meadowlark optics
spatial light modulators

SB0520

Specification Backgrounder for XY Series Phase SLMS

Introduction

This document defines the specifications listed in the XY Series Phase SLM data sheet. Validation of each specification falls into one of three categories:

DP **Design Parameter** – Specifications in this category are defined by the design parameters and hence will not vary from device to device. As a result, validation of these specifications is not required.

ED **Empirical Data** – Specifications in this category required validation testing upon initial product launch, but due to manufacturing procedures does not vary from device to device therefore testing of this specification is not performed for each device manufactured.

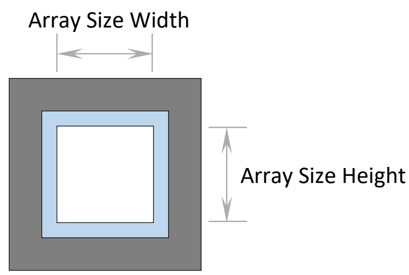
VI **Validated Information** – These specifications are tested for each device manufactured. Only devices that pass all VI tests will be shipped along with a test report.

VR **Validated on Request** – These specifications are only tested for a device upon request. Typically this applies to specifications for a non-standard use, such as using an XY Series Phase SLM in an Amplitude Mode.

Specifications

Specifications are listed in alphabetical order.

DP **Array Size** – This is the active area of the SLM specified as width by height, in millimeters. It is equivalent to the number of pixels along one axis multiplied by the pixel pitch.



DP **Calibration Wavelength** – This is the wavelength utilized for Validated Information for which all data will be measured for a given SLM.

VR **Contrast Ratio** – Occasionally an XY Series Phase SLM will be utilized in an Amplitude Mode. When requested, these devices will be validated for contrast ratio.

The optical layout for contrast ratio measurements is shown in Figure 1.

1. A half wave plate is placed between the laser and the first polarizer to tune the intensity of light transmitted through the polarizer
2. The polarizers are oriented at +/-45 degrees to the SLM. The first polarizer should be set at +45 degrees, and the second polarizer is crossed with the first. You can validate the polarizers are crossed by placing both polarizers immediately after the half wave plate. Rotate the half wave plate to maximize light transmitted through the first polarizer. Then rotate the second polarizer to extinguish transmission. After setting the angle of the second polarizer, place the second polarizer after the SLM.
3. Place an iris just before the SLM to match the diameter of the illumination to the active area of the SLM. Validate the position and radius of the iris with respect to the SLM by imaging the SLM onto a camera. The illumination should slightly under-fill the active area of the SLM as shown in Figure 2.

Sample images from the camera, and traces from the large area detector are shown to illustrate the contrast ratio. The images from the camera will easily saturate because the camera has an 8 bit framegrabber. The camera is only used to verify the optical layout is acceptable, and measurements of contrast ratio are completed by placing the large area detector in the Fourier plane aligned with the 0th order.

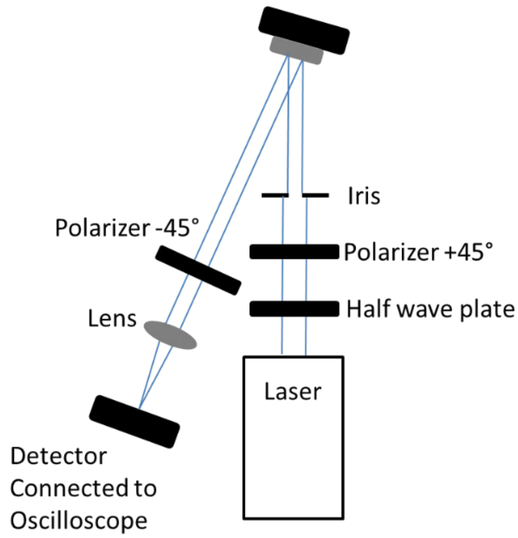


Figure 1 – Slightly off axis configuration to use the Nematic SLM as an amplitude modulator.

