Meadowlark Optics' Spatial Light Modulators

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. They are used in various applications like optical processing, data routing, and information display.

SLMs can work through different methods in materials such as liquid crystals (LC). LC-based SLMs have advantages like high birefringence and low-voltage operation, allowing for large optical effects in thin layers. They can create large arrays operating at high data rates, even though individual pixels switch quickly. Integrating LCs with silicon backplanes is a key technology for smart pixel devices, combining detectors, electronic logic, and modulators into a single device.

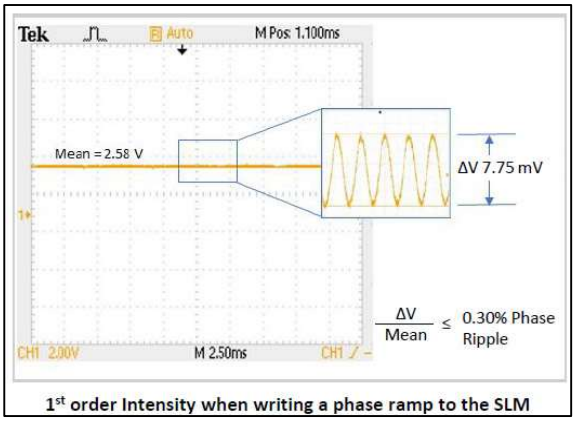
Sintec Optronics is the authorized distributor of Meadowlark Optics' liquid crystal on silicon (LCoS) spatial light modulators in Southeast Asia and India. Meadowlark Optics' LCoS SLMs boast exceptional speed, efficiency, and high resolution, ensuring accurate and reliable results. They are uniquely designed for pure phase applications and incorporate analogue data addressing with high refresh rates. This combination provides users with the fastest response times and highest phase stabilities commercially available. Phase-only SLMs can also be used for amplitude-only modulation or take advantage of the rectangular aperture for simultaneous phase and amplitude modulation.

Selection Guide

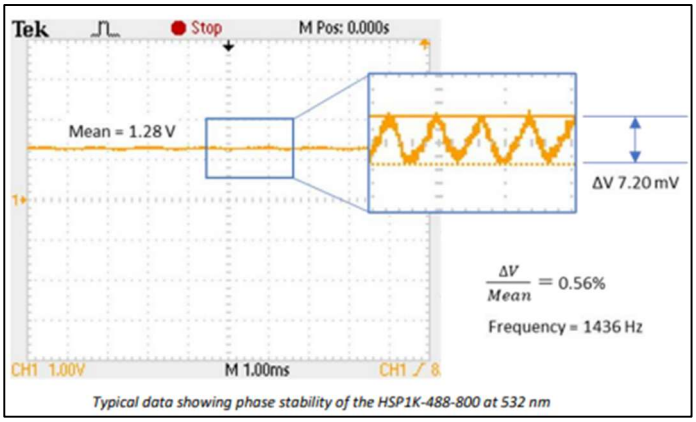
Models	Series / Versions	Optional Add-Ons
1920 x 1200 Analog SLM	• E-Series • S-Series • S-Series with dielectric mirrors (DM)	-WCS1: Liquid Cooling System (ambient) -TCS2: Variable Temperature Heating (ambient to 75degC, 1k SLMs only) -TCS3: WCS and TCS2, Variable Temperature Cooling (10degC to ambient) -CAL: Additional Calibration Wavelength -NI: Dynamic Recalibration Kit
1024 x 1024 Analog SLM	• High-speed version • High-speed version with DM • Ultra-high-speed version • Ultra-high-speed version with DM • Ultra-high-power version with DM	
1536 x 1536 Mid-wave Nematic SLM		

High Phase Stability

Meadowlark Optics are known for having the fastest SLMs with the least amount of phase ripple on the market. By combining traditional analogue drive scheme with new proprietary technologies, phase instabilities are suppressed to less than 0.40% to 2.0% (model dependent), without compromising speed. Phase ripple is quantified by measuring the variation in intensity of the 1st order diffracted spot as compared to the mean intensity while writing a blazed phase grating to the SLM. Since phase stability varies as a function of pixel voltage, this measurement approach is an average and does not represent all scenarios. For customers who require higher stability, custom options are available.



1st order Intensity when writing a phase ramp to the SLM

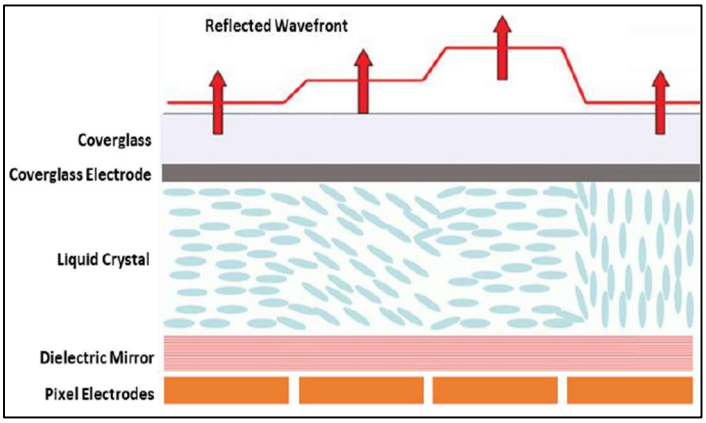


Typical data showing phase stability of the HSP1K-488-800 at 532 nm

Diffraction Efficiency (0th-order)

This is the amount of light retained in the 0th-order (dc) when writing solid grayscale images to the SLM as compared to the amount of light in the 0th order when the SLM is replaced with a reference mirror. This measurement quantifies losses in the coverglass coatings, losses due to wavelength dependent reflectivity of the pixel pads, as well as losses to diffraction from reflecting off the pixilated structure of the backplane. In the case of a dielectric mirror coated model, the measurement accounts for losses due to imperfect reflectivity of this dielectric mirror coating. The 0th order diffraction efficiency will vary as a function of wavelength due to differences in coating materials and designs. It will also vary with pixel value due to the inherent change in the index of refraction of the liquid crystal that results in a change in the Fresnel reflections inside the liquid crystal cell. Most standard SLMs will range from 70–90%, while the dielectric mirror coated models will range from 92–98%.

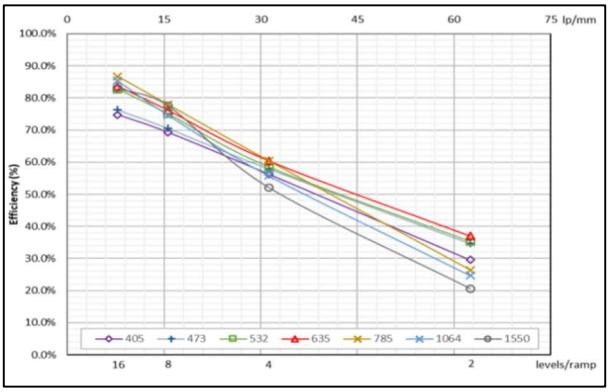
High Efficiency Dielectric Mirror Coating (Certain Models Only)



The reflective pixel structure of a LCoS SLM backplane diffracts some light into higher orders. By adding a dielectric mirror, the pixelated structure is replaced with an optically flat surface, thus eliminating the amplitude and optical path variations associated with the underlying aluminium pixel structure. The dielectric stack is kept thin to minimize any drop in electric field across the LC layer to maximize response time and minimize inter-pixel cross talk. Custom designs can be supported covering a bandwidth of up to 200nm.

