

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

Operating system(s): Windows XP Professional SP3 (32-bit), Windows Vista SP2 (32- and 64-bit) or Windows 7 (32- and 64-bit).

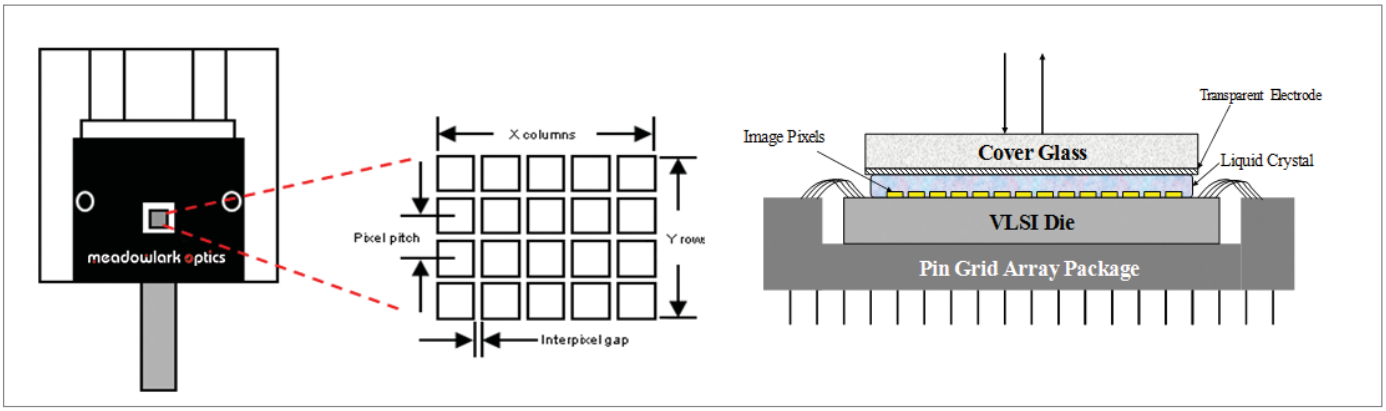
Dual-core processor and 1 GB of RAM (minimum).

Depending on the type of controller selected:

- PCIe 8-bit– one open x4, or larger PCIe slot

- PCIe 16-bit- one open x8, or larger PCIe slot

- DVI – Graphics controller with available DVI-D connector



Pixels are square and arranged in an XY pattern.

Cross section of a Meadowlark LCoS SLM.

SOFTWARE OPTIONS

Meadowlark offers several software options, enabling the user to select a program that will best suit their needs.

Blink Compact

Blink Compact is the basic software included with each purchase of an XY Nematic or FLC SLM system. Each USB card contains custom configuration files designed to provide improved performance on startup.

Blink Plus

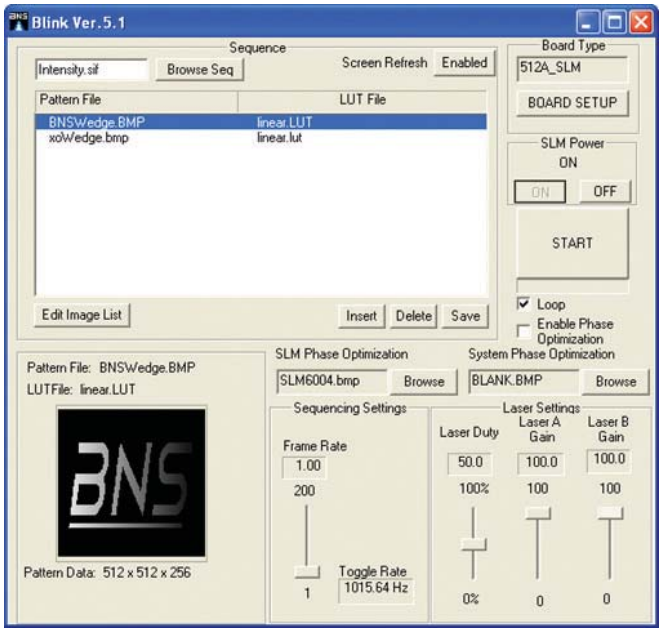
Blink Plus includes all of the features of Blink Compact, plus an added feature to remove the static phase patterns when working with the XY Nematic Series SLMs. (Not compatible with XY Ferroelectric Series SLMs.) Blink Plus is included with the purchase of a XY PhaseFlat SLM system. Each USB card contains custom configuration files designed to provide improved performance on startup.

