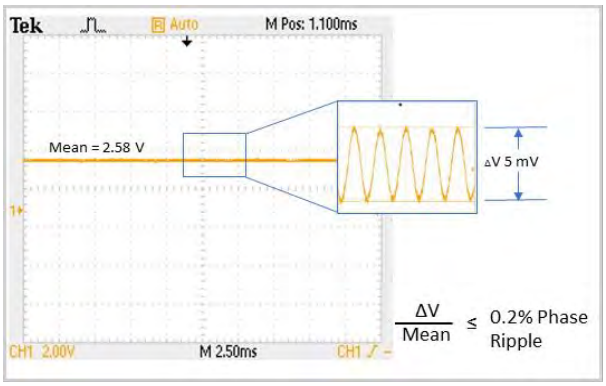
Spatial Light Modulator – 1920 x 1152

High Speed Analog

Meadowlark Optics' 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. Meadowlark offers 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. The 1920 x 1152 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 1920 x 1152 silicon backplane to enable high speed operation while simultaneously maximizing phase stability. Engineers successfully incorporated high refresh rates with analog drive schemes to suppress phase instabilities to an unprecedented 0.50 – 2.0% which, until recently, rivaled our standard speed systems. With the launch of our new 19x12 SLM, phase ripple was reduced even further to 0.10 – 0.30%. If your application requires extremely low phase ripple, please contact a Meadowlark Solutions Engineer for more information on the 19x12 SLM.

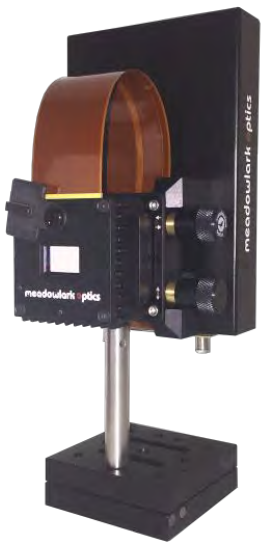
Phase ripple is quantified by measuring the variation in intensity of the 1st order diffracted spot as compared to the mean intensity while writing a blazed phase grating to the SLM.



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

Hardware Interface - The 1920 x 1152 SLM system includes a PCIe controller with input and output triggers and low latency image transfers.

PCIe Controller supports high frame rates (up to 844 Hz)



SLM Features

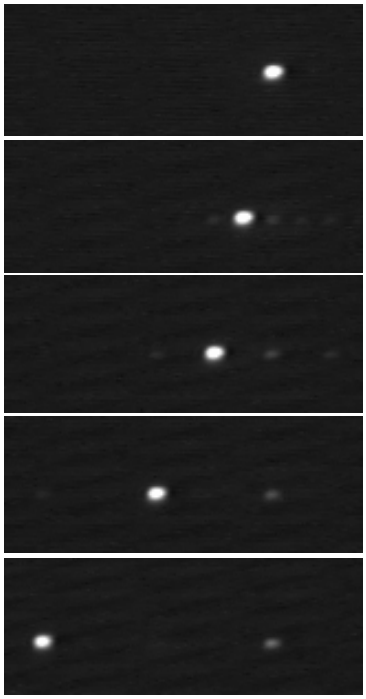
- High resolution
- High speed
- High Phase Stability
- Pure analog phase control
- High first order efficiency
- High reflectivity
- High power handling
- Compact design
- Wavelengths from 488-1650 nm

Software Features

- Input and Output Triggers
- Image Generation
- Automated Sequencing
- Wavefront Calibration
- Global and Regional Look Up Tables

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. An example measurement, taken at 1064 nm is shown below left, for phase ramps with 4 to 32 phase levels between 0 and 2π. The plot below right shows sample 1st order diffraction efficiency measurements, as a function of the phase ramp period, taken at various wavelengths.