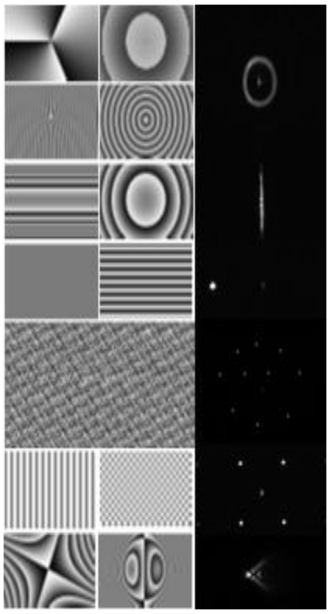
Diffraction Efficiency (1st-order)

This is the percentage of light measured in the 1st-order when writing a linear repeating phase ramp to the SLM as compared to the light in the 0th order when no pattern is written to the SLM. Diffraction efficiency varies as a function of the number of phase levels, or pixels, in the phase ramp. The plot to the right shows sample 1st order diffraction efficiency measurements, as a function of the phase ramp period, taken at various wavelengths.



Software

Our SLMs are supplied with a Graphical User Interface and software development kits that support LabVIEW, Matlab, Python and C++. The software allows the user to generate images, to correct aberrations, to calibrate the global and/or regional optical response over 'n' waves of modulation, to sequence at a user defined frame rate, and to monitor the SLM temperature.



Global or Regional Calibrations

Regional calibrations provide the highest spatial phase fidelity commercially available by regionally characterizing the phase response to voltage and calibrating on a pixel-by-pixel basis.

Image Generation Capabilities

- Bessel Beams: Spiral Phase, Fork, Concentric Rings, Axicons
- Lens Functions: Cylindrical, Spherical
- Gratings: Blazed, Sinusoid
- Diffraction Patterns: Stripes, Checkerboard, Solid, Random Phase, Holograms, Zernike Polynomials, Superimpose Images

1. 1920 x 1200 Spatial Light Modulator

E-Series: Educational, Economical and Entry-level
S-Series: 10-bit, High Efficiency, High Power

The E-Series SLM a good entry point into our SLM offerings. The standard S-Series offers additional features, including 10-bit operation, dielectric mirror coatings for improved efficiency, and liquid cooling.

SLM Features

- High resolution
- High phase stability, pure analogue phase control
- High first-order efficiency, high reflectivity
- High power handling
- Wavelengths from 400 – 1650 nm

Software Features

- Output triggers
- Image generation
- Automated sequencing
- Wavefront calibration
- Global and regional look up tables
- Dynamic Recalibration Kit for quick optimization

Hardware Interface Options 8-Bit and 10-Bit

The 1920 x 1200 SLM is offered with a 60Hz HDMI Controller configured for 8-bits in the E-Series, and 10-bits in the S-Series. Both hardware options include an output trigger for synchronization.

1920 x 1200 Analog SLM Specifications

- Resolution: 1920 x 1200
- Array Size: 15.36 x 9.60mm
- Pixel Pitch: 8.0 x 8.0µm
- Backplane Refresh: 1.35kHz
- Fill Factor: 95.6%
- 0^{th} Order Diffraction Efficiency: 76 – 91%
- 0^{th} Order Diffraction Efficiency: 92 – 98% (dielectric mirror)
- Controller: HDMI E-Series: 8-bit, S-Series: 10-bit

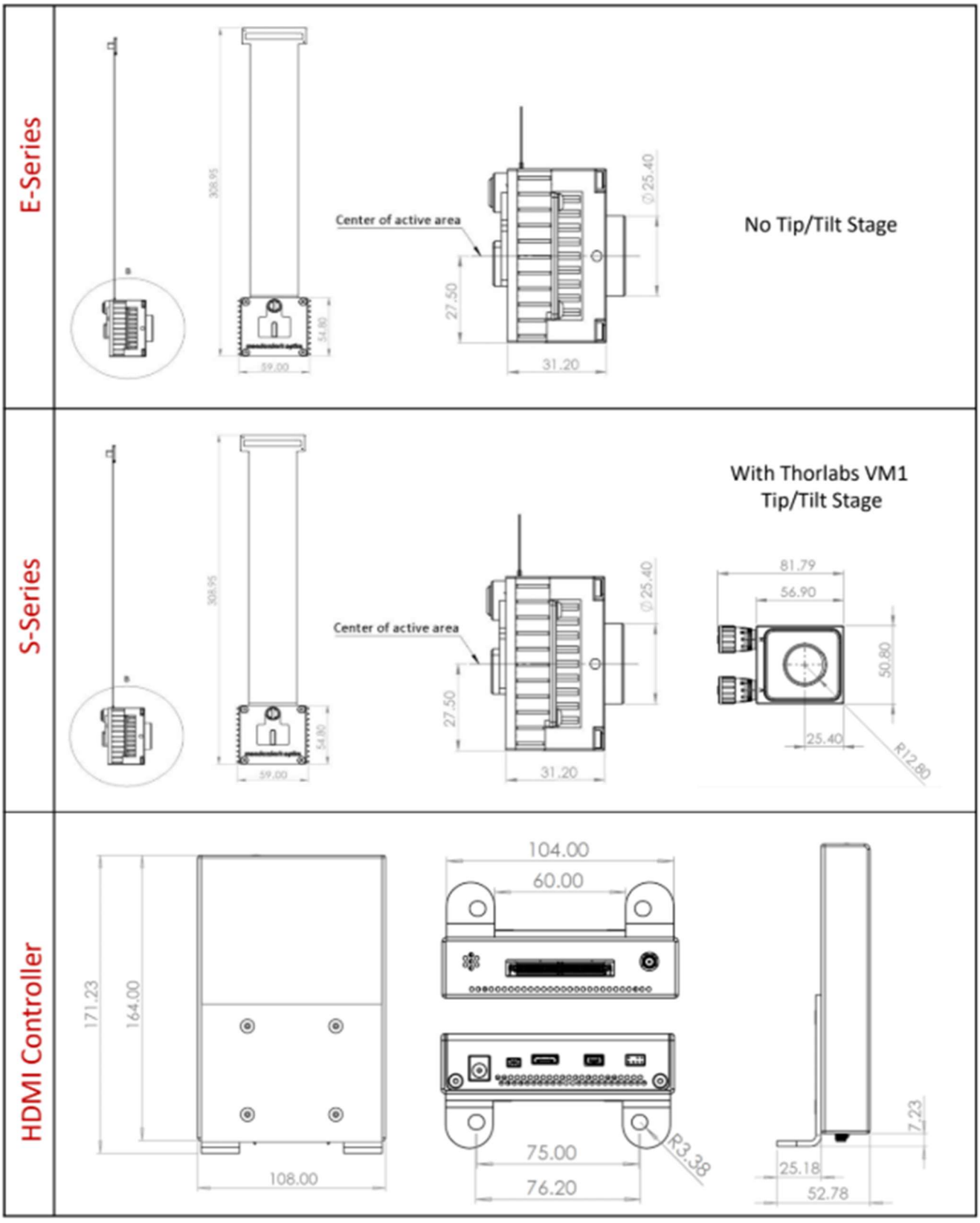
Standard Calibration Wavelengths	STANDARD SPEED Liquid Crystal Response Time			Calibrated Wavefront Distortion
	AR Coating 400 – 800nm	AR Coating 500 – 1200nm	AR Coating 850 – 1650nm	
405nm	≤ 14.0ms	–	–	λ/5
532nm	≤ 15.0ms	≤ 19.0ms	–	λ/7
635nm	≤ 15.0ms	≤ 20.0ms	–	λ/8
785nm	≤ 16.0ms	≤ 23.0ms	–	λ/10
1064nm	–	≤ 33.0ms	≤ 40.0ms	λ/10
1550nm	–	–	≤ 55.0ms	λ/12

