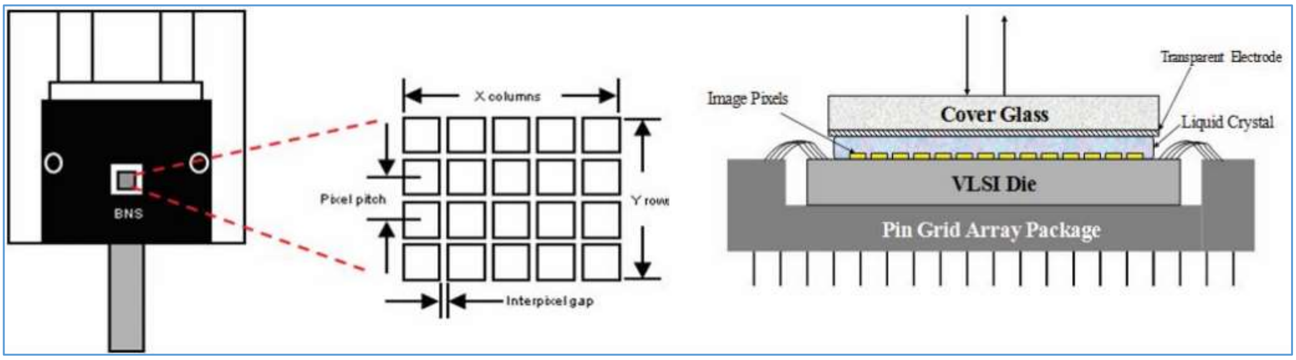
STM Series Spatial Light Modulators

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. SLMs are typically used to control incident light in amplitude, phase, or the combination of both.

SLM Device Construction
Several parameters help define SLM characteristics. Pixel pitch is defined as the center-to-center spacing between adjacent pixels. Interpixel gap describes the edge-to-edge spacing between adjacent pixels.



Polarized light enters the device from the top, passes through the cover glass, transparent electrode and liquid crystal layer, is reflected off the aluminum 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 transparent electrode on 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.

Why choose our Reflective SLMs ?
High Voltage Backplanes = Fastest Response Times
Our SLMs use custom backplanes, and proprietary drive schemes to achieve response times down to 1 ms (wavelength dependent). Most other liquid crystal spatial light modulators utilize display backplanes built with standard Nematic liquid crystal, limiting response time to >30 ms.

Highest Phase Stability Commercially Available –
Our backplanes are custom designed to allow high refresh rates (up to 6 kHz), and direct analog drive schemes. Refreshing the voltage at the pixel at rates far surpassing the response time of the liquid crystal ensures high temporal phase stability. Further, use of direct analog drive schemes, as opposed to digital dithering, reduces optical flicker as low as 0.1% (0.001 π radians). Low Inter-pixel Cross Talk - Our backplanes are custom designed to offer high voltage at the pixel (5 – 12 V), and a large pixel pitch. Further, our SLMs are built with our proprietary liquid crystal which minimizes the required thickness of the LC layer in the SLM. By maximizing the ratio of pixel pitch to LC thickness we are able to offer SLMs with minimal inter-pixel effects.

Broad Wavelength Capabilities – we are the only SLM supplier capable of offering SLMs designed for use from UV (>365 nm) up to the LWIR (8 - 12 µm). Analog is Better - All SLMs have been designed for phase modulation. Unlike many display LCoS backplanes which require a pulse width modulation (PWM) scheme, our backplanes utilize analog voltages at each pixel. This results in a very stable phase response over time.

High Bit Depth Controllers - we offer 8, 12, and 16-bit controllers to provide the most linear resolvable phase levels commercially available (up to 500). Fast transfer speeds from the computer to the SLM are offered up to 2 kHz.
Overview

Polarized light enters the device from the top, passes through the cover glass, transparent electrode and liquid crystal layer, is reflected off the aluminum pixel electrodes, and returns on the same path.

Drive signals travel through. There are 2 types of special light modulators: reflective analog SLMs and transmissive SLMs.

Reflective Analog SLMs: All of our liquid crystal on silicon (LCoS) backplanes incorporate analog data addressing with high refresh rates to provide the lowest phase ripple SLMs available. User's can select standard or high speed liquid crystal for optimal performance. Liquid cooling systems are available to remove heat via the back of the SLM chip in order to maximize optical power handling capabilities:

Transmissive SLMs: All of our liquid crystal on glass (LCoG) SLMs enable simple optical systems when low pixel counts are sufficient. Users can select single-mask or configurations for phase or amplitude modulation, or a dual-mask configuration for combined phase and amplitude modulation.

1. Reflective Analog SLMs

1.1 Spatial Light Modulator –1024 x 1024
High Speed Analog –up to 1 kHz

Our Liquid Crystal on Silicon (LCoS) Spatial Light Modulators (SLMs) are uniquely designed for pure phase applications and incorporate analog data addressing with high refresh rates. This combination provides users with the fastest response times with high phase stability. The 1024 x 1024 SLM is good for applications requiring high speed, high diffraction efficiency, low phase ripple and high-power lasers.

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. Engineers successfully achieved high speed without compromising phase stability.

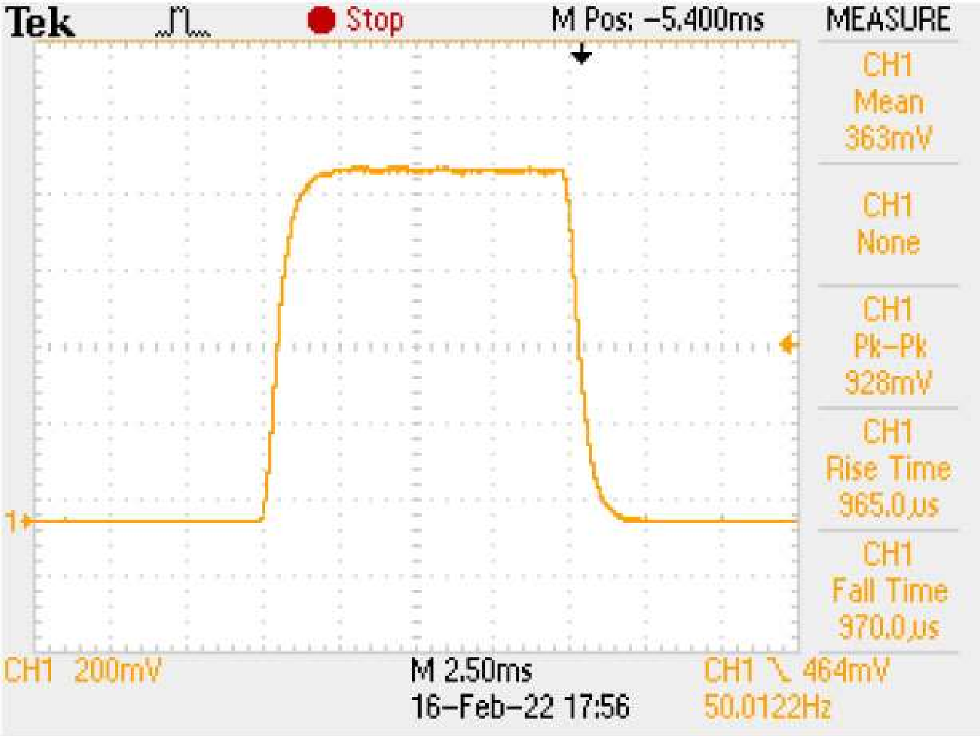
The 1024 x 1024 SLM is incredibly fast with liquid crystal response times ranging from 0.9 to 8 ms (wavelength dependent) for a full wave of modulation when running in typical room temperature environments.

SLM Features:
- High resolution
- High speed
- High Phase Stability
- Pure analog 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

Diffraction Efficiency (0th-order)
This is the amount of light measured in the 0th-order (dc) when the SLM is written with various solid gray levels as a percentage of the amount of light measured when the SLM is replaced with a reference mirror. Therefore, it takes into account losses in transmission through the coatings on the SLM cover window, as well as diffraction losses due to the pixel pads being less than 100% fill-factor. In addition to these losses, this measurement also accounts for losses due to imperfect reflectivity of the aluminum pixel mirrors, or 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

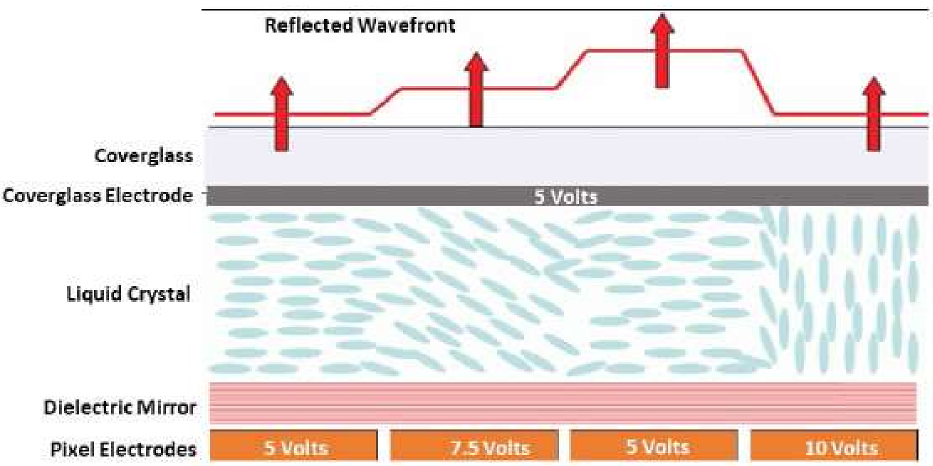
liquid crystal cell. Most standard SLMs will range from 70 –90%, while the dielectric mirror coated models will range from 92 –98%.



Sub-millisecond liquid crystal response times were measured in the far field when switching between an 8-pixel, 2π phase grating and a solid image at 532 nm. Data captured while operating in typical room temperature environment (26°C chip temperature), using 10 to 90% reference levels.