Measured 1st Order Diffraction Efficiency



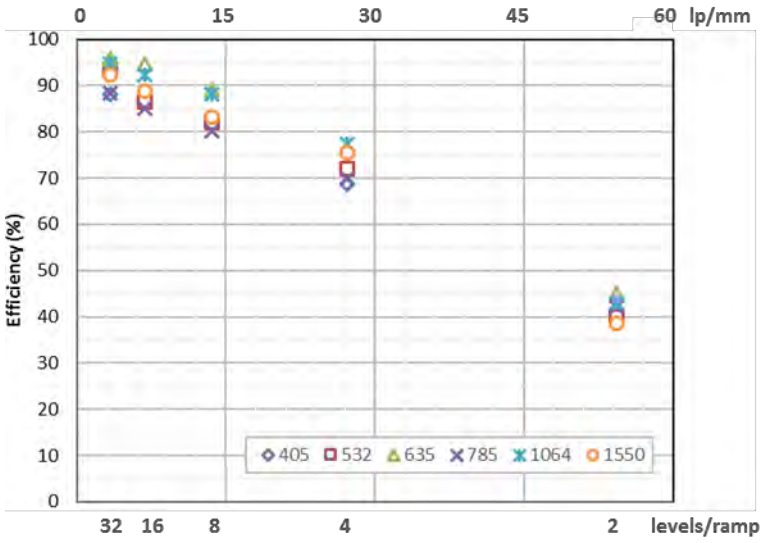
0th Order

32 phase levels, 0.2°
1st Order Diffraction
Efficiency: 94.6%

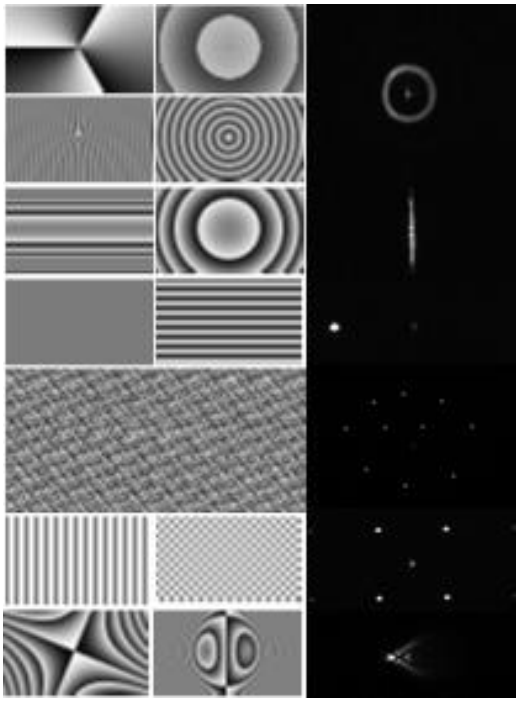
16 phase levels, 0.4°
1st Order Diffraction
Efficiency: 92.4%

8 phase levels, 0.8°
1st Order Diffraction
Efficiency: 88.0%

4 phase levels, 1.6°
1st Order Diffraction
Efficiency: 77.4%



Software - Meadowlark Optics' 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.



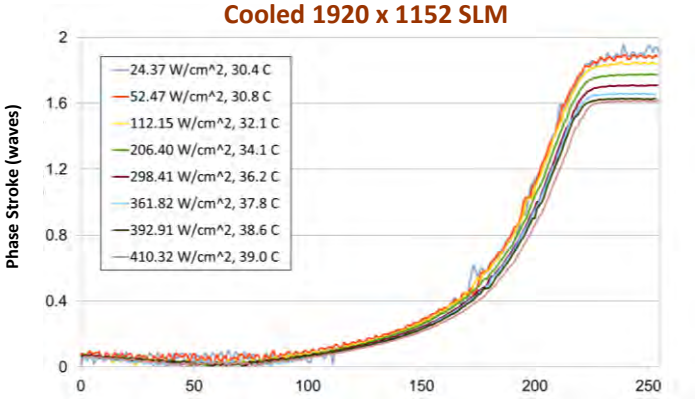
Global or Regional Calibrations - Regional calibrations provide the highest spatial phase fidelity commercially available by regionally characterizing the phase response to voltage and calibrating on a pixel by pixel basis.