Ordering Code

Series	P/N	AR Coating	Controller
E-Series	E19x12	400-800	HDM8
S-Series	S19x12	500-1200	HDM10
S-Series with Dielectric Mirrors	SDM19x12	850-1650	HDM10
Optional Add-ons	-WCS1: Liquid Cooling System (Ambient) -CAL: Additional Calibration Wavelength -NI: Dynamic Recalibration Kit		

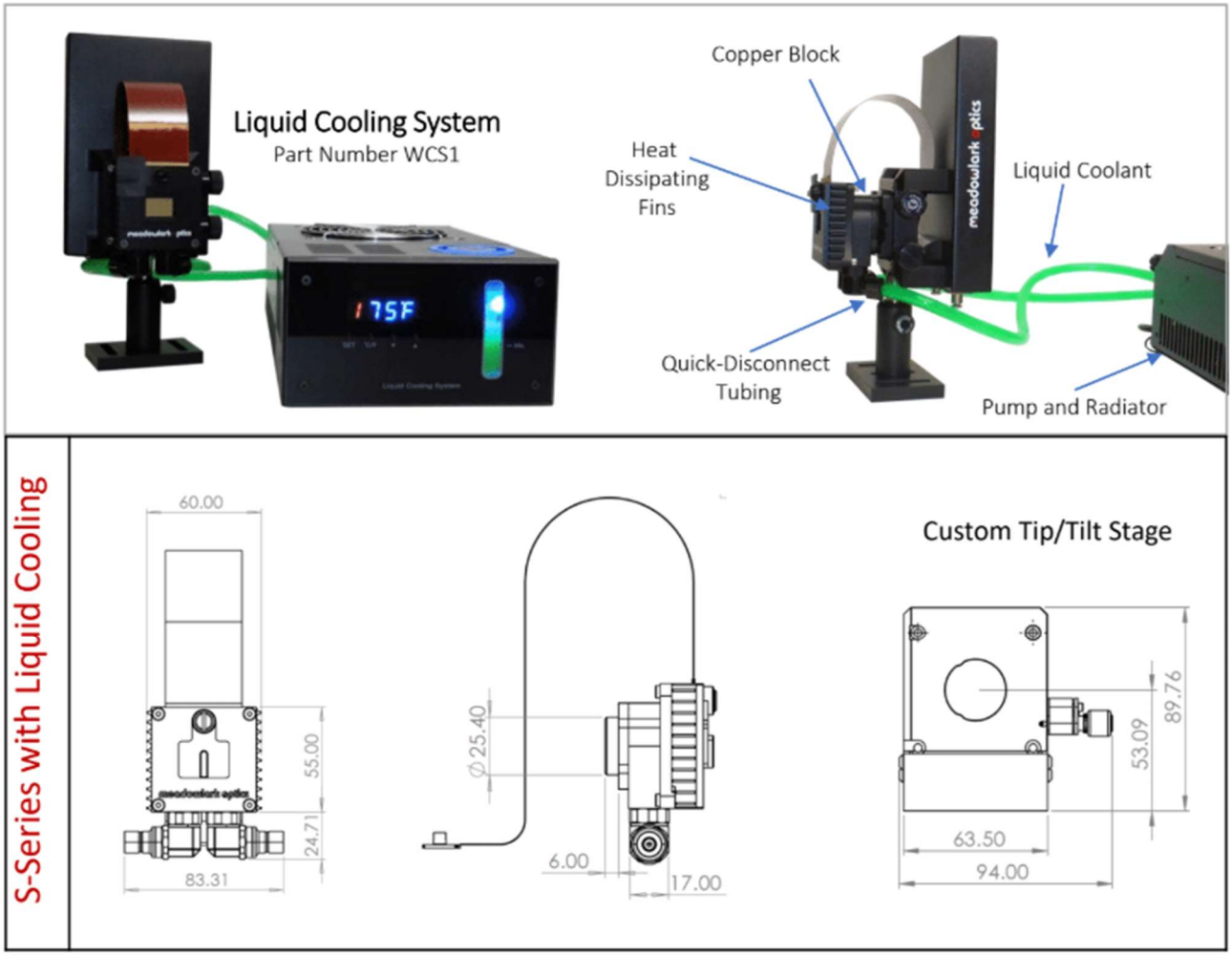
E.g.: E19x12-400-800-HDM8-WCS1: E-Series SLM with 400-800nm coating, HDMI 8-bit controller, with liquid cooling system

1920 x 1200 Spatial Light Modulator Component Dimensions



Optional Add-ons

Liquid Cooling System (Part Number WCS1) - A copper block is attached to the back of the optical head to draw heat out of the SLM chip. The copper block is coupled via 2 meters of quick-disconnect tubing to a cooling unit containing an external pump, radiator, and fan to cool the liquid down to ambient temperature. Includes one bottle of liquid coolant.



Dynamic Recalibration Kit (Part Number NI) – SLMs are shipped with a calibrated LUT at one of the standard test sources (405, 532, 635, 785, 1064, or 1550nm). If the user wants to work at a different wavelength or operating temperature, the dynamic recalibration kit allows the user to perform closed-loop automated calibration. Global or regional calibrations can be quickly generated and validated to account for a user's incident power, angle of incidence, and desired spatial frequency of pattern applied.

The kit is shipped with software and a National Instruments data acquisition card. The user only needs to provide a photodetector at their desired wavelength.

2. 1024 x 1024 Spatial Light Modulator

High Speed Analog, Phase Only – up to 1.7kHz

The 1024 x 1024 SLM is good for applications requiring high speed, high diffraction efficiency, low phase ripple and high-power lasers.

SLM Features

- High resolution
- High speed
- High phase stability
- Pure analogue phase control
- High first order efficiency
- High reflectivity
- High power handling
- On-board Memory
- Wavelengths from 488 – 1650 nm

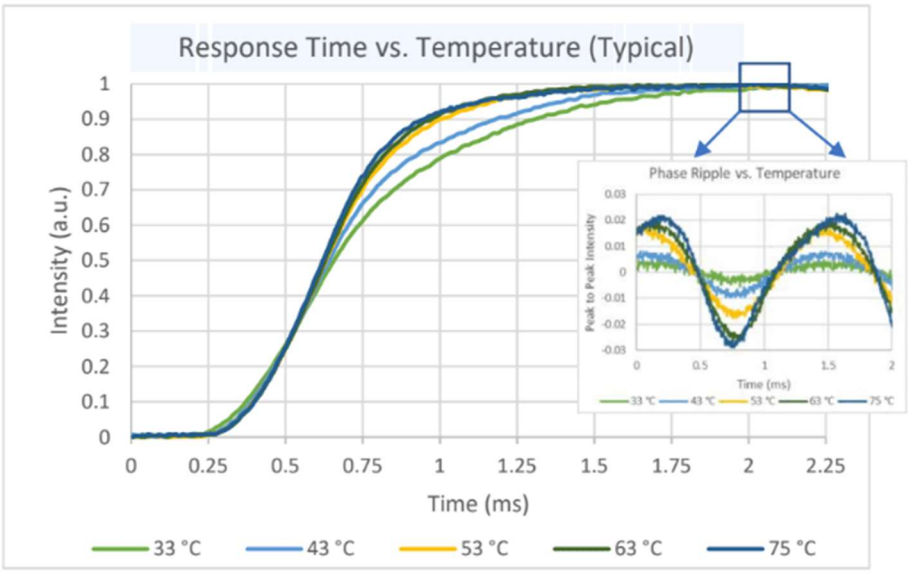
Software Features

- Input and output triggers
- Image generation
- Automated sequencing
- Wavefront calibration
- Global and regional look up tables
- Temperature monitoring
- Dynamic Recalibration Kit