Blink Full

Intended for programmer's familiar with Microsoft Visual C++ and device driver design, Blink Full is useful for those who wish to write their own software interface, and wish to modify the device driver. This software package includes the source code used to generate the Blink program. Source code is included for the upper level graphical user interface, as well as for the run-time libraries and device drivers.

Visual C++ Software Developer Kit

Intended for programmers familiar with Microsoft Visual C++ who intend to write their own software interface, but have little desire to modify the device driver. This simplified software package has a minimal user interface. It is meant to demonstrate how to call the run time library functions available to the user, and the order that those functions should be called in. An included example shows the user how to perform basic functions. Source code is included for the upper level graphical user interface, but is not included for the device driver.



LabVIEW Software Developers Kit

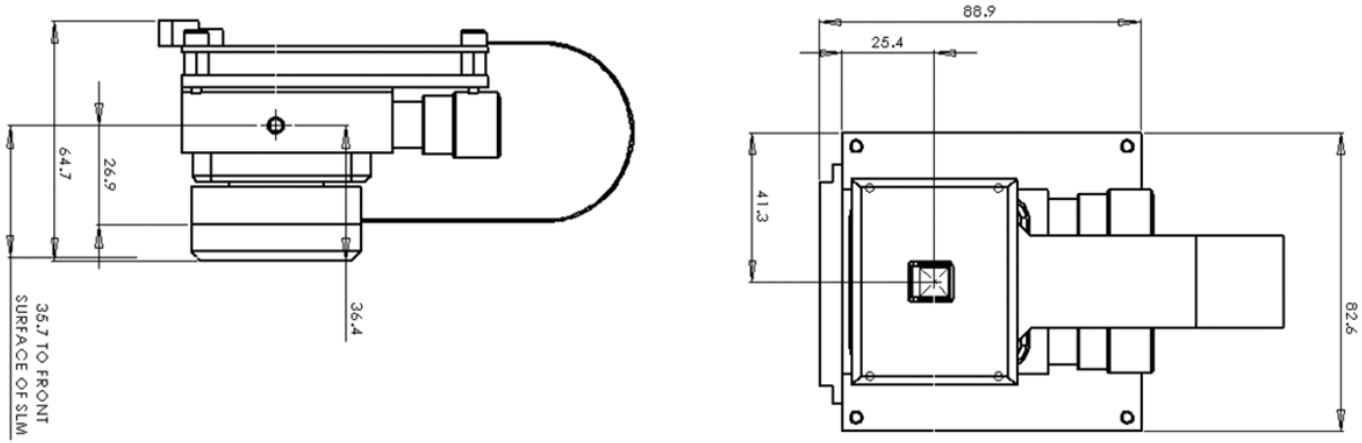
Intended for programmers familiar with Microsoft Visual C++ and LabVIEW who intend to write thier own LabVIEW VI to drive the SLM, but have little desire to modify the device driver. This simplified software package has a minimal user interface. It is meant to demonstrate how to call C++ functions through a DLL from LabVIEW, and the order that those functions should be called in.