Image Generation Capabilities

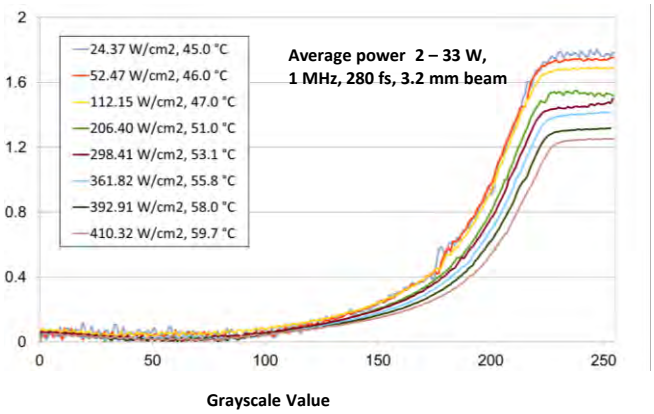
Bessel Beams: Spiral Phase, Fork, Concentric Rings, Axicons
Lens Functions: Cylindrical, Spherical
Gratings: Blazed, Sinusoid
Diffraction Patterns: Stripes, Checkerboard, Solid, Random Phase
Holograms, Zernike Polynomials, Superimpose Images

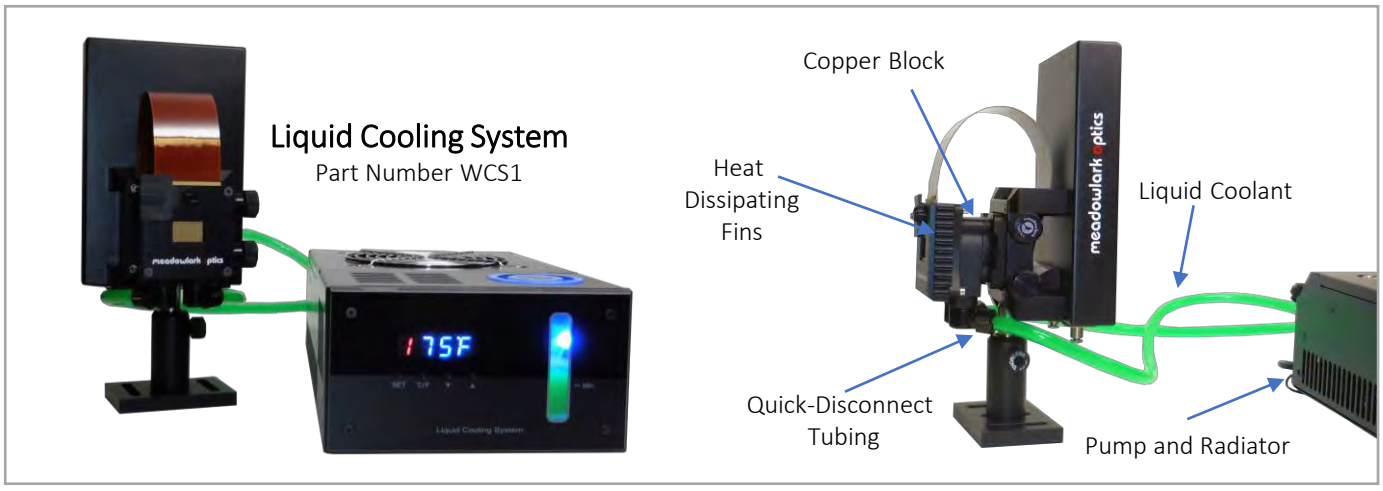
High Power Capability - Meadowlark Optics' Spatial Light Modulators have been tested for compatibility with high power pulsed and CW lasers. In the graphs below, the optical response of the 1920 x 1152 pixel SLM with and without liquid cooling was measured as the incident power was incremented up to 15 GW/cm^2 peak power or 410 W/cm^2 average power.

Cooled 1920 x 1152 SLM



Standard 1920 x 1152 SLM





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.

1920 x 1152 Analog Spatial Light Modulator Specifications

Resolution: 1920 x 1152 **Array Size:** 17.6 x 10.7 mm **Zero-Order Diffraction Efficiency***: 88%