High Speed with High Phase Stability

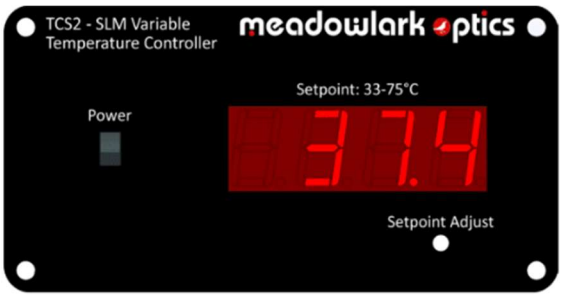
Great care was taken in the design of the 1024 x 1024 silicon backplane to enable high speed operation while simultaneously maximizing phase stability. The 1024 x 1024 SLM is incredibly fast with liquid crystal response times ranging from 0.6 to 8ms (wavelength dependent) for a full wave of modulation. In the ultra-high-speed model, users can control the temperature set point to find the perfect balance between switching speed and phase stability.

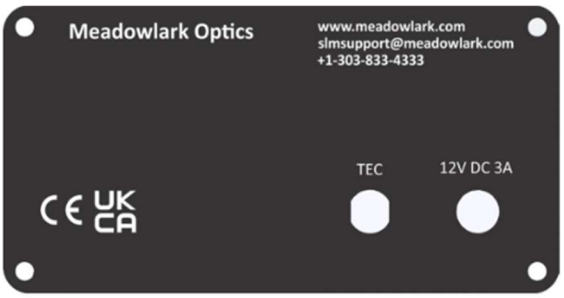
Tunable temperature control to balance speed and stability

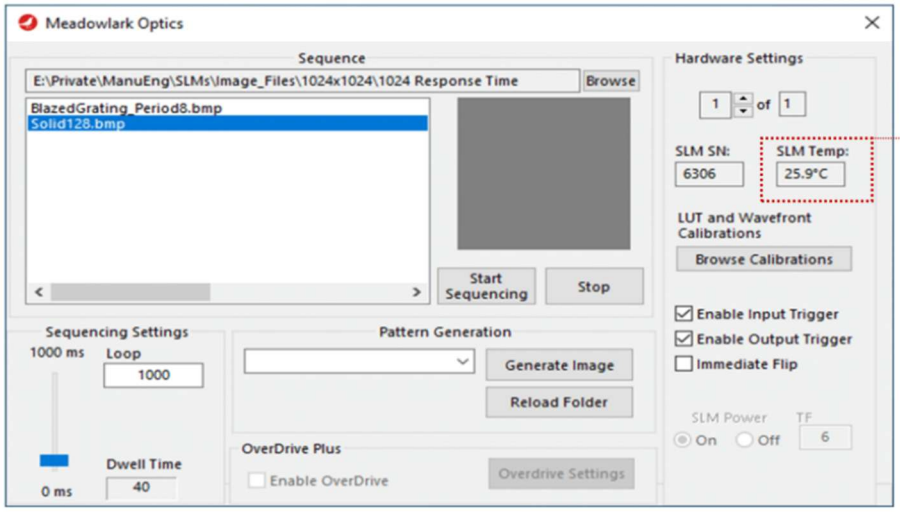


Sub-millisecond liquid crystal response times are measured in the far field. Images applied to the SLM are toggled between an 8-pixel, 2π phase grating and a solid image. Data captured while operating from 33°C to 75°C, using 10 to 90% reference levels. Results show typical switching speeds and phase stability at 532nm.

TEC Heater (Optional Add-on, Part Number TCS2)
TEC gives the user control over the temperature in which to operate the SLM. Heating the liquid crystals increase the switching speed, and cooling the liquid crystals improves phase stability.

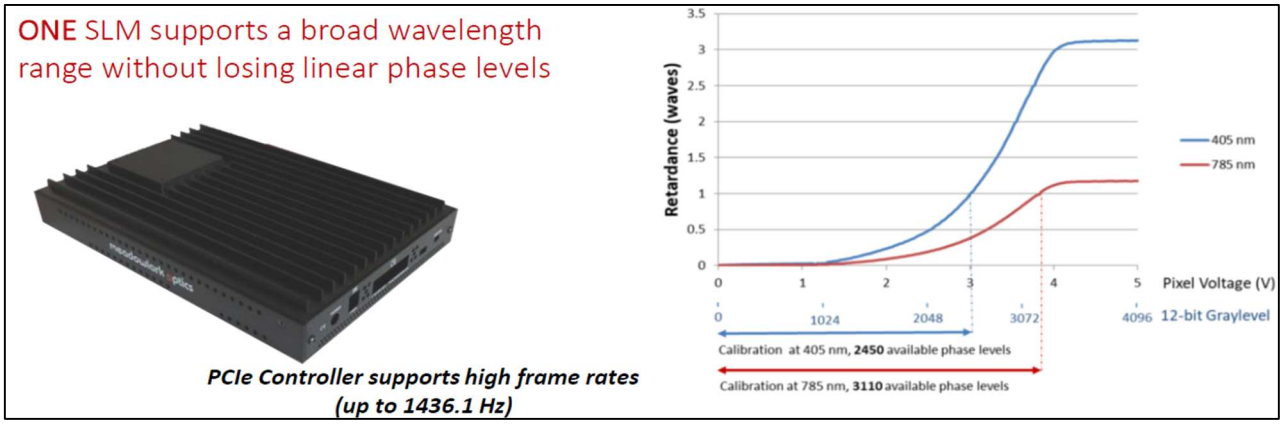






On chip temperature sensors allow the user to monitor the SLM temperature either through the example program or the software developer kits.