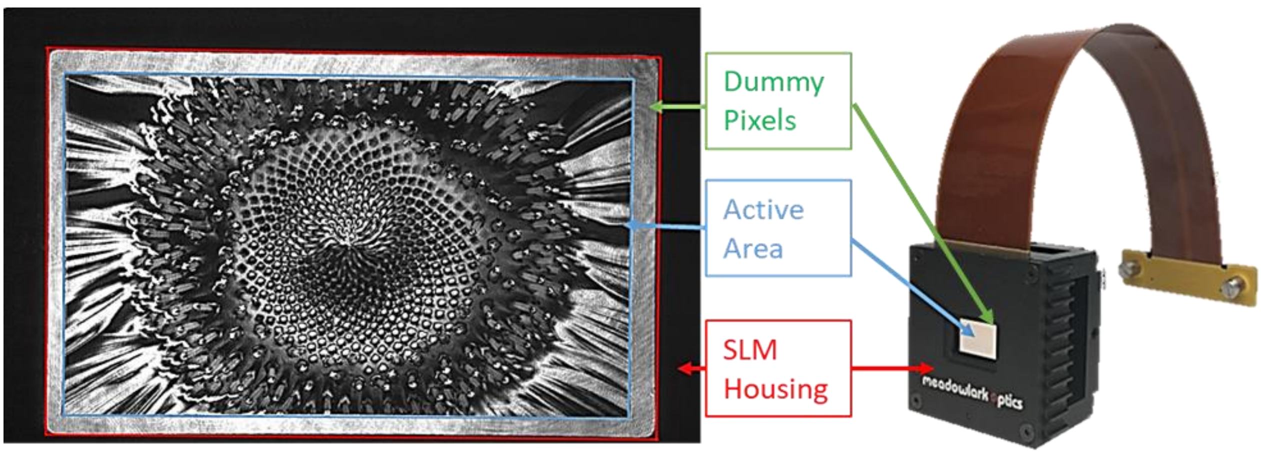


Figure 2 – Nematic SLM imaged as an amplitude modulator in a slightly off axis configuration. The blue box indicates the active area of the SLM.

Figure 3 – (left) Solid pattern resulting in an off state = 5.71 mV (right) solid pattern resulting in an on state = 1.26 V

Figure 4 – background noise with laser blocked = 517 µV

Figure 3 and Figure 4 illustrate the measured on state, off state, and the background noise. Contrast Ratio = (On – Background)/(Off – Background). For this example the contrast ratio is 242:1.

DP

Controller Phase Levels – This is the maximum number of unique analog voltage levels that can be addressed by the Controller.

DP

Design Wavelength – This is the wavelength, or wavelength range, over which the SLM was specified to be operational. Many specifications will change as a function of wavelength, see also Calibration Wavelength.

ED

CPU to SLM Transfer Time – This is the time needed to transfer one image frame from the computer to the SLM chip. Please note this number can vary considerably from one computer to another based on the computer, software, and other hardware connected to the computer.

ED

CPU to Controller Transfer Frequency – This is the rate at which frames can be continuously sent from the computer to the SLM Controller. Please note this number can vary considerably from one computer to another based on the computer, software, and other hardware connected to the computer.

ED

External Window – This is the average reflectivity over the defined wavelength range of the outer surface of the external window. This data is measured on a sample from each new lot of coated windows.

VI

Diffraction Efficiency (zero-order) – This is the maximum percentage of light measured in the zero-order compared to the amount of light incident upon the SLM. This measurement accounts for all light lost through diffraction into higher orders or absorption by the various layers in the SLM. Typically this will be specified as a range

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since the measured efficiency changes as a function of applied pixel value as the liquid crystals rotate and present a different index of refraction causing a change in the Fresnel reflections at the liquid crystal cell boundaries.

The optical layout for the measurement is shown in Figure 5. The efficiency is calculated by dividing the power of the light in the 0th order after reflecting off the SLM by the power in the laser. The iris is used to block out higher orders from illuminating the power meter.