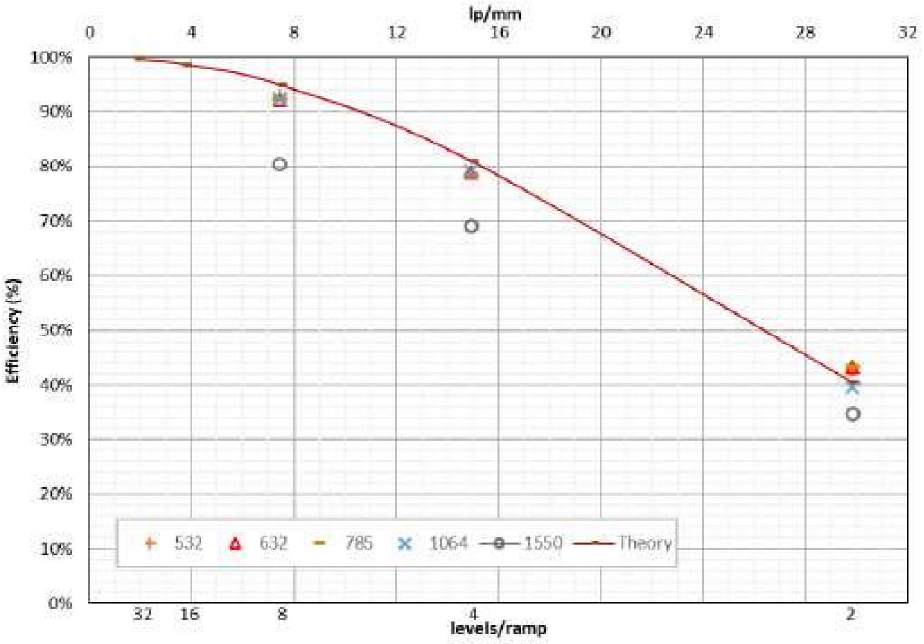
High Efficiency Dielectric Mirror Coating

All the light reflecting off the SLM is modulated –including the light between the aluminum pixel electrodes. The reflective pixel structure associated with a LCoS SLM backplane acts as an amplitude grating diffracts some light into higher orders. Optically, the active area of the backplane is converted into a flat dielectric mirror by depositing 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 LC layer as shown in the figure below. In other words, there are no abrupt changes in phase modulation (such as dead zones) between pixels due to the smoothing which results from separating the LC modulator from the driving electrodes



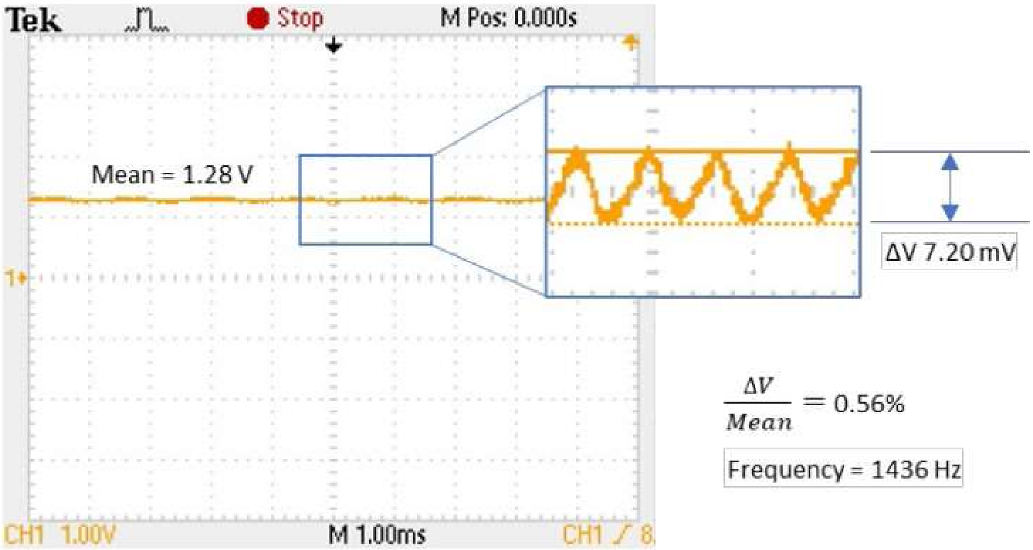
Diffraction Efficiency (1st-order)

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 0thorder 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. Example measurement data taken at various wavelengths is shown below for phase ramps with 2 to 8 phase levels between 0 and 2π.



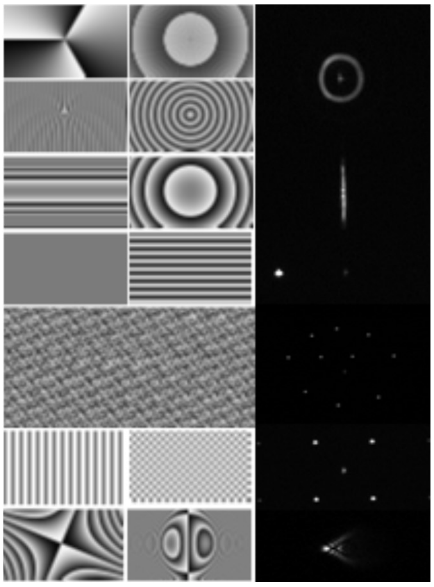
Typical Measured 1st Order Diffraction Efficiency

High Phase Stability –Making an LCOS SLM faster usually means the phase stability becomes worse. However, we've combined our traditional analog drive scheme with some new proprietary technologies to suppress phase instabilities to an unprecedented 0.05 –1.0% without compromising the speed. If your application requires extremely low phase ripple, please contact our engineer for more information on the 19x12 SLM. Phase ripple is quantified by measuring the variation in intensity of the 1storder 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.



Typical data showing phase stability at 532 nm

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.

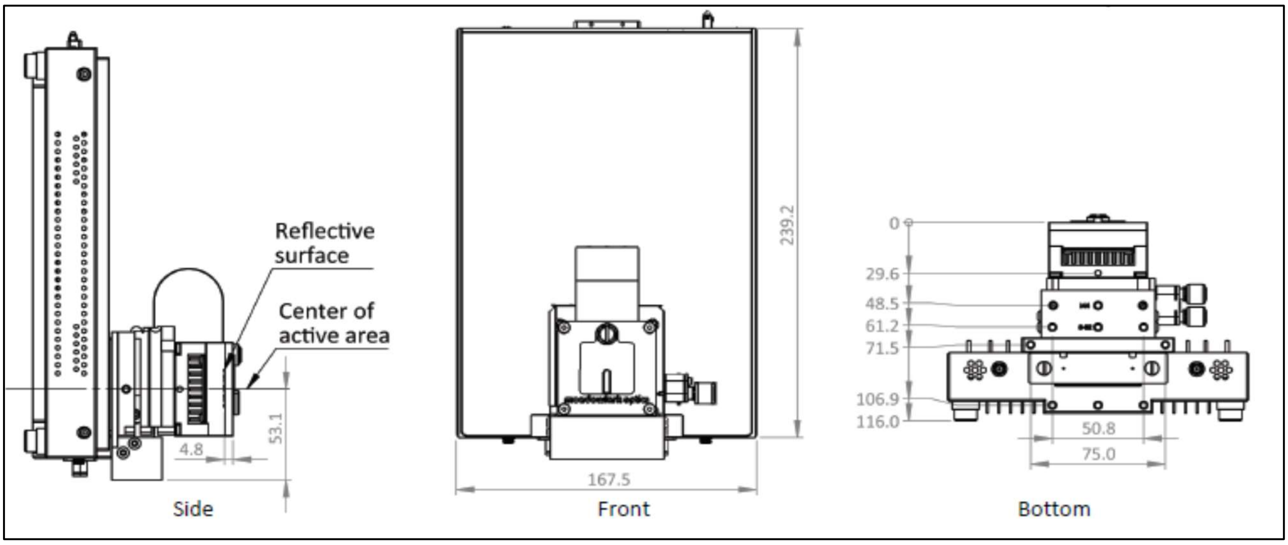
Image Generation Capabilities
Bessel Beams: Spiral Phase, Fork, Concentric Rings, Axicons
Lens Functions: Cylindrical, Spherical
Gratings: Blazed, Sinusoid
Diffraction Patterns: Stripes, Checkerboard, Solid, Random Phase
Holograms, Zernike Polynomials, Superimpose Images

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

Standard calibration wavelength	Liquid crystal response time/system frame rate			Calibrated wavefront distortion
	AR coating range 400-800nm	AR coating range 500-1200nm	AR coating range 850-1650nm	
532 nm	≤ 1.0 ms / ≥ 1000.0 Hz	≤ 1.4 ms / ≥ 714.3 Hz	–	λ/5
635 nm	≤ 1.3 ms / ≥ 769.2 Hz	≤ 1.8 ms / ≥ 555.6 Hz	–	λ/6
785 nm	≤ 1.8 ms / ≥ 555.6 Hz	≤ 2.4 ms / ≥ 416.7 Hz	–	λ/7
1064 nm	–	≤ 3.4 ms / ≥ 294.1 Hz	≤ 5.5 ms / ≥ 181.8 Hz	λ/10
1550 nm	–	–	≤ 8.0 ms / ≥ 125.0	λ/12
Part number	STM-HSP1K-488-800-PC8	STM-HSP1K-500-1200-PC8	STM-HSP1K-850-2650-PC8	

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.

PCIe Controller supports high frame rates (up to 1436.1 Hz)



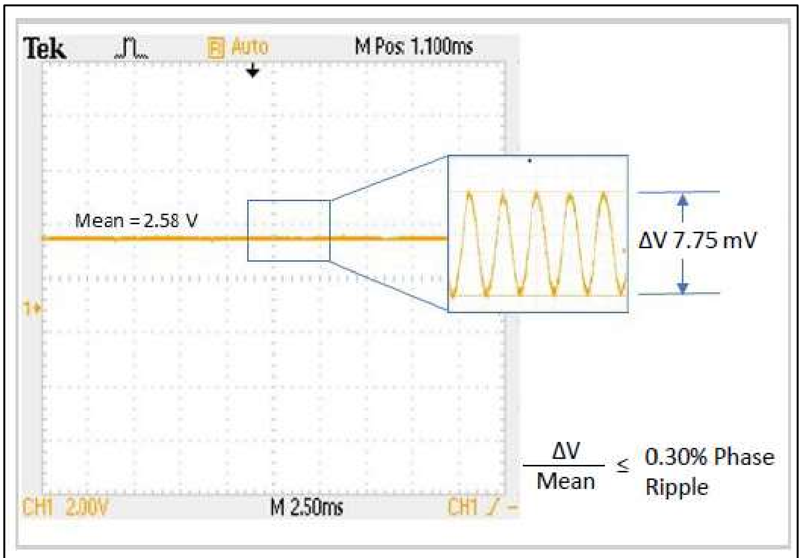
1.2 Spatial Light Modulator – 1920 x 1200
E - Series: Educational, Economical & Entry - level

We are pleased to introduce our latest E - Series Spatial Light Modulator (SLM) . Don't let the name fool you ; with improved specifications over our previous model, it is anything but entry - level . It is, however, economical and ideally suited for educational labs with a limited budget . Liquid Crystal on Silicon (LCoS) Spatial Light Modulators (SLMs) are uniquely designed for pure phase applications and incorporate analog data addressing with high refresh rates . This combination provides users with the fastest response times and highest phase stabilities commercially available . We offer both transmissive and reflective SLMs in either one - or two - dimensions . Phase - only SLMs can also be used for amplitude - only or a combination of both.