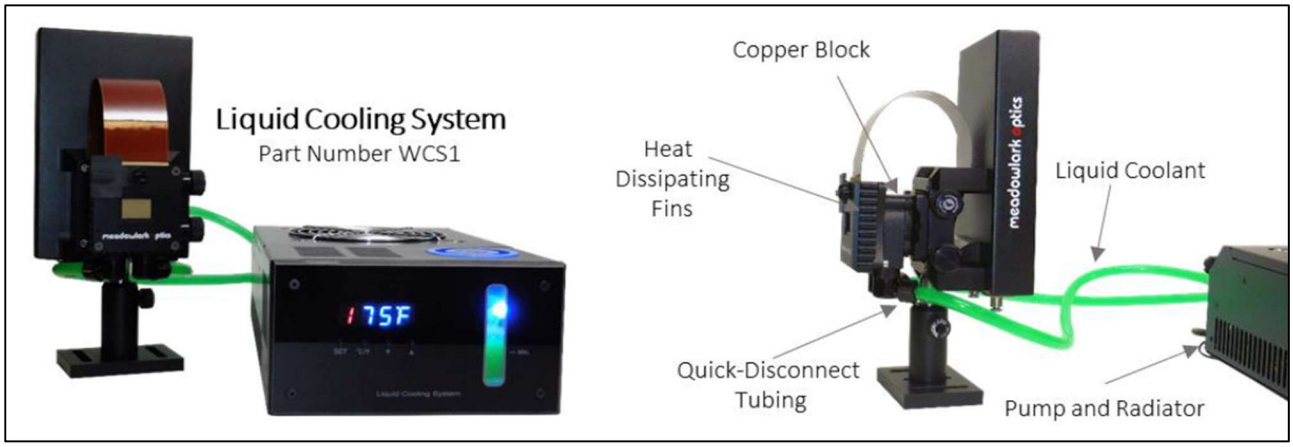
Hardware Interface
The 1024 x 1024 SLM system includes a Gen3 x8 PCIe controller with input and output triggers and low latency image transfers. Triggering can be performed on SLM chip refresh period boundaries of 696 µs, or even in the middle of refresh periods for applications requiring the SLM be tightly synchronized to external hardware. The controller also includes 752 frames of internal memory that can be loaded in advance, then sequenced at full speed in order to minimize traffic on the PCIe bus during operation. Using the 8-bit input/12-bit out design enables the SLM to support a broad wavelength range without sacrificing linear phase levels.



High Power Capability
Meadowlark SLMs are designed for compatibility with high power lasers through use of low absorption materials, large pixel pads, dielectric mirror options, and liquid cooling. High power options include:

A. Ultra-high-power SLM
This SLM design uses a sapphire cover glass for conductive heat dissipation, active thermoelectric temperature stabilization, and liquid cooling to handle extreme power loads. The Ultra-High Power SLM is rated to ≥1000 W of CW power at 1070 nm. Refer to Section 3 for more details.

B. Liquid Cooling System (Part Number WCS1)
The addition of liquid cooling enhances the power handling of any of our standard SLM products. A copper block is attached to the back of the optical head to draw heat out of the SLM chip. The copper block is coupled via 2 meters of quick-disconnect tubing to an external radiative cooling unit.



1024 x 1024 Analog SLM Specifications
- Resolution: 1024 x 1024
- Array Size: 17.40 x 17.40mm
- Fill Factor: 97.2%
- Pixel Pitch: 17 x 17µm
- Zero-Order Diffraction Efficiency: 75 – 87%
- With Dielectric Mirror Coating:92 – 98%

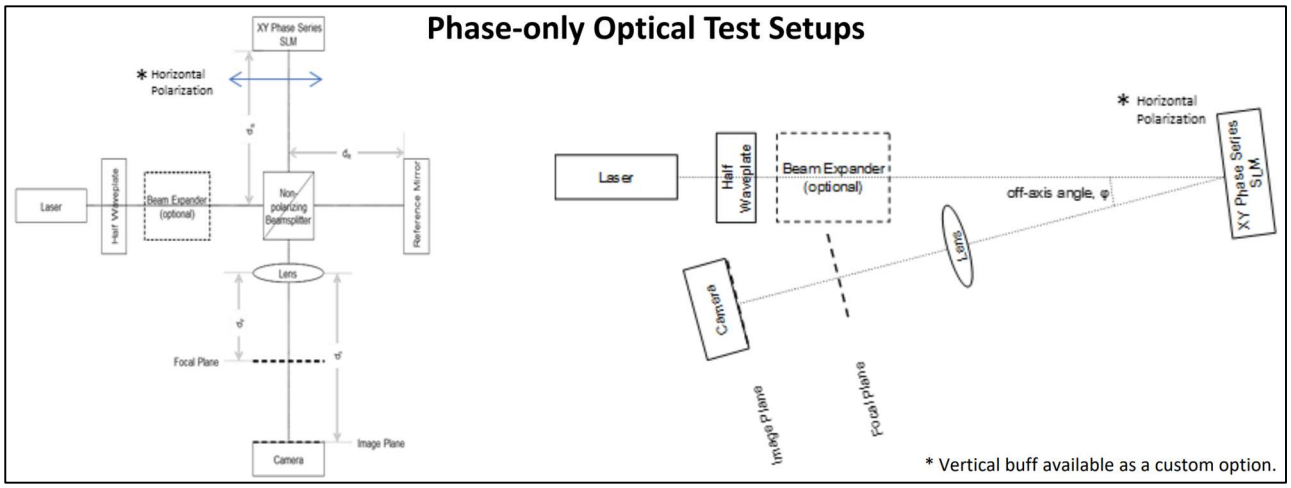
Standard calibration wavelength	HIGH SPEED Liquid Crystal Response Time			Calibrated wavefront distortion
	AR coating range 488-850nm	AR coating range 500-1200nm	AR coating range 850-1650nm	
532nm	≤ 1.0ms	≤ 1.4ms	–	λ/5
635nm	≤ 1.3ms	≤ 1.8ms	–	λ/6
785nm	≤ 1.8ms	≤ 2.4ms	–	λ/7
1064nm	–	≤ 3.4ms	≤ 6.0ms	λ/10
1550nm	–	–	≤ 9.0ms	λ/12

Standard calibration wavelength	ULTRA HIGH SPEED Liquid Crystal Response Time			Calibrated wavefront distortion
	AR coating range 488-850nm	AR coating range 500-1200nm	AR coating range 850-1650nm	
532nm	≤ 0.6ms	≤ 0.7ms	–	λ/5
635nm	≤ 0.7ms	≤ 0.9ms	–	λ/6
785nm	≤ 0.9ms	≤ 1.2ms	–	λ/7
1064nm	–	≤ 1.7ms	≤ 2.0ms	λ/10
1550nm	–	–	≤ 3.9ms	λ/12