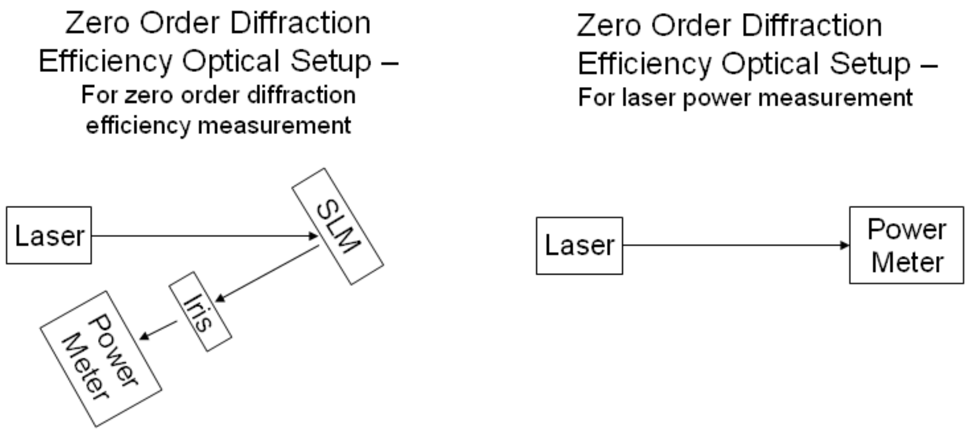


Figure 5 – Optical layout used to measure 0th order diffraction efficiency.

VI

Diffraction Efficiency (1st-order) – This is the maximum percentage of light measured in the 1st-order with a phase ramp compared to the light in the 0th order when no pattern is written to the SLM.

The optical layout for this test is shown in Figure 6. A half wave plate is used to align the incident polarization with the SLM. The SLM should be flood illuminated. First, turn off the power to the SLM. Align the large area detector with the 0th order, and record the intensity of the 0th order focal point. Then turn on the SLM power, load the LUT for this SLM, load phase ramp to the SLM, and translate the detector such that the 1st order focal point is incident on the detector. The first order beamsteering efficiency is the ratio of the light in the 1st order to the light in the 0th order. This will be measured and specified as a function of the ramp grating period.

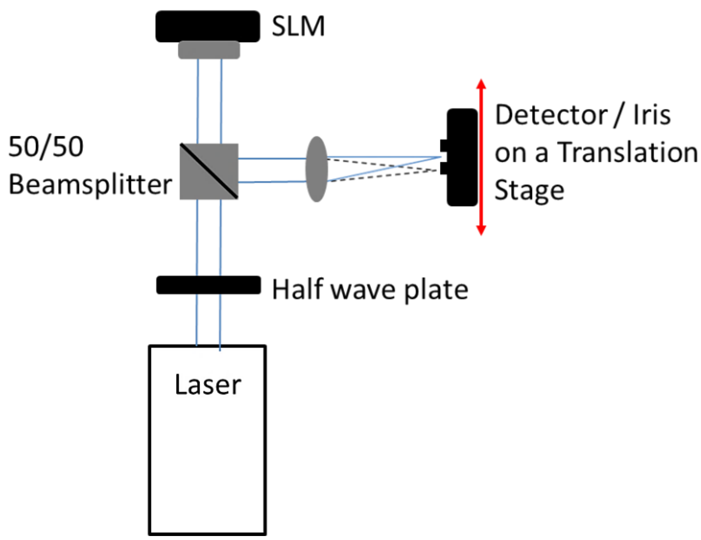
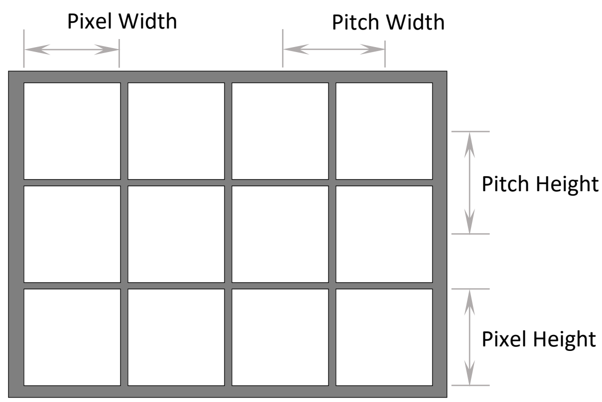


Figure 6 – Optical layout used to measure 1st order beamsteering efficiency.

DP **Duty Cycle** – This is the maximum percentage of time the SLM can display a valid pattern. This Duty Cycle is affected by the liquid crystal response time and the user-configured Frame Rate. As the Frame Rate increases the Duty Cycle will decrease.

ED **External Window** – This is the average reflectivity over the defined wavelength range of the outer surface of the external window. This data is measured on a sample from each new lot of coated windows.

ED **Fill Factor** – This is the percentage of Area within each pixel that is reflective. Mathematically it is the (Pixel Width / Pitch Width) * (Pixel Height / Pitch Height). This specification is a Design Parameter that has also been verified with Empirical Data.



DP **Format** – This is the total number of individual pixels in the active area of the SLM.