SLM Features:
- High resolution
- High phase stability
- Pure analog phase control
- High first order efficiency
- High reflectivity
- High power handling
- Compact design
- Wavelengths from 400–1650 nm

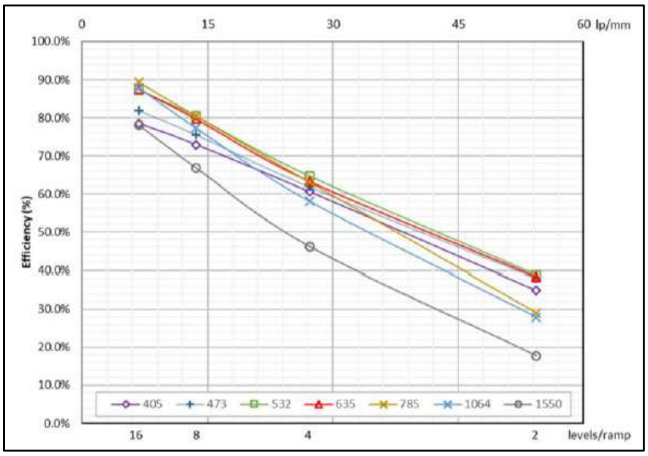
Software Features
- Output triggers
- Image generation
- Automated sequencing
- Wavefront calibration
- Global and regional look up tables

High Phase Stability – We are known for having the fastest SLMs with the least amount of phase ripple on the market . Our backplanes are custom designed with high refresh rates and direct analog drive schemes, resulting in phase ripple for standard products ranging between 0.10 - 0.30% . For customers who require even better performance, customization is possible with phase ripple as low as 0.025% (0.0008 π radians) . Phase ripple is quantified by measuring the variation in intensity of the 1 st order diffracted spot as compared to the mean intensity while writing a blazed phase grating to the SLM.

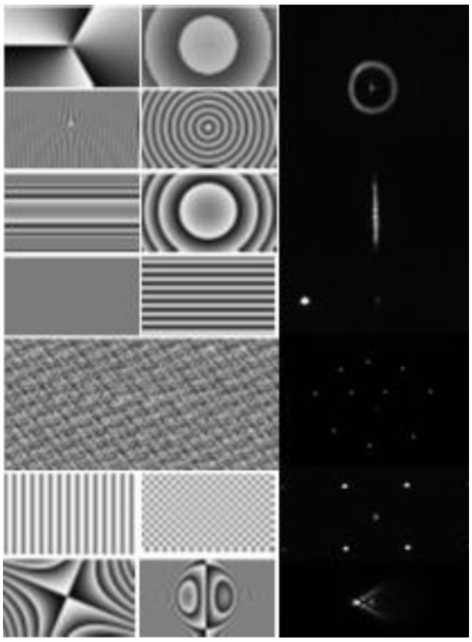


1st order Intensity when writing a phase ramp to the SLM

Hardware Interface Options - The 1920 x 1200 SLM is offered with a 60 Hz HDMI Controller enabling customers to take advantage of our fast liquid crystal response times. Standard hardware includes output trigger for synchronization.



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 in the phase ramp. The plot to the right shows sample 1 st order diffraction efficiency measurements, as a function of the phase ramp period, taken at various wavelengths.

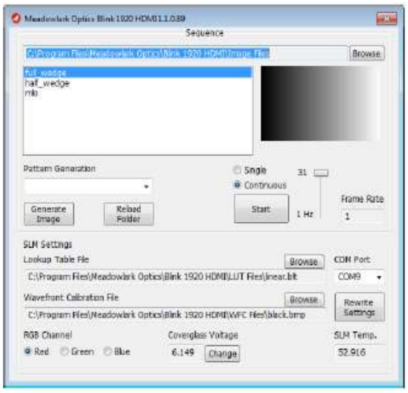
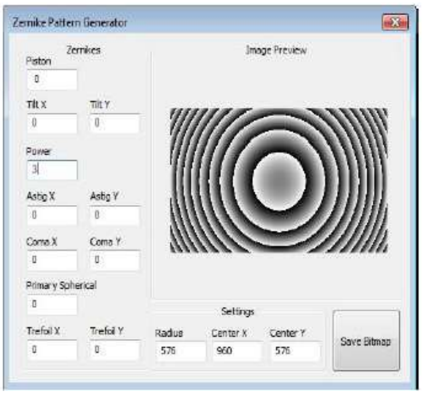
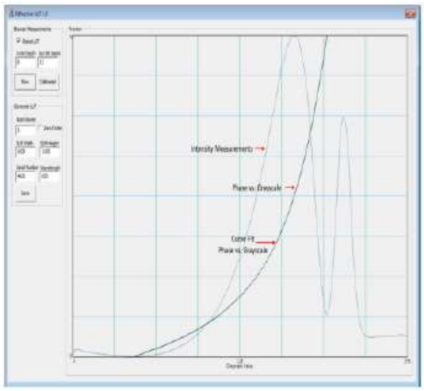


Global or Regional Calibrations - Regional calibrations provide the highest spatial phase fidelity commercially available by regionally characterizing the phase response to voltage and calibrating on a pixel-by-pixel basis.

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

10 Bukit Batock Crescent #07-02 The Spire Singapore 658079 Tel: 6316 7112 Fax: 63167113
http://www.SintecOptronics.com http://www.sintec.sg sales@sintec.sg sales@SintecOptronics.com

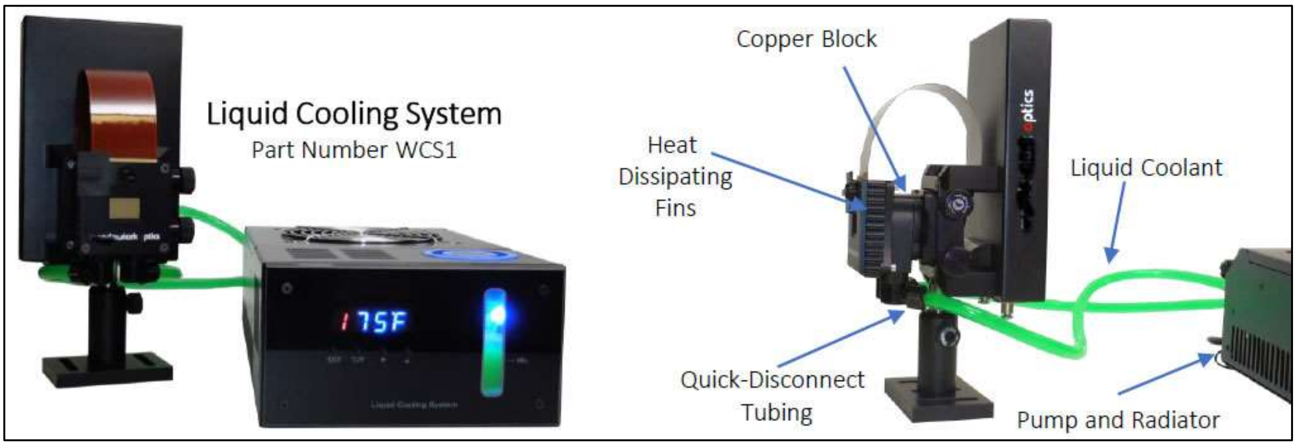




1920 x 1200 Analog Spatial Light Modulator Specifications

- Resolution: 1920 x 1200
- Array Size: 15.36x9.60 mm
- Phase Ripple: 0.10-0.30% (custom as low as 0.025%)
- Fill Factor: 95.6%
- Pixel Pitch: 8.0x8.0 µm
- Controller: HDMI 8-bit

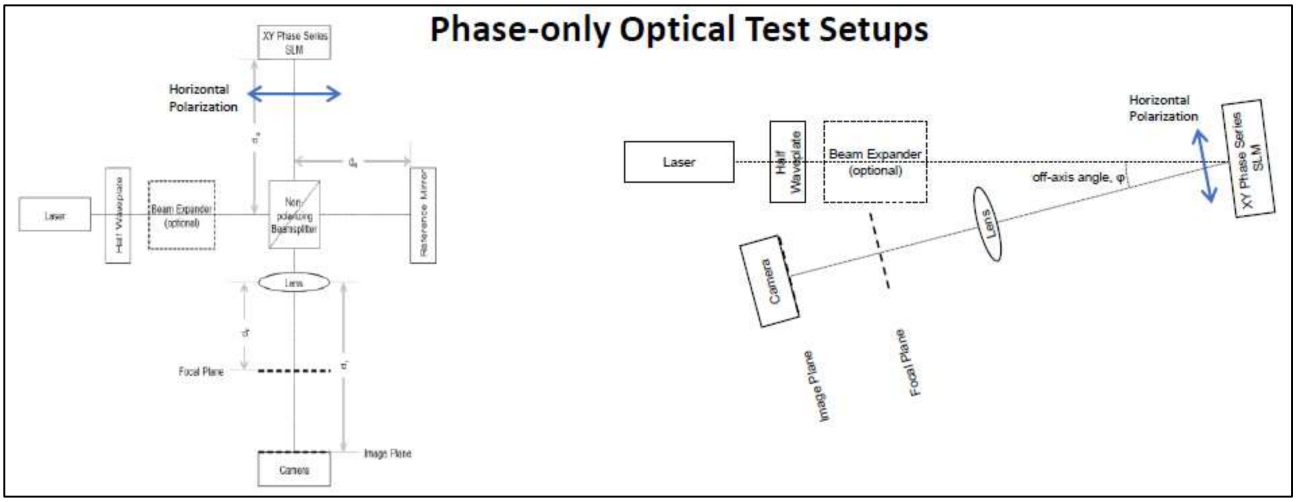
Standard Speed System -Standard Liquid Crystal with HDMI Controller