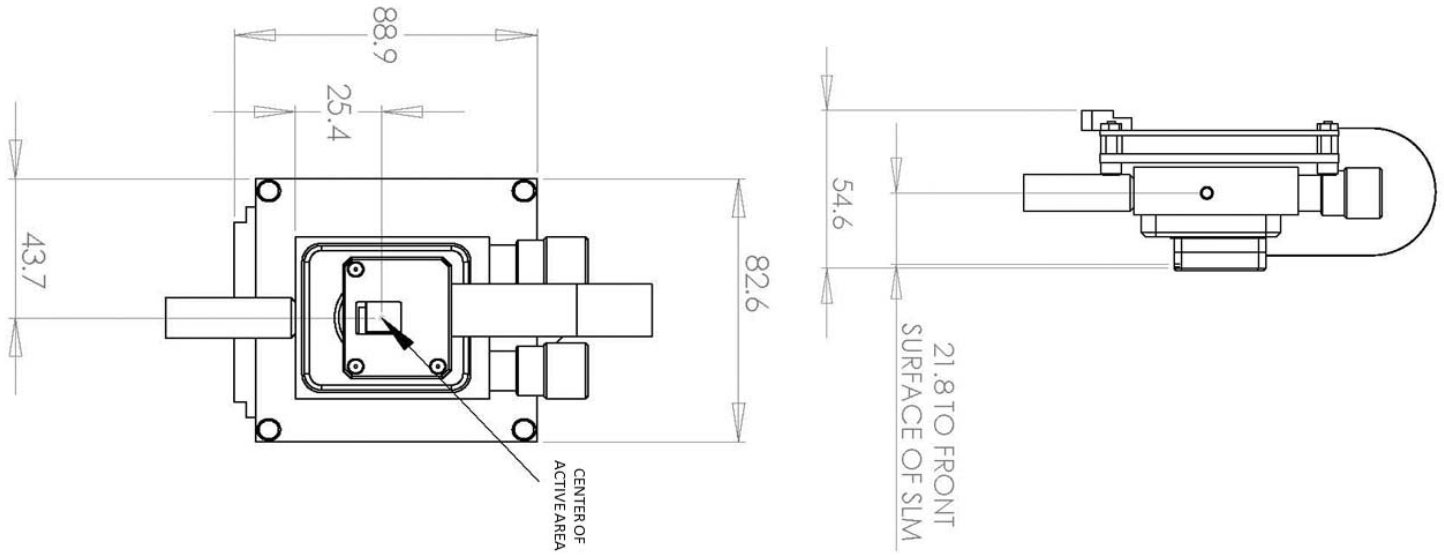
Matlab Software Developer Kit

Intended for programmers familiar with Matlab who intend to write their own software interface, but have little desire to modify the device driver. This simplified software package has a minimal user interface. It is meant to demonstrate how to call the run time library functions available to the user, and the order that those functions should be called in.

512 NEMATIC SLM SPECIFICATIONS

	Model P512 – 0532	Model P512 – 0635	Model P512 – 0785	Model P512 – 1064	Model P512 – 1550
Array Size	7.68 x 7.68 mm				
Zero-Order Diffraction Efficiency (standard)	61.5% (maximum)				
Zero-Order Diffraction Efficiency (with High Efficiency Mirror)	90 - 95% (maximum)				
Duty Cycle	Up to 100%				
External Window	Broadband antireflection coated for Ravg <1% over operating wavelengthrange, Standard ranges include: 450-865, 600-1300, 865-1650 nm				
Fill Factor (standard product)	83.4%				
Fill Factor (with High Efficiency Mirror)	100%				
Format	512 x 512 (262,144 active pixels)				
Mode	Reflective				
Modulation	Controllable index of refraction				
Phase Stroke (double-pass)	Typically 2π at user-specified laser line (π to 6π upon request)				
Contrast Ratio (if used in Amplitude Mode)	200:1				
Pixel Pitch	15 x 15 µm				
Spatial Resolution (maximum)	33 lp/mm				
Reflected Wavefront Distortion - RMS (standard)	λ/3 @ 532 nm	λ/4 @ 635 nm	λ/5 @ 785 nm	λ/6 @ 1064 nm	λ/8 @ 1550 nm
Reflected Wavefront Distortion – RMS (typical) with software compensation over the circular area	λ/7 @ 532 nm	λ/8 @ 635 nm	λ/10 @ 785 nm	λ/10 @ 1064 nm	λ/12 @ 1550 nm
Standard Liquid Crystal Response Time / Switching Frequency	≤ 33.3 ms / ≥ 30 Hz	≤ 33.3 ms / ≥ 30 Hz	≤ 55.5 ms / ≥ 18 Hz	≤ 66.7 ms / ≥ 15 Hz	≤ 100 ms / ≥ 10 Hz
High Speed Liquid Crystal Response Time / Switching Frequency	≤ 7 ms / ≥ 142 Hz	≤ 12 ms / ≥ 83 Hz	≤ 17.2 ms / ≥ 58 Hz	≤ 10 ms / ≥ 100 Hz	≤ 20 ms / ≥ 50 Hz
High Efficiency with High Speed Liquid Crystal Response Time / Switching Frequency	≤ 10 ms / ≥ 100 Hz	≤ 16.7 ms / ≥ 60 Hz	≤ 22.2 ms / ≥ 45 Hz	≤ 16.7 ms / ≥ 60 Hz	≤ 28.5 ms / ≥ 35 Hz
Wavelength Range	515 – 585 nm	615 – 700 nm	760 - 865 nm	1030 - 1170 nm	1505 - 1650 nm