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VI

Liquid Crystal Response Time – The Liquid Crystal Response Time is a 10-90% measurement of the SLM switching through one wave of Phase Stroke.

This measurement is performed using the optical layout of Figure 6.

1. Align the SLM such that the 0th order is aligned with the center of the rail that the detector is mounted on.
2. Use Blink to open a sequence of two images consisting of: a solid image with all pixels set a mid-point grayscale, and a repeating phase ramp with 8 pixels per grating.
3. Load the custom Look-Up Table (LUT) to the SLM that generates a linear 0 to 2π optical response at the wavelength under test.
4. Use Blink to load the repeating phase ramp to the SLM to generate a 1st order focal point. Translate the detector to measure the 1st order intensity.
5. Set the sequencing rate to something reasonably slow, around 50 Hz. Begin toggling between the two images and measure the rise and fall time to switch onto and off of the repeating phase ramp. This is the 10-90% rise and fall time. The response time recorded is the slower of the two measurements.

VI

Maximum Liquid Crystal Switching Frequency – The Maximum Liquid Crystal Switching Frequency is specified in Hertz and is = 1 / Liquid Crystal Response Time (in seconds).

See Liquid crystal Response Time for the validation method.

DP

Mode – The Mode will be either Reflective or Transmissive.

DP

Modulation – This describes the method by which the liquid crystal modulates light as a function of applied voltage. Note the index of refraction can only be varied in one polarization axis. This is the vertical axis for the Small 512 x 512, the 256 x 256 and the 1920 x 1152 SLMs, the horizontal axis for the Large 512 x 512, and the 1 x 12288 SLM.

VI

Phase Ripple – This is the percentage of variation when maintaining a steady-state phase pattern on the SLM. This test is completed using the optical layout of Figure 6.

1. Align the SLM such that the 0th order is aligned with the center of the rail.
2. Use Blink to load the repeating phase ramp with 8 pixels per ramp to the SLM to generate a 1st order focal point.
3. Translate the detector to measure the *mean 1st order intensity*. Note the time scale of the oscilloscope should be set to the scale of the DC balancing rate, see table below.

SLM Model	Oscilloscope Time Scale
Small 512 x 512	~1 ms/div
Large 512 x 512	~1 ms/div
1920 x 1152	~2 ms/div

4. On the oscilloscope change the settings from DC Coupled to AC coupled such that it is easier to measure the *peak to peak variation*.
5. The Phase Ripple = (*peak to peak variation/mean 1st order intensity*) *100

VI

Phase Stroke – This is the minimum Phase Stroke the SLM will provide at the Design Wavelength when swinging the applied voltage over the maximum range. This is the total phase stroke achieved on double-pass, i.e. the light goes in, then comes back out of the SLM. This test is completed using the optical layout of Figure 6.

To measure the phase stroke of the SLM, stripe diffraction patterns, with 8 pixels per stripe, are loaded to the SLM. The value of one graylevel in the stripe pattern is held constant as a reference, and the other is varied across the full range of grayscales available. As each diffraction grating is loaded to the SLM, the 1st order intensity is measured. A null – peak transition corresponds to 0.5 waves of phase delay. Thus, in the example below the modulation depth of the SLM is 2.75 waves.