Specify Calibration Wavelength	Wavefront Distortion	LC Response Time / System Frame Rate	AR Coatings (Ravg <1%)	0th-order Diffraction Efficiency (varies with pixel value)	Reference this Model Number when Ordering
405 nm	λ/3	13.4 ms / 60 Hz	400 – 850 nm	83 – 90%	
473 nm	λ/4	13.7 ms / 60 Hz	400 – 850 nm	84 – 90%	
532 nm	λ/5	14.0 ms / 60 Hz	400 – 850 nm	80 – 88%	STM-E19x12-400-700-HDMI
635 nm	λ/6	14.5 ms / 60 Hz	400 – 850 nm or 500 – 1200 nm	84 – 89%	
785 nm	λ/7	20.5 ms / 30 Hz	500 – 1200 nm	76 – 79%	STM- E19x12-500-1200-HDMI
1064 nm	λ/10	25 ms / 30 Hz	500 – 1200 nm or 850 – 1650 nm	85 – 88%	STM-E19x12-850-1650-HDMI
1550 nm	λ/12	45 ms / 15 Hz	850 – 1650 nm	85 – 91%	

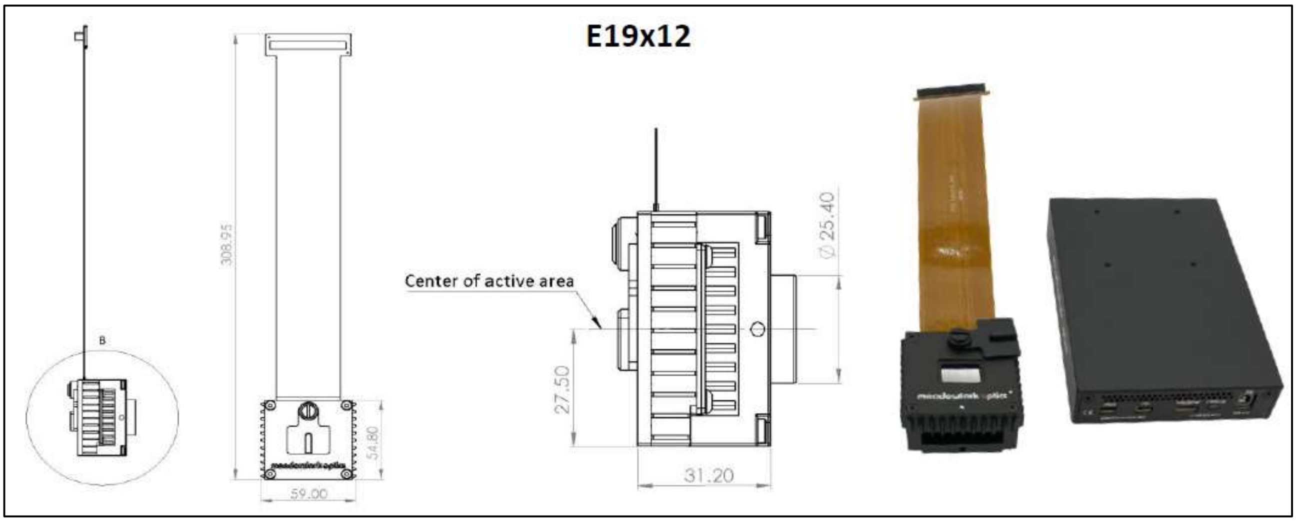


A copper block is attached to the back of the SLM to draw heat out of the SLM. The copper block is attached with 2 meters of quick-disconnect tubing to cooling unit containing an external pump, radiator, and fan to cool the liquid down to ambient temperature. Includes one bottle of liquid coolant.

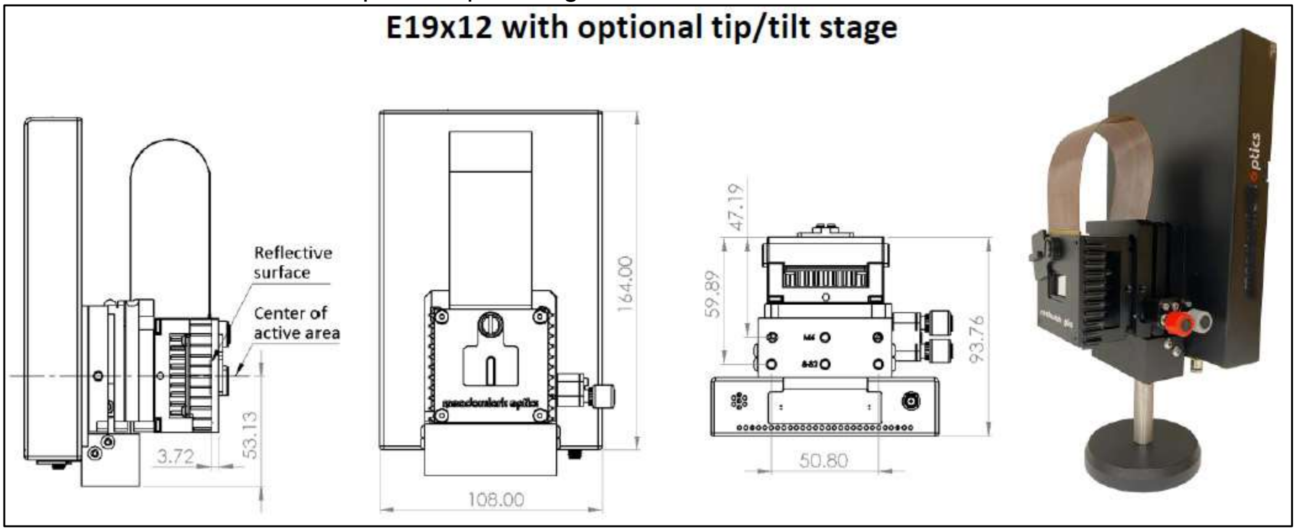
Depending on the application of the XY Phase Series SLM, many different optical setups can be used for either combined phase-amplitude mode or phase-only mode.



Dimensions of E19x12:



Dimensions of E19x12 with optional tip/tilt stage



Specifications of Part Numbers

Specifications P19x12-400-700-HDMI

	E-Series 1920 x 1200 Nematic SLM System
Part Number	E19X12-400-700-HDMI
Design Wavelength (Ad)	400 - 700 nm
Calibration Wavelength (Ac)	Select from one of 405, 473, 532,or 635 nm
Array Size	15.36 x 9.60 mm

External Window	AR coated, R_{avg} < 1 %, 350 - 850 nm
Format	1920 x 1200 (2,304,000 active pixels)
Pixel Pitch	8.0 x 8.0 pm
Fill Factor	95.6%
Zero-Order Diffraction Efficiency	84 - 89% @ 635 nm
	80 - 88% @ 532 nm
	84 - 90% @ 473 nm 83 - 90% @ 405 nm
Phase Stroke (Double Pass)	2n @ Ac, calibrated, ~2.5n @ 635, uncal.
Reflected Wavefront Distortion (RMS Calibrated)	Ac/6 @ 635 nm
	Ac/5 @ 532 nm
	Ac/4 @ 473 nm Ac/3 @ 405 nm
Liquid Crystal Response Time (10-90%)	< 14.5 ms @ 635 nm
	< 14.0 ms @ 532 nm
	13.7 ms @ 473 nm; 13.4 ms @ 405 nm
Maximum Liquid Crystal Switching Frequency	> 69.0 Hz @ 635 nm
	> 71.0 Hz @ 532 nm
	73.0 Hz @ 473 nm; 74.6 Hz @ 405 nm
SLM Phase Levels (resolvable)	256 linear, 2n phase, over Ad, when calibrated
HDMI Controller Output Trigger Signal	Included - SMA connector provides normally high TTL signal which goes low for ~200 ns when image data from CPU changes
CPU to HDMI Controller Phase Levels	256 / 8 bits
HDMI Controller to SLM Phase Levels	4,096 analog
CPU to SLM Transfer Time (one image)	16.7 ms
Maximum System Frame Rate	60 Hz, limited by HDMI frame rate
Tip/Tilt Stage:	Optional

Specifications E19x12-500-1200-HDMI

	E-Series 1920 x 1200 Nematic SLM System
Part Number	E19x12-500-1200-HDMI
Design Wavelength (Ad):	500 - 1200 nm
Calibration Wavelength (Ac):	Select from one of 532, 635, 785, 1064 nm
Array Size:	15.36 x 9.60 mm
External Window:	AR coated, R_{avg} < 1 %, 500 - 1200 nm
Format:	1920 x 1200 (2,304,000 active pixels)
Pixel Pitch:	8.0 x 8.0 pm
Fill Factor:	95.6%
Zero-Order Diffraction Efficiency:	85 - 88% @ 1064 nm
(Maximum, varies with pixel value)	76 - 79% @ 785 nm
	84 - 89% @ 635 nm
	80 - 88% @ 532 nm
Phase Stroke (Double Pass):	2n @ Ac, calibrated, ~3n @ 1064, uncal.
Reflected Wavefront Distortion (RMS Calibrated):	Ac/10 @ 1064 nm
	Ac/7 @ 785 nm
	Ac/6 @ 635 nm
	Ac/5 @ 532 nm
Liquid Crystal Response Time (10-90%):	< 25.0 ms @ 1064 nm
	< 20.5 ms @ 785 nm
	< 19.5 ms @ 635 nm
	< 16.5 ms @ 532 nm
Maximum Liquid Crystal Switching Frequency:	> 40.0 Hz @ 1064 nm
	> 48.8 Hz @ 785 nm
	> 51.3 Hz @ 635 nm
	> 60.6 Hz @ 532 nm
SLM Phase Levels (resolvable):	256 linear, 2n phase, over Ad, when calibrated
HDMI Controller Output Trigger Signal:	Included - SMA connector provides normally high TTL signal which goes low for ~200 ns when image data from CPU changes
CPU to HDMI Controller Phase Levels:	256 / 8 bits