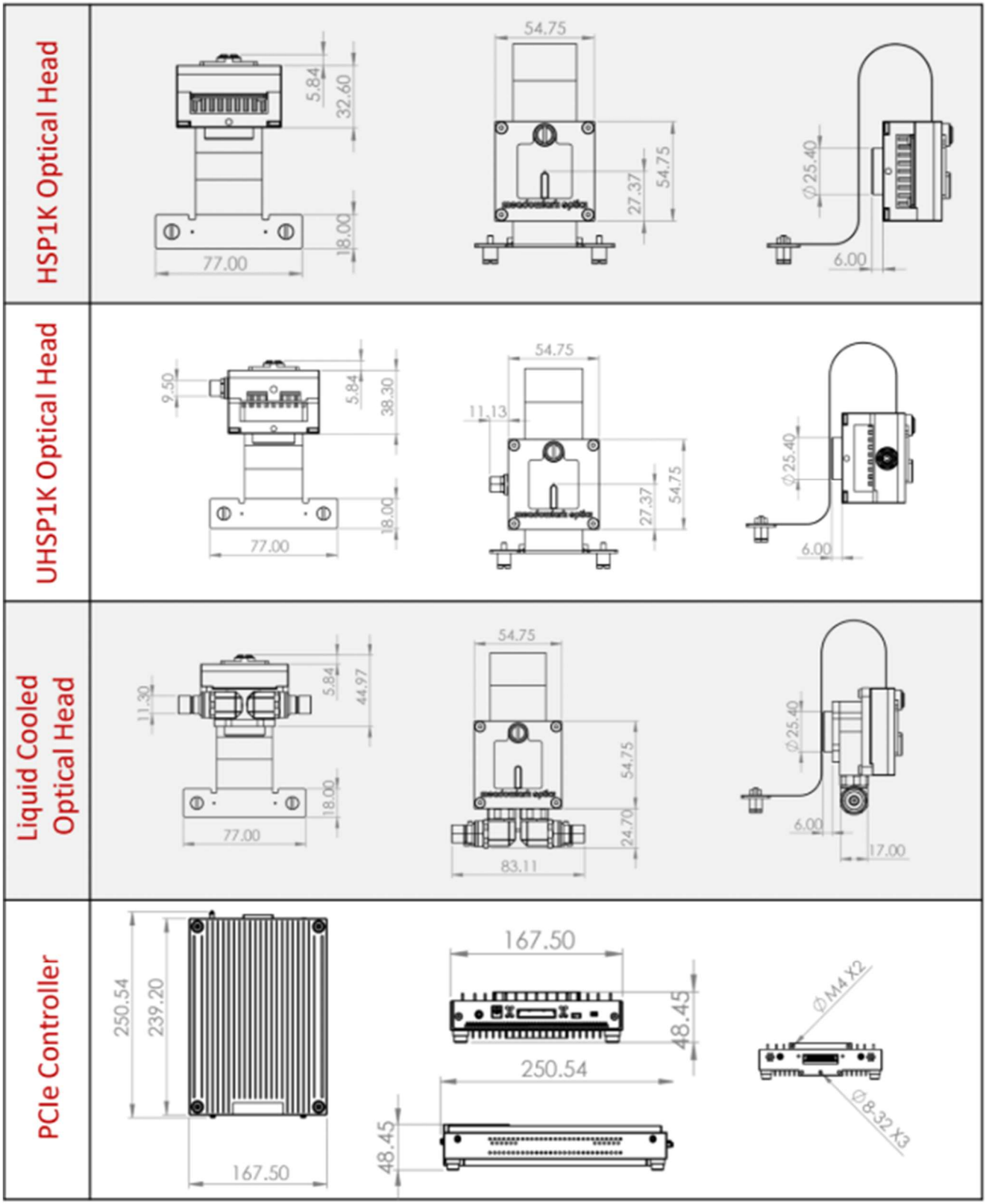
Ordering Code

Series	P/N	AR Coating	Controller
High Speed	HSP1K	488-850 500-1200 850-1650	PC8
High Speed, High Efficiency with Dielectric Mirrors	HSPDM1K		
Ultra High Speed	UHSP1K		
Ultra High Speed, High Efficiency with Dielectric Mirrors	UHSPDM1K		
Optional Add-ons	-WCS1: Liquid Cooling System (ambient) -TCS2: Variable Temperature Heating (ambient to 75degC) -TCS3: WCS and TCS2, Variable Temperature Cooling (10degC to ambient) -CAL: Additional Calibration Wavelength -NI: Dynamic Recalibration Kit		

E.g.: HSP1K-488-850-PC8-WCS1: High Speed 1024x1024 SLM with 488-850nm coating, PCIe 8-bit controller, with liquid cooling system



1024 x 1024 Spatial Light Modulator Component Dimensions



3. Spatial Light Modulator - 1024 x 1024

Ultra-High Power – ≥ 1kW at 1070nm

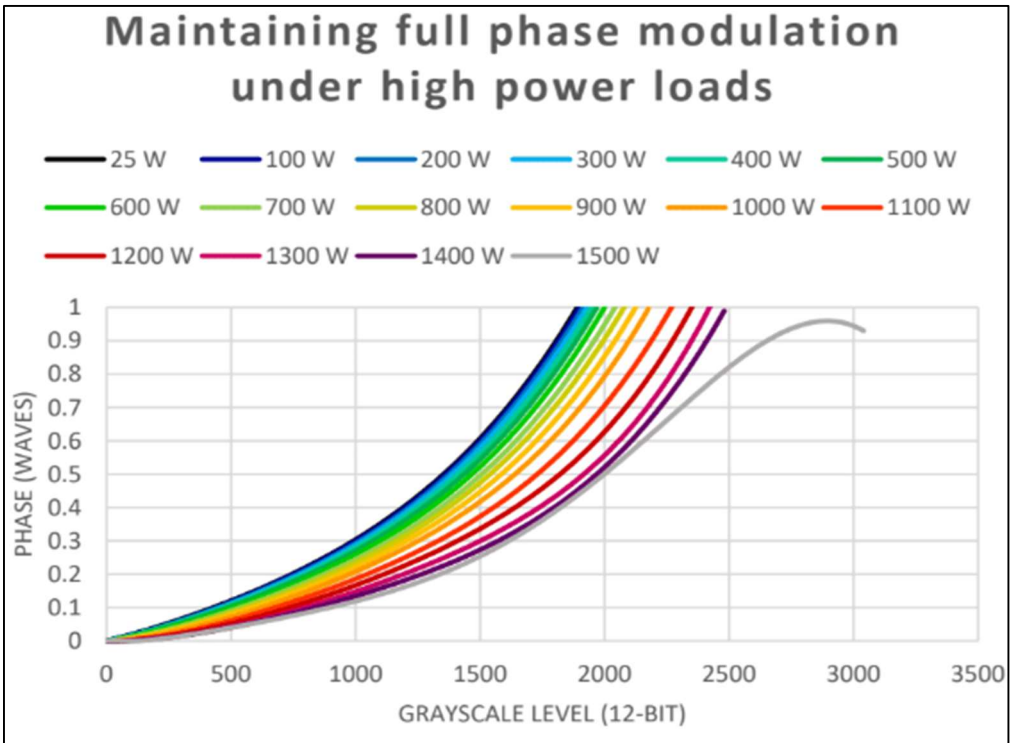
High average power handling - The newest SLM boasts CW power handling of ≥ 1kW at 1070nm. In tests at SPICA, the SLM retained its full >1 wave range of phase modulation at powers up to 1.4kW. With sapphire cover glass, built-in water cooling and a suite of calibration tools, the high power SLM can maintain calibrated performance under extreme laser power loads.

SLM Features

- 17.4 x 17.4 mm active array
- 1024 x 1024 pixel count
- 97.20% fill factor
- Water-cooled
- TEC active heat dissipation
- AR-coated sapphire cover glass
- Dielectric mirrored backplane
- 750 – 850 nm or 980 – 1150 nm
- Pure analogue phase control
- On-board Memory

Software Features

- Input and output triggers
- Image generation
- Automated sequencing
- Wavefront calibration
- Global and regional look up tables
- Temperature Monitoring
- Look-up-table Calibration Kit



Measured phase-voltage response at 1070 nm showing the SLM's ability to maintain a full wave of calibrated phase control. Tools are available so the SLM can be calibrated for well-controlled performance at every operating power level in range.

Designed for high power - The Ultra-High Power SLM is designed for performance under high laser power loads.

Active TEC cooling - The UHP SLM includes active thermoelectric cooling to stabilize operating temperature (at lower heat loads) and to combat laser-induced heating at higher temperatures.