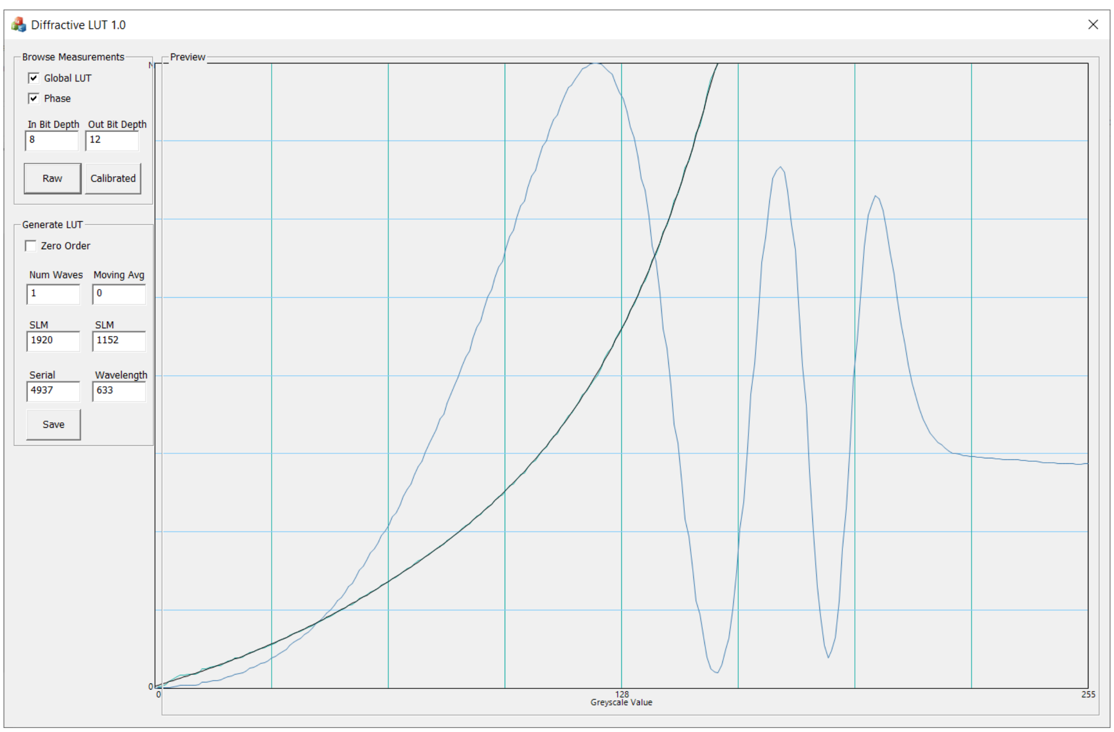
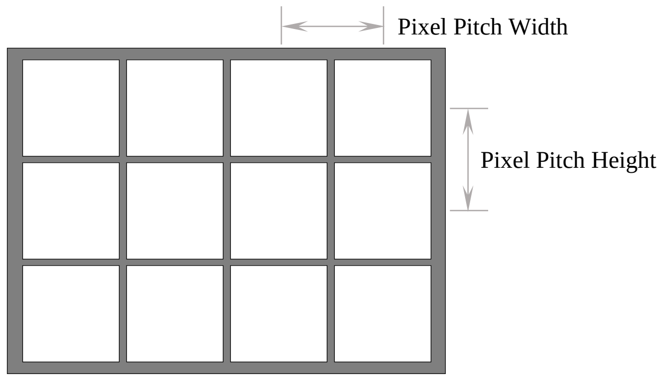


Figure 7 – Intensity measurements are recorded as diffraction gratings are loaded to the SLM. By post processing the intensity measurements the modulation depth of the SLM can be determined.

Pixel Pitch – This is the center-to-center spacing between pixel pads along both the Width and Height of the SLM.



Reflected Wavefront Distortion (standard) – This is the RMS Wavefront Distortion across the Array Size as measured using a fringe analysis of an interferogram recorded using a Twyman-Green Interferometer.

Reflected Wavefront Distortion (calibrated) – A phase calibration map is captured for each SLM. This calibration map is then loaded into the SLM to offset the Reflected Wavefront Distortion. The RMS Wavefront Distortion across the Array Size is then measured in a Twyman-Green Interferometer. This calibration map is delivered with each SLM and can be used with the supplied software in combination with any of your desired phase patterns to effectively calibrate out any inherent aberrations in the SLM, minimizing phase errors.

SLM Phase Levels – This is the minimum number of Linear Phase Levels achievable with the selected SLM and controller combination. Liquid crystal does not provide a linear response to applied voltage, therefore this number will always be lower than the bit-depth of the selected Controller. This test is performed when the LUT file is generated. The optical layout of Figure 6 is used.

1. Align the SLM such that the 0^{th} order is aligned with the center of the rail.
2. Use Blink to load a stripe diffraction grating sequence with 8 pixels per stripe and use a linear LUT. Scroll through the stripes until you find the image that minimizes the 0^{th} order and maximizes the 1^{st} order.
3. Translate the detector until it is aligned with the 1^{st} order, and set the iris so that only the 1^{st} order can illuminate the detector.
4. Loop through all the diffraction gratings and measure the 1^{st} order intensity.
5. Post process the intensity measurements to generate a LUT calibration. The number of linear phase levels found from 0 to 2pi corresponds to the number of unique output values in the LUT calibration.

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