HDMI Controller to SLM Phase Levels:	4,096 analog
CPU to SLM Transfer Time (one image):	16.7 ms
Maximum System Frame Rate:	30 Hz at 1064, 785, and 635 nm, 60 Hz at 532 nm, limited by HDMI (CPU to Controller Transfer Time)
Tip/Tilt Stage	Optional

Specifications E19x12-850-1650-HDMI

	E-Series 1920 x 1200 Nematic SLM System
Part Number	E19x12-850-1650-HDMI
Design Wavelength (Ad):	850 - 1650 nm
Calibration Wavelength (Ac):	Select from one of 1064 or 1550 nm
Array Size:	15.36 x 9.60 mm
External Window:	AR coated, R_{avg} < 1 %, 850 - 1650 nm
Format:	1920 x 1200 (2,304,000 active pixels)
Pixel Pitch:	8.0 x 8.0 pm
Fill Factor:	95.6%
Zero-Order Diffraction Efficiency:	85 - 91% @ 1550 nm
	85 - 88% @ 1064 nm
Phase Stroke (Double Pass):	2n @ Ac, calibrated, ~3n @ 1550, uncalibrated
Reflected Wavefront Distortion (RMS Calibrated):	Ac/12 @ 1550 nm
	Ac/10 @ 1064 nm
Liquid Crystal Response Time (10-90%):	< 45.0 ms @ 1550 nm
	< 25.0 ms @ 1064 nm
Maximum Liquid Crystal Switching Frequency:	> 22.2 Hz @ 1550 nm
	> 40.0 Hz @ 1064 nm
SLM Phase Levels (resolvable):	256 linear, 2n phase, over Ad, when calibrated
HDMI Controller Output Trigger Signal:	Included - SMA connector provides normally high TTL signal which goes low for ~200 ns when image data from CPU changes
CPU to HDMI Controller Phase Levels:	256 / 8 bits
HDMI Controller to SLM Phase Levels:	4,096 analog
CPU to SLM Transfer Time (one image):	16.7 ms
Maximum System Frame Rate:	15 Hz at 1550, 30 Hz at 1064 nm, limited by HDMI (integer multiples of CPU to Controller Transfer Time)
Tip/Tilt Stage:	Optional

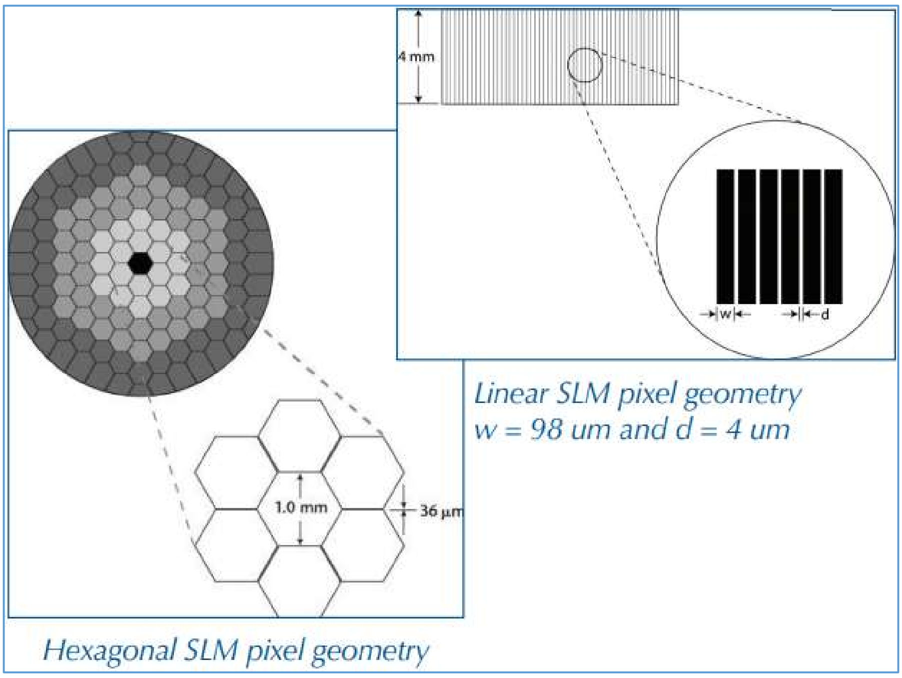
2. Transmissive Spatial Light Modulators

All of our liquid crystal on glass (LCoG) SLMs enable simple optical systems when low pixel counts are sufficient. Users can select single-mask or configurations for phase or amplitude modulation, or a dual-mask configuration for combined phase and amplitude modulation.

2.1 1x128 Linear Array Spatial Light Modulator

The linear SLM has a linear pixel array geometry. This system can be used to alter the temporal profile of femtosecond light pulses via computer control. Applications requiring these short pulses include analysis and quantum control of chemical events, optical communication and biomedical imaging. This linear SLM offers high fill factor, good transmitted wavefront distortion, and options for single or dual-plane for modulating phase, amplitude, or both simultaneously. These SLMs find use in other applications including Hadamard spectroscopy, optical data storage and wavefront compensation.

Pixel format	Response time	Pixel pitch	Efficiency	Fill factor	Active area (mm)
1x128	35 – 70 ms	100 um	85 – 92%	98.0%	12.80 x 5.00
Hex	1 mm	》90%		93.1	12.00Ø

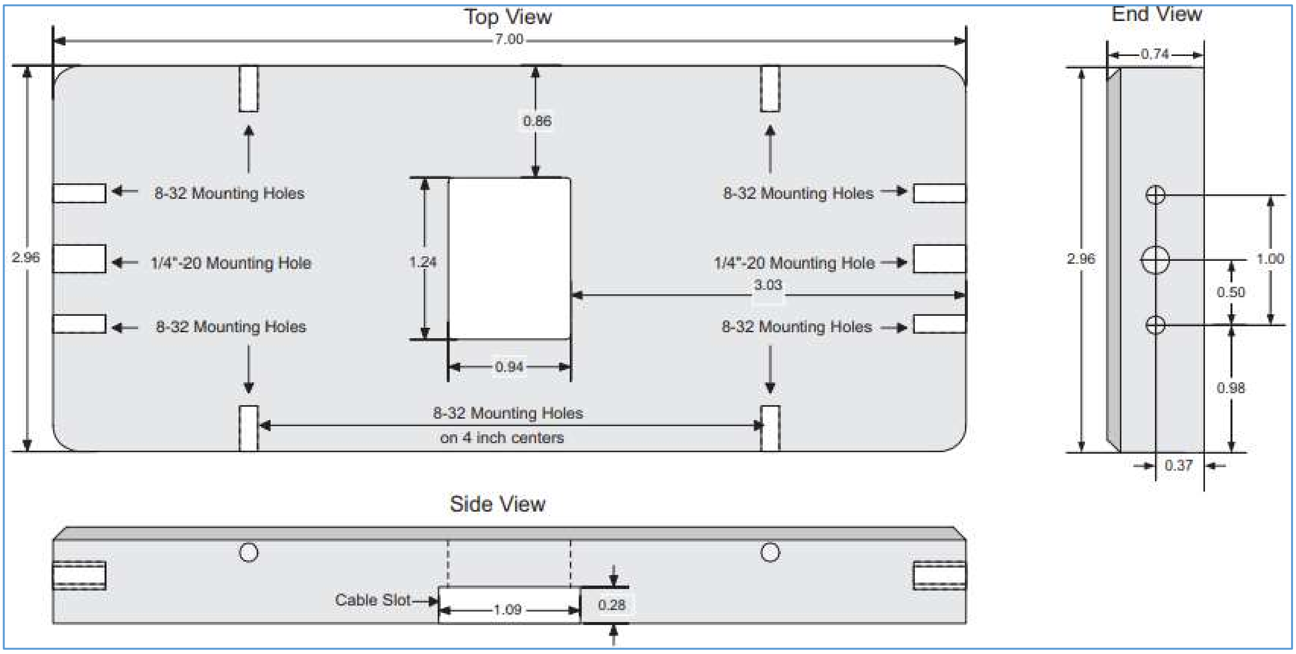


2.2 Spatial Light Modulator Controller

Our spatial light modulator controller allows for independent voltage control of up to 128 liquid crystal cells or pixels. The SLM Controller connects via USB cable to a Windows™ based computer. Supplied software allows for convenient setting of individual pixel retardance and for the programming of retardance profiles across a pixelated device. Custom software can be written using the included LabVIEW™ Virtual Instrument Library to allow for integration into custom applications.

Key Features

- High transmission
- Compact optical housing design
- Computer controlled
- Phase or amplitude modulation



Optical head specifications

Retarder material	Nematic liquid crystal
Substrate material	Optically quality synthetic fused silica
Center wavelength	450-1800nm (specify)
Modulation range	
Phase (min) amplitude	1λ optical path difference 0-100%
Retardance uniformity	<2%rms variation over clear aperture
Transmitted wavefront distortion	≤ λ/4 (P-V @ 633) [≤ λ/10 (RMS @ 633)]
Surface quality	40-20 scratch-dig
Beam deviation	< 2 arc min
Transmittance	> 90% (without polarizers)
Reflectance (per surface)	≤ 0.5% at nominal incidence
Dimension	7.00 x 2.96 x 0.74 in
Recommended safe operating limit	500W/cm², CW 300mJ/cm², 10ns, 532nm
Temperature range	10 - 45 °C