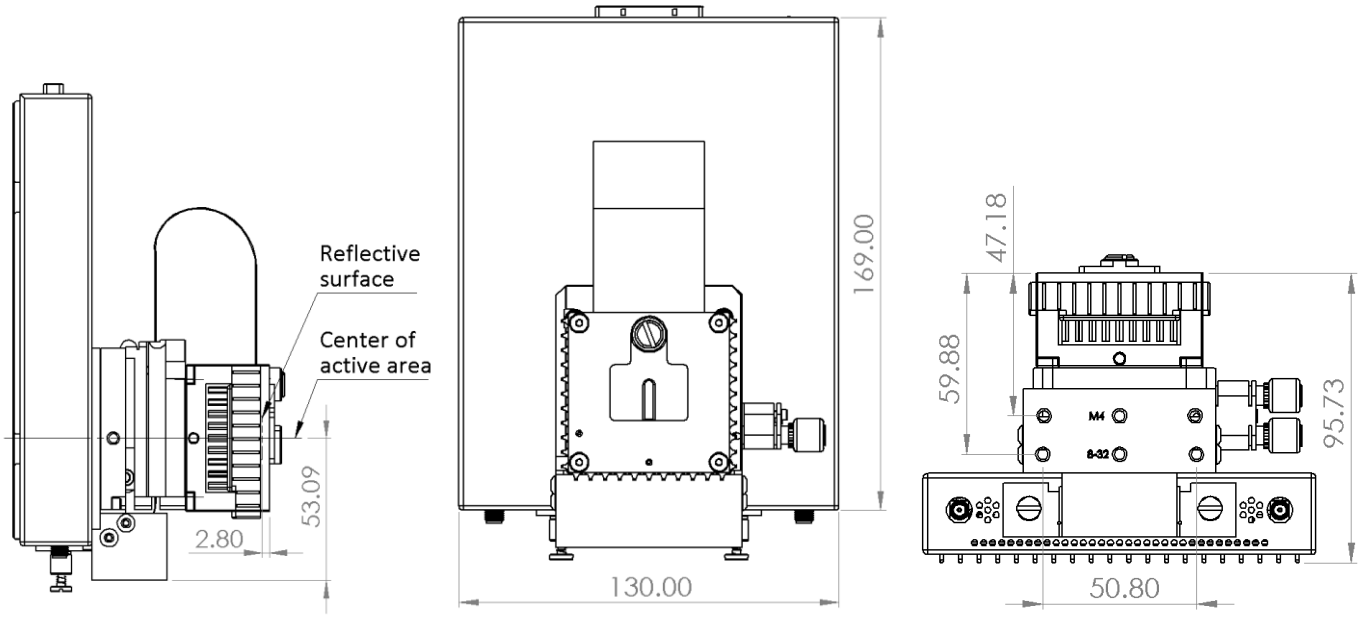
Fill Factor: 95.7% **Pixel Pitch**: 9.2 x 9.2 µm **Controller:** PCIe 8/12-bit

High Speed System – High Speed Liquid Crystal with High Speed PCIe Controller

Specify Calibration Wavelength	Wavefront Distortion	LC Response Time / System Frame Rate	AR Coatings (Ravg <1%)	Reference this Model Number when Ordering
532 nm	λ/5	1.4 ms / 422.4 Hz	488 – 800 nm	Model HSP1920-488-800-HSP8
635 nm	λ/6	1.8 ms / 422.4 Hz	488 – 800 nm	
785 nm	λ/7	2.3 ms / 422.4 Hz	500 – 1200 nm	Model HSP1920-500-1200-HSP8
1064 nm	λ/10	3.3 ms / 281.6 Hz	500 – 1200 nm	
1550 nm	λ/12	4.7 ms / 211.2 Hz	850 – 1650 nm	Model HSP1920-850-1650-HSP8

*Silicon backplane, performance varies as a function of wavelength.

PCIe 1920 x 1152 System Dimensions



Side Front Bottom

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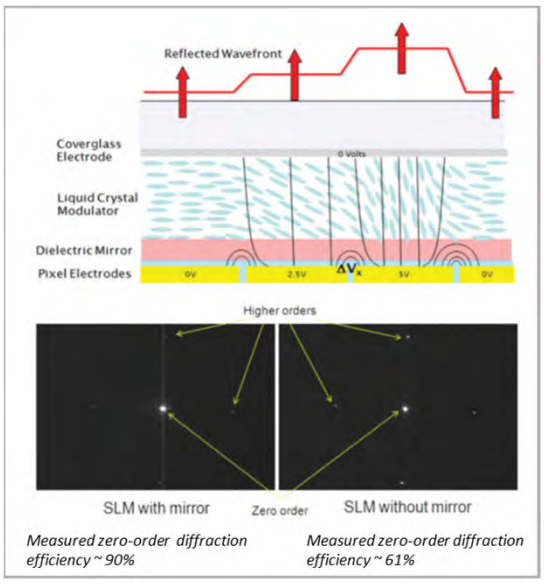
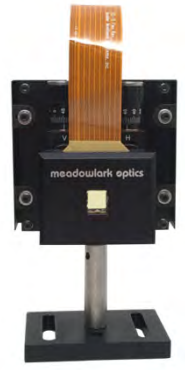
Spatial Light Modulator – 512 x 512

Meadowlark Optics 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 user's with the fastest response times and highest phase stabilities commercially available. Meadowlark offers 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. The 512 x 512 SLM is good for applications requiring high speed, with synchronization / triggering capabilities. The optional dielectric mirror coating provides users with 100% fill factor, which increases optical efficiency.