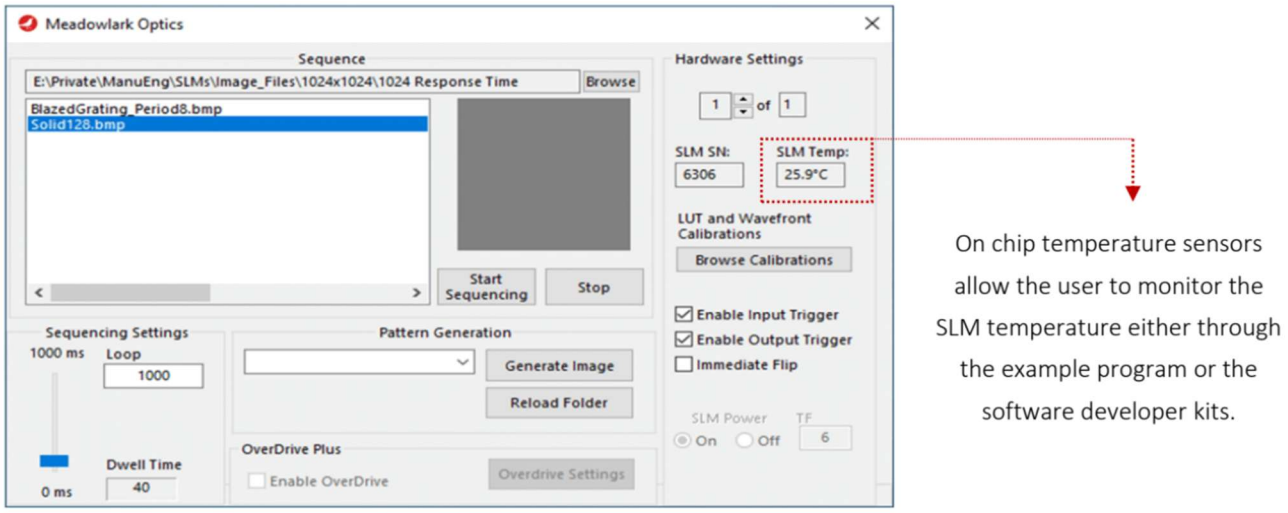
Water cooling - The UHP SLM includes a water-cooled copper heat sink with quick-disconnect tubing to connect to an external chiller.

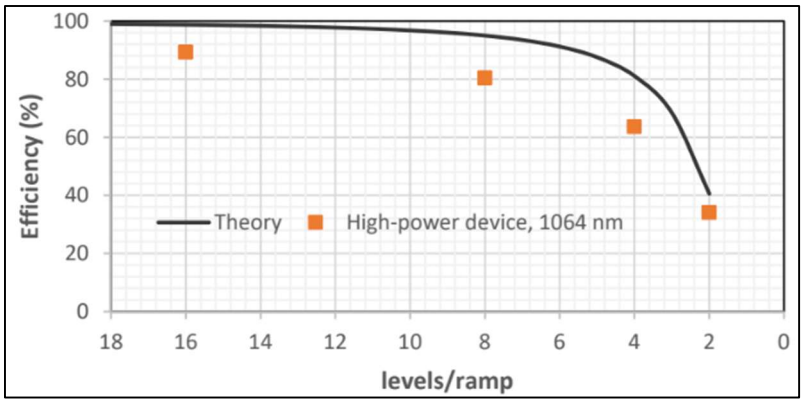
Sapphire coverglass - The high thermal conductivity of the sapphire coverglass allows heat to be directed away from the active area. The SLM housing is designed to thermally contact the coverglass and provide a heat dissipation path into the water-cooled heat sink.

High-temperature liquid crystal - The UHP SLM has a custom liquid crystal formulation that maintains its performance at elevated temperatures, allowing the usable power range of the SLM to be extended.

Calibration for high performance at high power - A lookup table calibration kit allows the user to calibrate the SLM at their laser's wavelength and power level.

Real-time temperature reporting - On-chip temperature sensors allow the user to monitor the SLM temperature either through the example program or the software developer kits.





Diffraction Efficiency (1st-order) - This is the percentage of light measured in the 1st-order when writing a linear repeating phase ramp to the SLM as compared to the light in the 0th order when no pattern is written to the SLM. 1st-order diffraction efficiency varies as a function of the number of phase levels, or pixels, in the phase ramp.

0th order diffraction efficiency at 1064nm: 95%

1024 x 1024 Analog Spatial Light Modulator Specifications

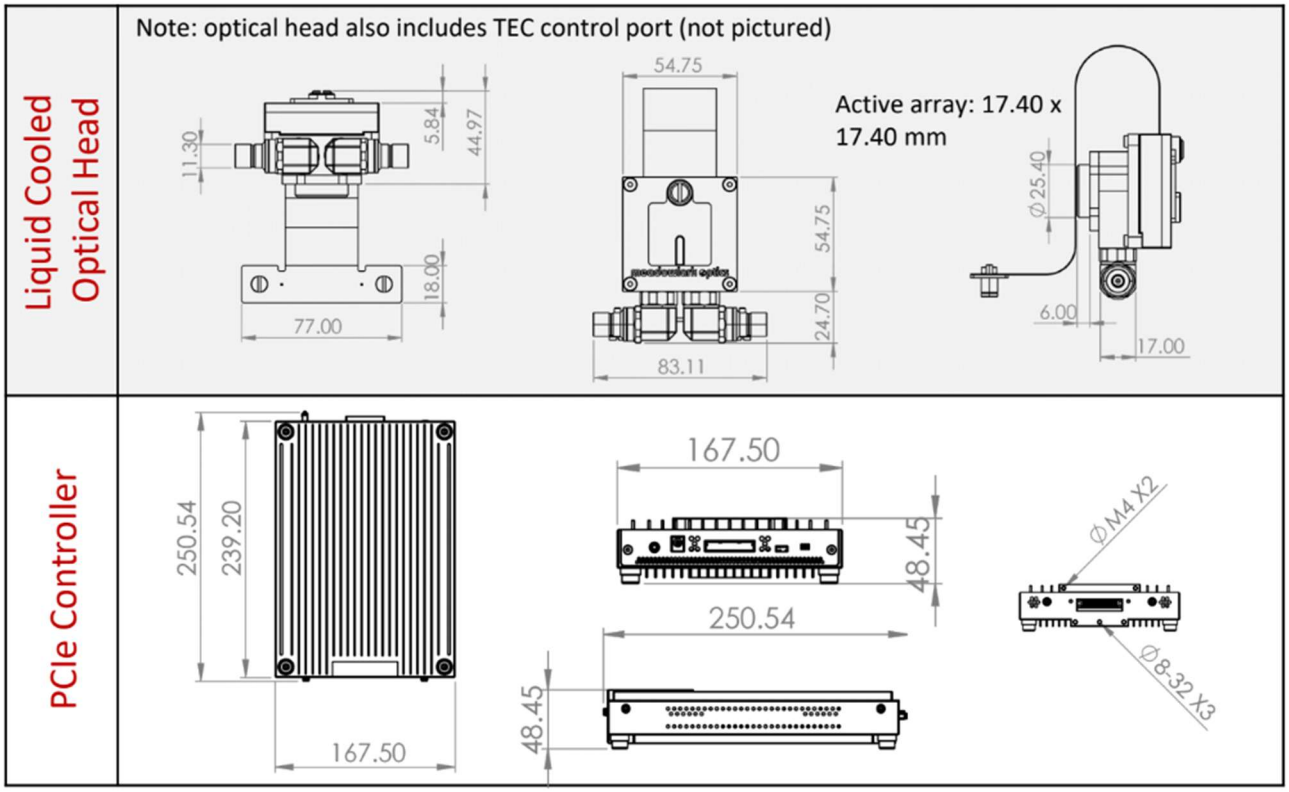
- Resolution: 1024 x 1024
- Array Size: 17.40 x 17.40mm
- Zero-Order Diffraction Efficiency: 95% (at 1064nm)
- Fill Factor: 97.2%
- Pixel Pitch: 17 x 17µm