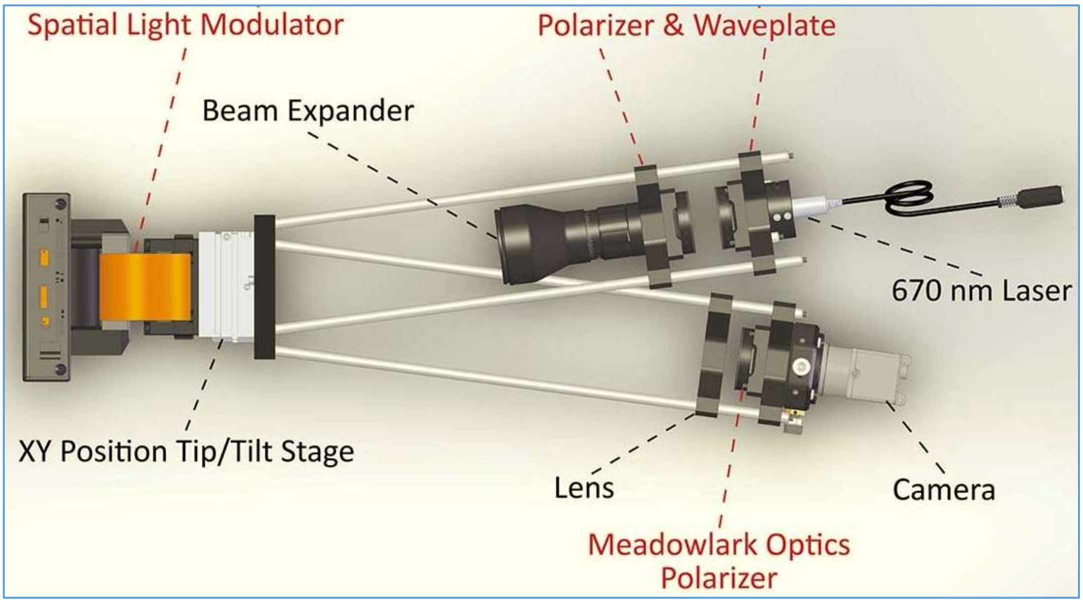
Controller specifications	
Output voltage	2kHz ac square wave digitally adjustable 0-10 Vrms
Voltage resolution	2.44mV (12 bit)
Computer interface	USB
Power requirements	100 – 240VAC @ 47-63Hz, 1A
Dimensions	9.50 x 6.25 x 1.50 in
Weight	2 lbs.
Note that the D31258 in included with the purchase of the SLM system	

Ordering information			
Name	Pixel geometry	Version	Part number
1 x 128	98 µm x 4 mm linear	Phase	SSP – 128P - λ
		Amplitude	SSP – 128A - λ
Hexagonal 127	1 mm across flat	Phase	Hex – 127P - λ
		Amplitude	Hex – 127A - λ
Please specify your operating wavelength λ in nm when ordering. Custom SLM sizes and formats are available			

Optional polarizers		
Type	Wavelength range (nm)	Part number
Visible	450 - 700	SDP – VIS
Near infrared 1	775 – 890	SDP – IR1

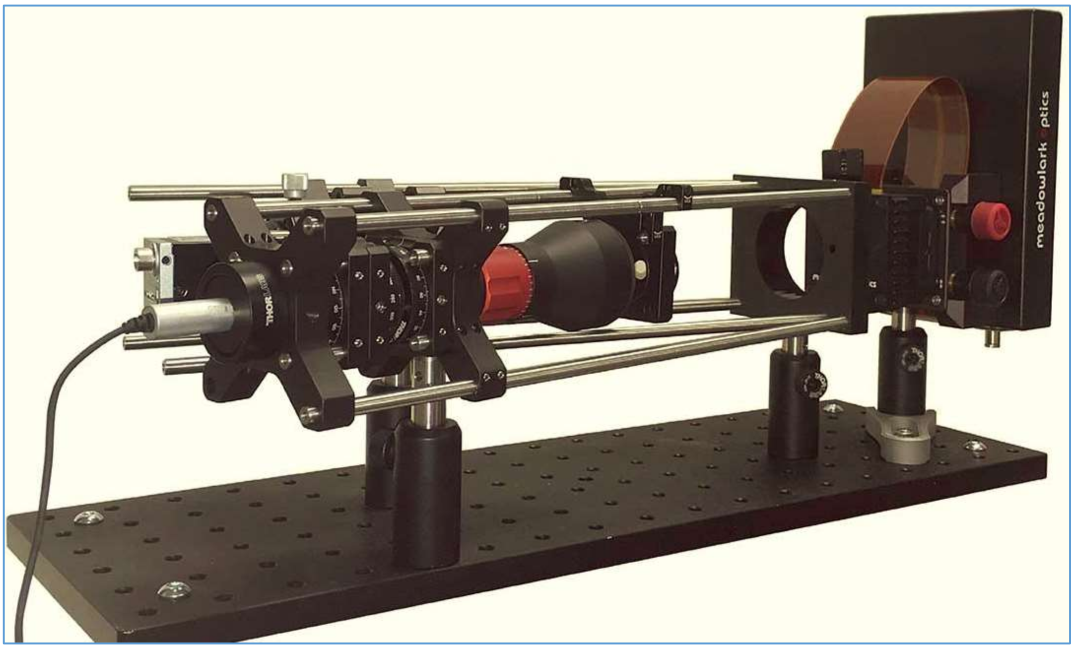
3. Optics Kit

Includes optics & mounts for simple phase or amplitude experiments. Available pre-aligned and ready to use over 405 - 1550 nm. Available with optional camera and laser.

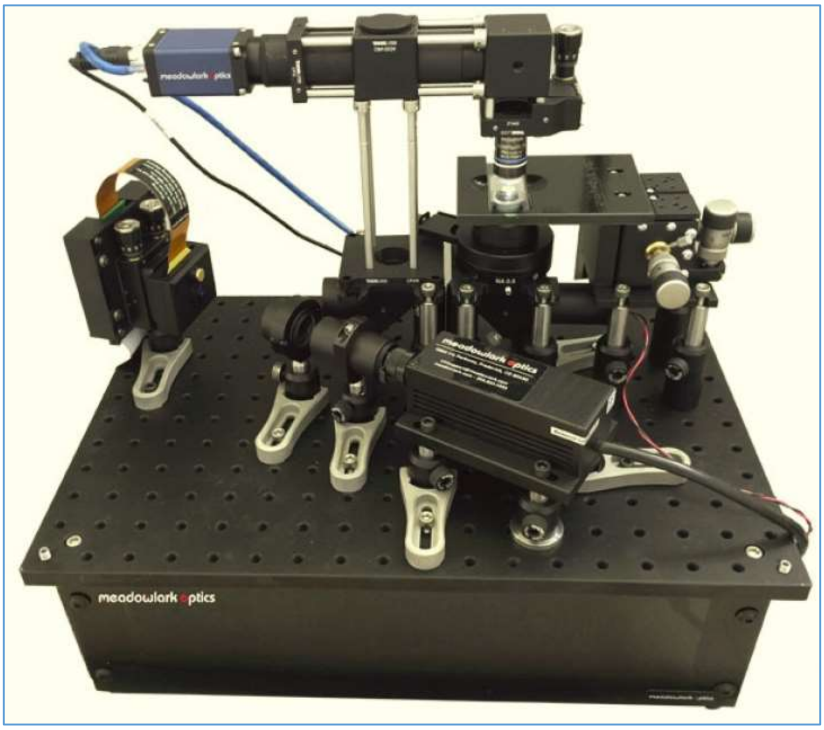


Spend your time on important research rather than designing an optical system for your SLM. The SLM Optics Kit provides you with a set of optics and cage-mount components enabling the user to start research with the SLM system immediately. The kit includes a Half-Wave Retarder, a pair of Linear Polarizers, lenses, and all necessary mount hardware, including a custom adapter plate to quickly align the SLM system to the optics in an off-axis configuration. Optional items are also available including a laser, beam expander optics, and a camera. This approach provides optimum efficiency with minimal design effort.

Optics Kit includes:
Polarizers and waveplates
Beam expander
Lenses
Tip/tilt stage
Base plate and posts
Laser and camera (optional)



4. 1-Photon SLM Microscopy Kit

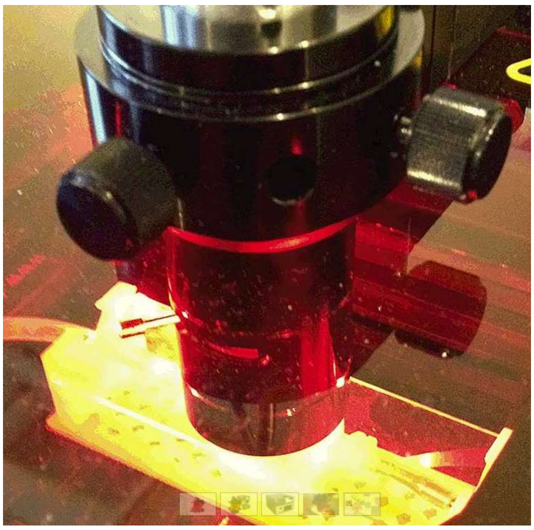


The 1-Photon SLM Microscopy Kit is a scan-less SLM-based epi-fluorescence upright microscope that enables three dimensional calcium imaging and/or photoactivation of neurons in brain slices. The microscope can be used to excite and monitor activity of neuronal ensembles, enabling studies of neuronal circuit activity both in vitro and in vivo. Add-on to existing microscope or use as stand-alone microscope.

KEY FEATURES

- Scan-less SLM-based
- Fully functional programmable excitation system
- Brightfield and/or Epifluorescence microscope
- 3D calcium imaging capability
- Point and click software to define excitation patterns

5. Optical Tweezers Cube



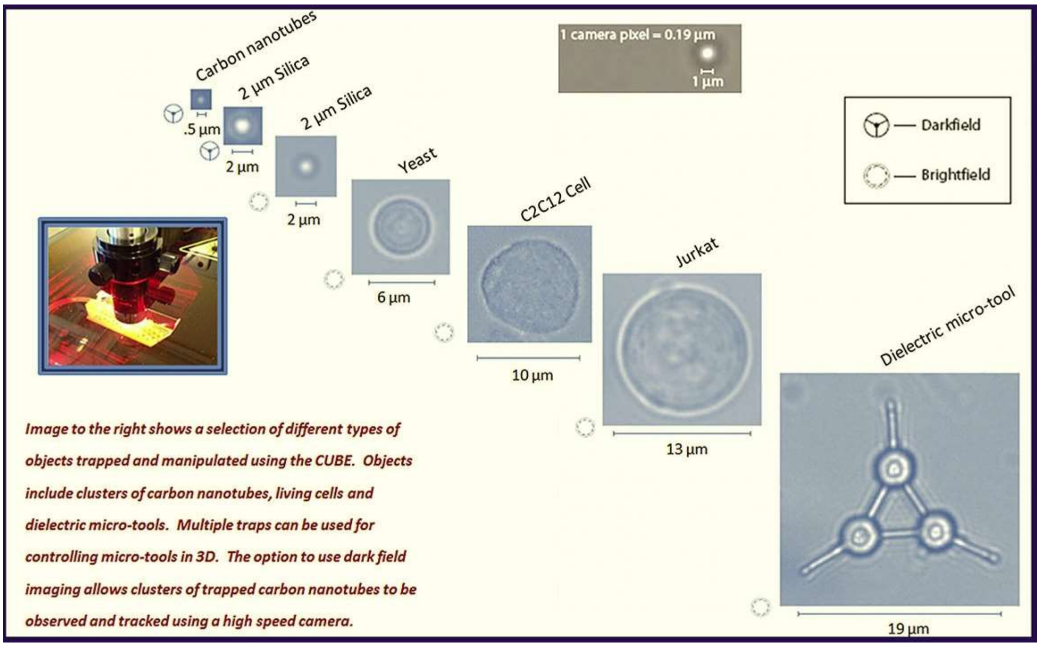
Our cube provides researchers with a portable, stand-alone, optical tweezers system just one cubic foot in size. This compact instrument allows a user to optically trap and thus physically manipulate hundreds of microscopic objects in three dimensions (3D) using computer control to set and move each optical trap independently.