256 NEMATIC SLM SPECIFICATIONS

	Model HSP256 – 0532	Model HSP256 – 0635	Model HSP256 – 0785	Model HSP256 – 1064	Model HSP256 – 1550
Array Size	6.14 x 6.14 mm				
Zero-order Diffraction Efficiency (standard)	71.5% (maximum)				
Zero-Order Diffraction Efficiency (with High Efficiency Mirror)	90 - 95% (maximum)				
Duty Cycle	Up to 100%				
External Window - 600 to1300 nm also available (see chart on page 12)	Broadband antireflection coated for Ravg < 1% (over 450 - 865 nm)				
Fill Factor (standard product)	90%				
Fill Factor (with High Efficiency Mirror)	100%				
Format	256 x 256 (65,536 active pixels)				
Mode	Reflective				
Modulation	Controllable index of refraction				
Phase Stroke (double-pass)	Typically 2π at user-specified laser line (π to 6π upon request)				
Contrast Ratio (if used in Amplitude Mode)	200:1				
Pixel Pitch	24 x 24 µm				
Spatial Resolution (maximum)	20 lp/mm				
Reflected Wavefront Distortion - RMS (standard)	λ/7 @ 532 nm	λ/8 @ 635 nm	λ/10 @ 785 nm	λ/12 @ 1064 nm	λ/15 @ 1550 nm
High Speed Liquid Crystal Response Time / Switching Frequency	≤ 2 ms / ≥ 500 Hz	≤ 2.5 ms / ≥ 400 Hz	≤ 4.5 ms / ≥ 222 Hz	≤ 7 ms / ≥ 142 Hz	≤ 14 ms / ≥ 71 Hz
High Efficiency with High Speed Liquid Crystal Response Time / Switching Frequency	≤ 2.8 ms / ≥ 350 Hz	≤ 3.3 ms / ≥ 300 Hz	≤ 5.7 ms / ≥ 175 Hz	≤ 10 ms / ≥ 100 Hz	≤ 20 ms / ≥ 50 Hz
Wavelength Range	515 – 585 nm	615 – 700 nm	760 - 865 nm	1030 - 1170 nm	1505 - 1650 nm

Standard Liquid Crystal options are not available with the 256 x 256 model.

512 FLC SLM SPECIFICATIONS

	Model A512 – 0532	Model A512 – 0635	Model A512 – 0785	Model A512 – 1064	Model A512 – 1550
Array Size	7.68 x 7.68 mm				
Format	512 x 512				
(262,144 active pixels)	90 - 95% (maximum) 90 - 95% (maximum)				
Zero-Order Diffraction Efficiency (standard)	61.5% (maximum)				
External Window	Broadband antireflection coated for Ravg < 1% (over 450 - 865 nm)				
Mode	Reflective				
Modulation	Controllable optic axis orientation				
Contrast Ratio (monochromatic input light)	200:1				
FLC Response Time	≤ 450 µs				
FLC Switching Frequency	1015 Hz (maximum)				
Duty Cycle	50%				

FLC SLMs are available in 512 x 512 models only.

DRIVER SPECIFICATIONS

	PCIe 8-bit	PCIe 16-bit	DVI
Transfer Time (computer dependent)	400 µs (CPU to SLM)	400 µs (CPU to SLM)	60 Hz – 16.7 ms (CPU to SLM) 200 Hz - 5.0 ms (CPU to SLM
Driver Phase Levels	256 (8-bits)	65,536 (16-bits) Combined red & green channels	65,536 (16-bits) Combines red & green channels
Platform Independence Window / Driver	NO	NO	Windows Color Pallet Dependent
On Board Look-Up-Table (LUT)	Yes	Yes	Yes
SLM Models Available	256x256, 512x512, 1 x 12,288 all models	256x256, 512x512, 1 x 12,288 (all models)	60 Hz – Standard 512x512 200 Hz - High Speed 512x512

Meadowlark Optics has provided world-class liquid crystal solutions and polarization optics from a state-of-the-art manufacturing facility since 1998. To ensure precision and top quality, our 20,000-square-foot headquarters boasts the latest in clean rooms, optical fabrication, metrology facilities and a breath-taking view of Colorado's Front Range.

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