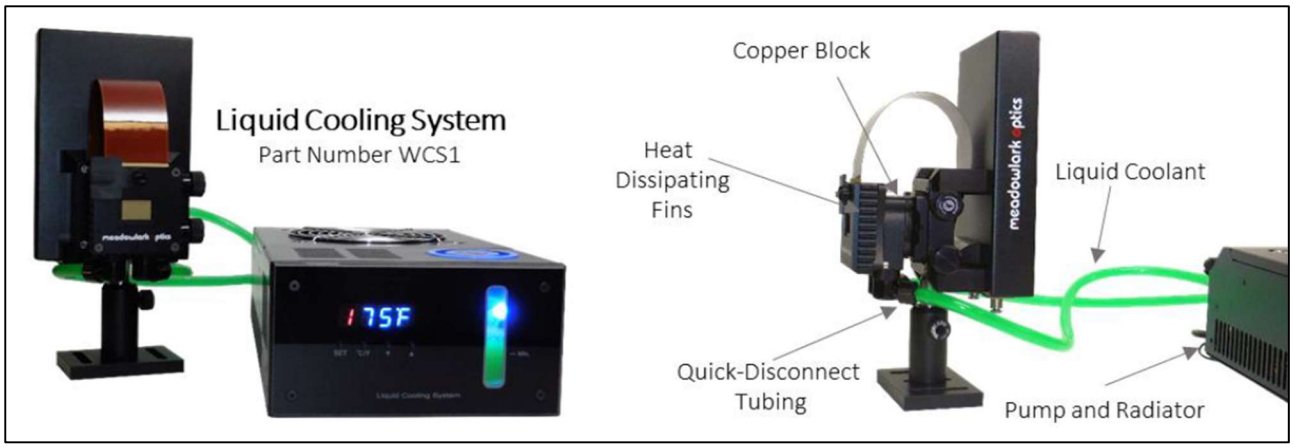
Standard Calibration Wavelengths	Coating range	Average power rating	HIGH AVERAGE POWER Liquid crystal response time vs operating temperature		
			19 C	44 C	70 C
785nm	750 - 850nm	(tests pending)	(tests pending)	(tests pending)	(tests pending)
1064nm	980 - 1150nm	≥ 1000W (at 1070nm)	≤ 100ms	≤ 22ms	≤ 8. ms

Ordering Code:

Series	P/N	AR Coating	Controller
Ultra-high-power, with dielectric mirrors	UHPDM1K	750-850 980-1150	PC8
Optional Add-ons	-WCS1: Liquid Cooling System (Ambient) -TCS2: TEC Heater for Variable Temperature Heating -TCS3: WCS and TCS2 for Variable Temperature Cooling -CAL: Additional Calibration Wavelength -NI: Dynamic Recalibration Tool		

E.g.: UHPDM1K-750-850-PC8: Ultra-high-power 1024x1024 SLM with 750-850nm coating, high-efficiency dielectric mirrors, PCIe 8-bit controller, with liquid cooling system

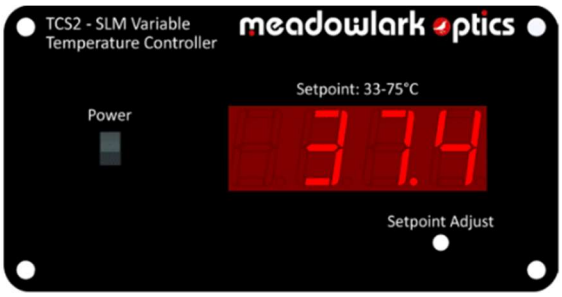


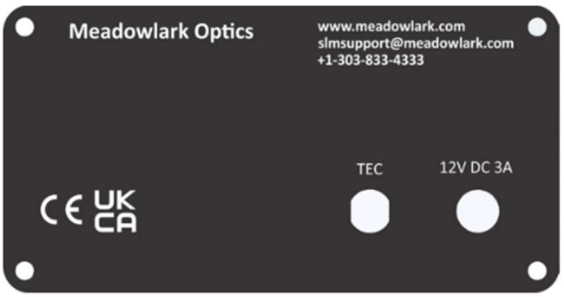


Note: radiant cooler/chiller model depends on heat dissipation requirements

Thermo-electric controller

A thermo-electric controller provides active heat dissipation toward a liquid – cooled copper block.





4. 1536 x 1536 Spatial Light Modulator

Custom designed for high-speed neuroscience applications

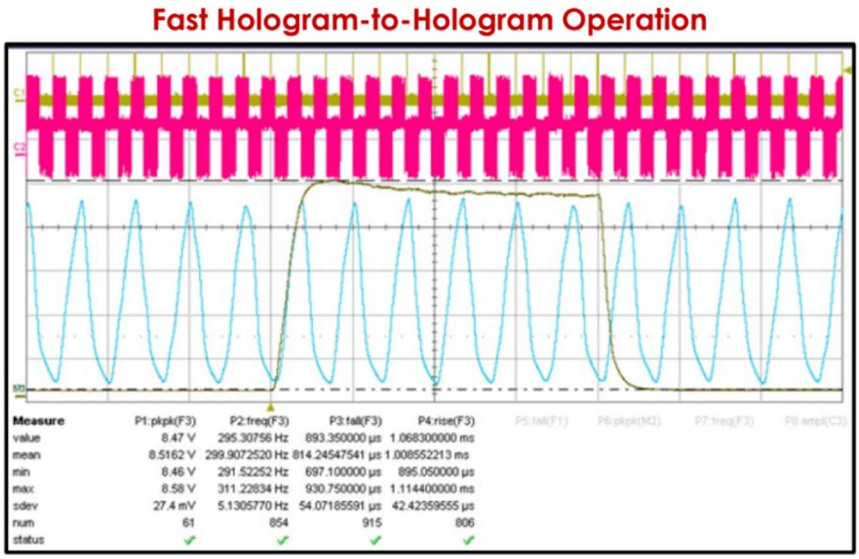
- Pixel Count: 1536 x 1536
- Array Size: 30.7 x 30.7mm
- Pixel Pitch: 20µm x 20µm
- Pixel Voltage: 12V
- Fill Factor: 96%
- Maximum GS Hologram Frame Rate at 1064nm: 600fps
- (1000 fps available at reduced efficiency)
- Trigger Response for On-board Holograms: 6µs latency / 3 – 9 µs jitter

The High-Speed 1536 x 1536 SLM, combining high pixel count and high frame rate with efficient diffraction. By building on success with other models, the 1536 x 1536 SLM leverages the same pixel design in a reduced array size format for even faster addressing.

The 1536 x 1536 SLM is built for speed. It uses large high-voltage, high-capacitance pixels which are essential for increasing switching speed. These factors also serves to reduce fringing field effects and phase ripple to improve photostimulation efficiency, especially at large diffraction angles. To optimize performance, the entire SLM head is thermally controlled for operation at elevated temperatures.

The SLM drive electronics receive 8-bit 1536 x 1536 phase masks from the host computer over a 16-bit PCIe pipeline for fast transfer rates. For further speed enhancement, a library of up to 2,045 user-specified phase masks can be stored on the driver board and then selected in any sequence using on-board OverdrivePlus transition calculation.

These capabilities work together to provide hologram-to-hologram frames rates of up to 600fps at 89% of steady-state diffraction efficiency. Frame rates of up to 1,000fps have been demonstrated with commensurate decreases in diffraction efficiency.



Blue = 600 fps; Gold = 100 fps