Optical trapping can be used to manipulate objects ranging in size from 10's of nanometers to 10's of microns and objects with a variety of material characteristics. Trapping examples include cellular organisms, dielectric spheres, metallic spheres, metallic nanoshells, carbon nanotubes, air bubbles, and even water droplets in air.

One application of the CUBE includes biological research. This tool enables measurements of cell properties and controlled studies of how cells interact with foreign objects. Another application example is trapping metallic objects and carbon nanotubes for engineering materials with unique thermal and electrical properties.

KEY FEATURES

- Complete optical trapping system
- 3D particle manipulation using holographic beam control
- 100's of traps (demonstrated 400)
- High temporal trap stability
- Spatially uniform trapping across 200x200 micron field of view



Application Notes: Spatial Light Modulators

3D Mapping of Neural Circuits In Vivo Opens the Window on Neurological Disease

Modifications with SLMs to existing two-photon microscopes can provide noninvasive probes deep within the cortex.

Despite extensive research, brain function and neurological diseases are poorly understood. Complexities arise from the quantity of neurons in the brain and from the densely interconnected networks of intermixed cell types. Tools neuroscientists have traditionally relied upon include the patch clamp, which probes electrical activity of a single neuron, and fMRI, which images activity in volumes containing millions of neurons.

These approaches target two vastly different scales. However, it is possible that the brain functions through firing patterns in neural circuits and that neurological disease is the result of alterations to the physical structure of circuits or circuit dynamics. These circuits exist at an intermediate scale that neither patch clamp nor fMRI can readily address. In order to give neuroscientists a range of tools to study brain function, there is a need for methods that noninvasively probe the underlying microcircuitry in the brain with single-cell resolution.

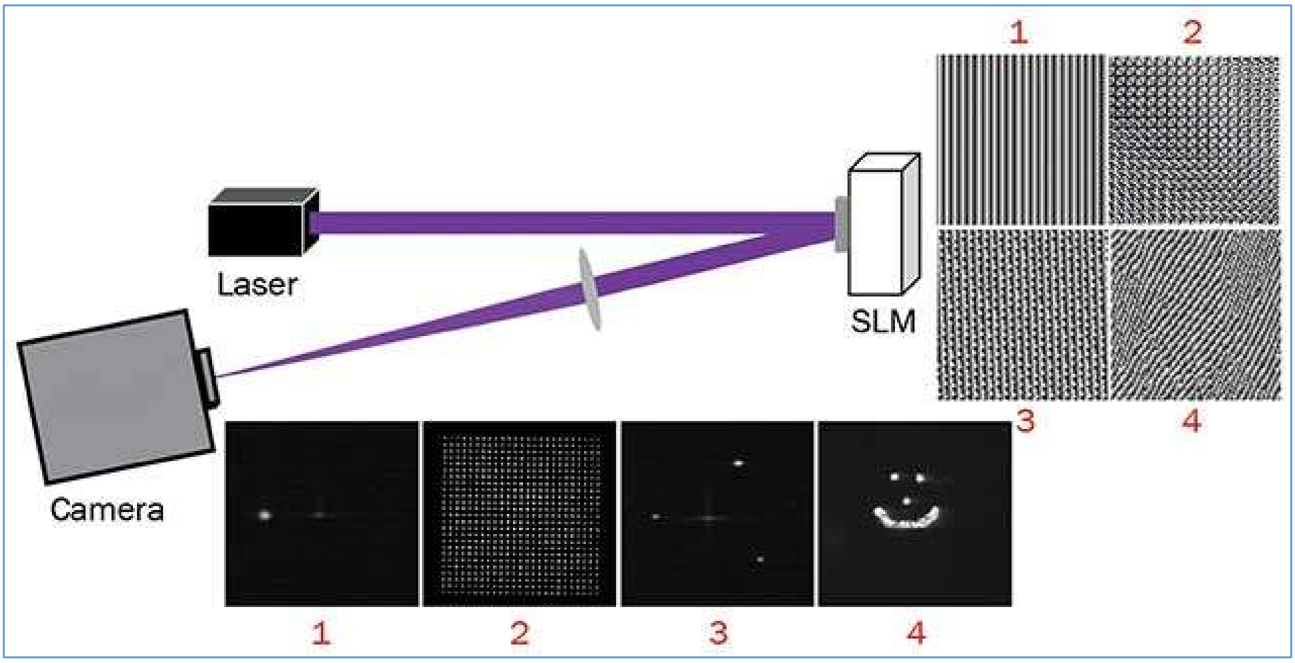


Figure 1. By manipulating the wavefront of a single incident beam, the spatial light modulator (SLM) can be used to superimpose lens and grating functions with weighting functions to redirect light to arbitrary locations to simultaneously create hundreds of focal points within a 3D volume.

Over the last decade, calcium imaging and photoactivation have emerged as solutions to this problem, providing all-optical means to monitor and manipulate circuit activity1. Calcium imaging uses calcium indicators that bind with calcium to alter the fluorescence characteristics of neurons. When a neuron fires, there is an uptake of calcium into the cell body. If the firing neuron is illuminated with an excitation source during the firing event, then the fluorescence emission increases, generating an optical response that corresponds to electrical activity.

Complementary to calcium imaging is photoactivation, which can use photosensitive proteins (optogenetics) or opto-chemical (caged) compounds to manipulate firing patterns either by causing neurons to fire or by silencing neurons. This combination of calcium imaging and photoactivation offers a means for neuroscientists to record the spatiotemporal dynamics of activity and map physical structure of circuits with single-cell resolution. However, without advanced microscopes for neuroscience, the benefits of calcium imaging and photoactivation cannot be realized.

Confocal microscopes have become a core technology for biology, but have fundamental limitations that hinder their use for neuroscience. The first is slow temporal resolution from raster scanning a laser through the sample to build an image pixel by pixel. Without the ability to parallelize excitation to arbitrary locations within a 3D volume, it is impossible to monitor firing patterns of multiple cells simultaneously. This is critical for mapping connectivity of neural circuits and understanding circuit dynamics.

The second limitation is two-dimensional imaging, which is inappropriate for studies of neural circuits. This restricts studies to a small subset of the neurons and limits the scope of the circuits that neuroscientists are trying to map and understand. The third limitation is confocal microscopy's coupling of one-photon excitation with a pinhole to block out-of-focus fluorescence emission. This results in low signal from trivially low depths in strongly scattering and absorbing samples, such as neurons within the cortex.

Two-photon microscopy provides submicron lateral and axial excitation confinement without requiring a pinhole, and the longer wavelength simultaneously minimizes scattering. When coupled with spatial light modulators (SLMs), two-photon microscopes are capable of parallelized excitation for photoactivation and volumetric imaging. SLMs can come in a variety of forms, including micromirror arrays and liquid-crystal (LC)-on-silicon modulators.

In a two-photon microscope, the micromirror array is imaged to the sample so that pixels turned on reflect light to neurons for excitation, and pixels turned off reflect light to a block. This allows a simple method to illuminate cell bodies. Micromirror arrays also offer response times on the order of 20 kHz, far surpassing the current response time requirements of neuroscience. However, because the micromirror array is an amplitude modulator as opposed to a phase modulator, it is not possible to generate lens functions for probing activity in a 3D volume or to actively redirect light from pixels that are turned off to desired focal point locations in the sample.

These limitations are overcome through use of LC-SLMs in microscopes. The SLM acts as a programmable lens manipulating the wavefront of the excitation source. In its simplest form, the SLM can be used as a programmable prism, redirecting light to a single focal point with a lateral shift. By adding prism functions together, the SLM can be used to create multiple focal points within a 2D plane. Furthermore, by adding weighting functions and lens functions, the SLM can redirect light to hundreds of focal points with a programmable intensity in a 3D volume (Figure 1).

In two-photon microscopes, LC-SLMs enable multisite 3D scanless excitation for photoactivation2,3,4,5,6, as well as high-speed volumetric imaging to record a volume of circuit activity7. This combination provides neuroscientists with a toolbox for in vivo studies deep within the cortex to better understand the physical structure of neural circuits, the relationship of firing patterns, external stimuli and the resulting behavior, and how these processes are altered in the presence of neurological disease.

3D photoactivation

Traditional two-photon microscopes contain galvanometer-scanning mirrors used to raster scan the laser focus through the sample. The mirrors are conjugate to the back focal plane of the objective. The SLM is added to the system through an additional relay prior to the galvanometer scanning mirrors (Figure 2). The addition of the SLM and two lenses transforms the function of the microscope so that it can deliver light to any location in the field of view and simultaneously excite multiple 3D sites and use a fast camera to capture their responses8.

Optical layout of a two-photon microscope with an SLM

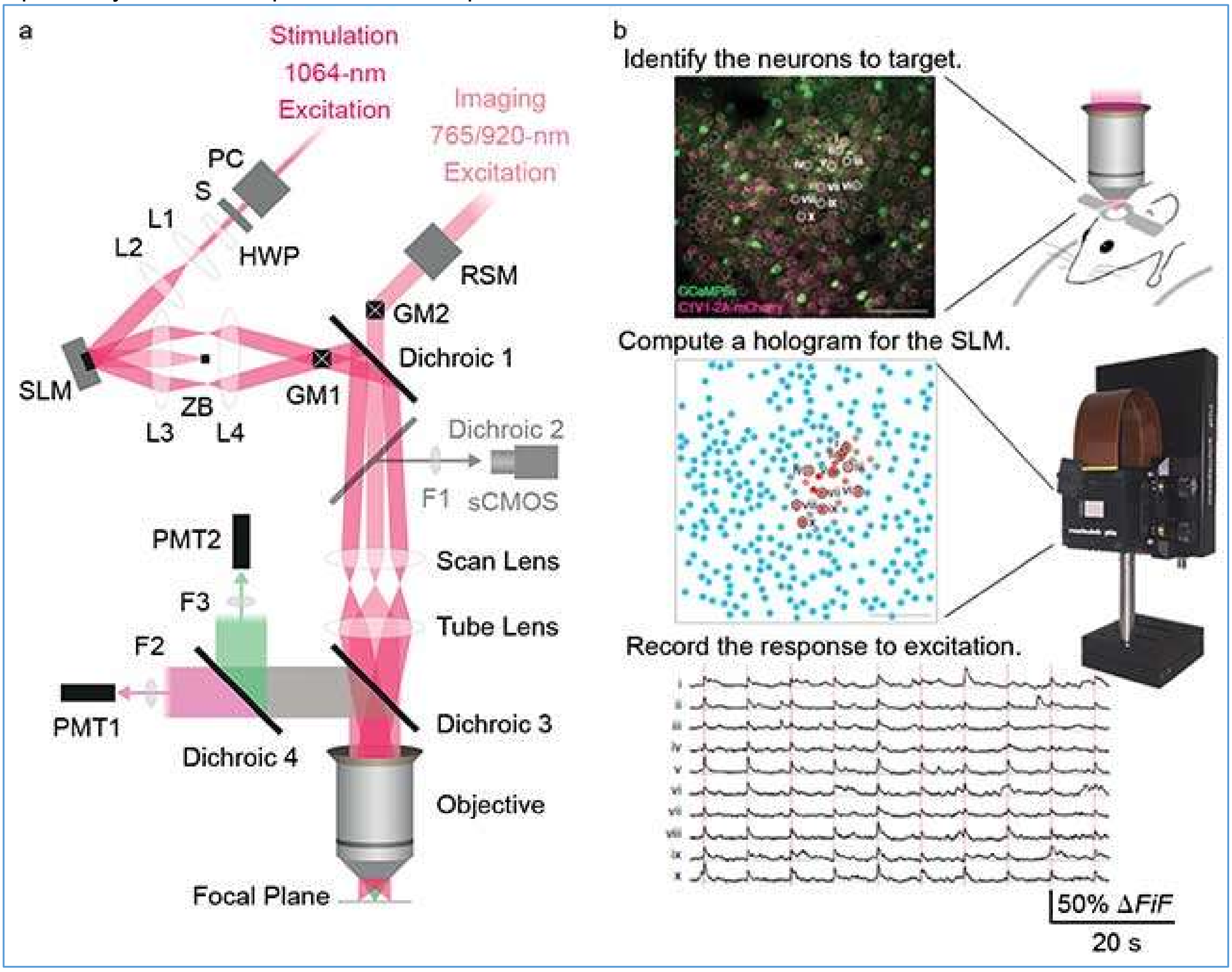


Figure 2. Optical layout of a two-photon microscope with an SLM to enable 3D photoactivation (a). Traditional scanning is used to map the locations of neurons in the sample (b, top). After the cell bodies have been found, specific cells in the field of view can be targeted using the SLM (b, middle). As the cells are excited, the response of the cell bodies can be recorded to map connectivity and record circuit dynamics (b, bottom). Courtesy of A. Packer, L. Russell, H. Dalgleish and M. Hausser, University College London.

In a typical experiment, the galvanometer mirrors raster scan the sample to find the location of cell bodies in the field of view. Holograms then are generated to modulate the wavefront of the source to illuminate individual neurons. This can be used to photoactivate specific cells to replicate firing patterns that have been identified or to manipulate firing patterns that have been observed. Following photoactivation, the response of the surrounding cells can be monitored to understand the impact of photoactivation on the response of the circuit.

When designing the microscope, there are several key criteria that should be considered. The resolution of the SLM determines the number of locations where light can be directed in the sample. The resolution and pixel pitch together determine the dimensions of the volume within the sample that the SLM can excite9. Ideally, the SLM will have a small pixel pitch with high resolution so it can steer to wide angles without under-filling the objective and sacrificing the lateral and axial excitation confinement.

The temporal phase stability of the SLM also is important to ensure reliable excitation. This is particularly important when dividing the light among many neurons and operating near the minimum threshold for excitation. Finally, the response time of the SLM will have significant impact on replicating the spatiotemporal dynamics, which can occur at rates up to 1 kHz110,11.

Volumetric imaging

The ability to manipulate firing patterns is critical to understanding circuit activity, but equally important is the ability to record the response of surrounding neurons at the highest possible frame rate. Traditional two-photon imaging systems build an image volume by mechanically scanning the objective and collecting 2D images (Figure 3). The time required to image the volume can be on the scale of minutes, which is sufficient for static samples. In neuroscience, the dwell time requirement coupled with indicators with limited brightness results in the inability of traditional two-photon imaging to monitor action potentials in complete neural circuits. This opens up the possibility of misinterpretation of action potentials because of the interaction of localized excitation with animal movement.

Comparison of Gaussian and Bessel imaging of a mouse dendritic spine

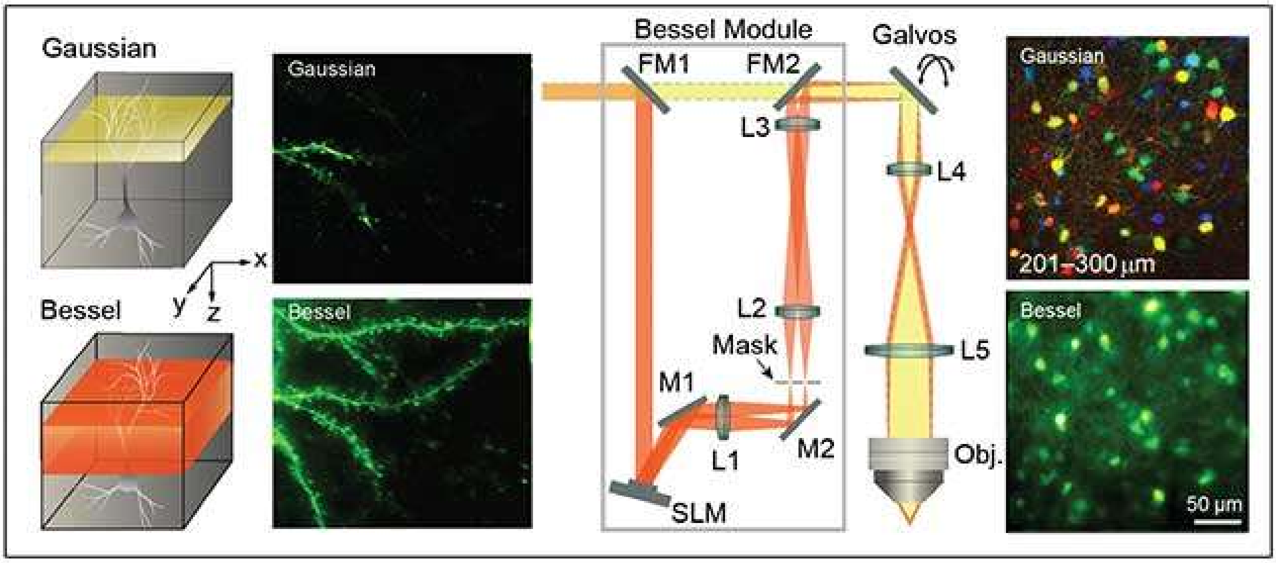


Figure 3. Comparison of Gaussian and Bessel imaging of a mouse dendritic spine (left). Scanning of a Gaussian focus coupled with dwell time requirements for fluorescence excitation leaves a small portion of the sample illuminated and an increased likelihood of activity occurring without fluorescence excitation. Bessel imaging monitors a volume at the same rate of 2D imaging with Gaussian illumination. The “Bessel module” easily integrates with existing 2P microscopes without software changes, enabling easy adaptation of existing microscopes and significantly enhanced capability (middle). A demonstration of the

Bessel module used for imaging inhibitory neurons in a mouse. With Gaussian imaging, a series of 2D scans are required to build the 3D projection, but the Bessel module enables imaging the entire volume without axial scanning (right). Courtesy of Na Ji, Janelia Research Campus.

One solution for high-speed volumetric imaging, presented by Na Ji, group leader at the Janelia Research Campus of the Howard Hughes Medical Institute, uses a Bessel focus-scanning technology (BEST) that samples activity in a volume with hundreds of microns in each dimension in the equivalent time that a Gaussian two-photon microscope images a 2D plane6.

The module for 3D imaging is simple and widely compatible with existing microscopes, consisting of an SLM, a static amplitude mask and three lenses (Figure 3). The lenses relay the image of the SLM to the sample. The amplitude mask is a static patterned mirror that selectively transmits the first diffracted order. The optional flip mirrors at the entrance and exit of the module allow optical addition or removal of volumetric imaging so that structures can be imaged with traditional Gaussian illumination if desired. The use of SLMs here allows flexible generation of Bessel foci of varying lateral sizes, axial lengths and axial intensity distribution, permitting users to optimize BEST for specific samples.

Ji has demonstrated the approach for enabling discoveries for neurobiology by imaging the calcium dynamics of volumes of neurons and synapses in fruit flies, zebrafish larvae, mice and ferrets in vivo. Calcium signals in objects as small as dendritic spines could be resolved at video rates. High-speed volumetric imaging is a critical advancement for microscopes adapted specifically to the needs of the neuroscience community.

The combination of SLMs, two-photon microscopy, calcium imaging and photoactivation is leading to advanced tools for neuroscientists to monitor and manipulate the activity of neural circuits in the brain. The methods require minor modifications to existing microscopes, allowing researchers to inexpensively and readily adapt existing tools to support 3D photoactivation with high-speed volumetric imaging. This significantly enhances capabilities of microscopes, providing a complete tool enabling studies of neural circuits, expanding the field of view, the depth and the temporal limits at which neuroscientists can monitor and manipulate circuit activity.