High Efficiency

All of the light reflecting off of the SLM is modulated – including the light between the aluminum pixel electrodes. The reflective pixel structure associated with a Liquid Crystal (LC) 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 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 (low pass spatial filtering) which results from separating the LC modulator from the driving electrodes.





Key Features

- High speed
- Pure analog phase control
- High bit-depth controllers (high phase resolution)
- High reflectivity option
- High power handling
- Synchronization / Triggering
- Wavelengths from 400-1650 nm

Applications

- Adaptive Optics
- Optical Trapping
- Multi-Spot Volumetric Beam Steering
- Optical Vortices
- Pulse Shaping
- Spectral Shaping
- Tunable Lens

SLM Family

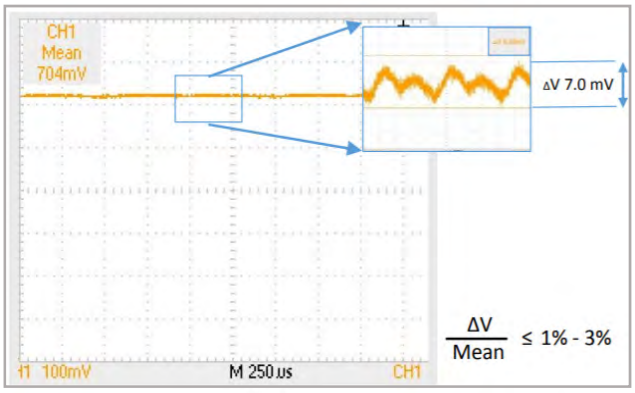
- 1920 x 1152
- 1 x 12,288
- E-Series 512 x 512
- 1 x 128
- Hex 127

High Phase Resolution

Meadowlark offers the industry's only 16-bit controllers for LCoS SLMs. With 16-bit voltage resolution these controllers provide unsurpassed phase resolution. When properly calibrated the SLMs typically have more than 10,000 unique pixel values over a 2π phase stroke. This high resolution is necessary when working with broad wavelength ranges, or large phase stroke SLMs in order to accurately hit the desired retardance at the operating wavelength. High phase resolution is also necessary in applications where the SLM is combined with polarizers to achieve amplitude modulation. With this approach, achieving good contrast ratio requires hitting the exact phase value yielding the darkest "off" state.

Low Phase Ripple

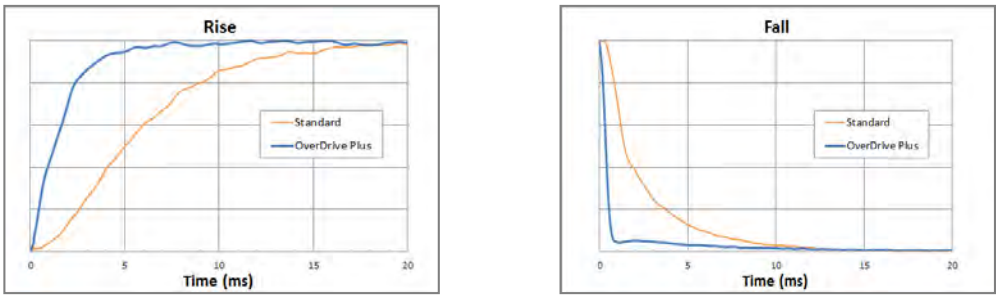
Meadowlark loads every pixel with 8-bit or 16-bit data several times per millisecond. This high speed addressing scheme eliminates phase ripple as demonstrated in the figure to the right. Meadowlark Optics' SLMs have been tested for compatibility with high power pulsed and CW lasers. In the measurements shown, the optical response of the 512 x 512 pixel SLM was measured as the incident power was incremented up to a peak power density of 112 MW/cm^2. Thermal effects resulted in a reversible reduction in modulation depth, and no permanent damage.



High Speed

The use of OverDrive Plus has shown reductions of the liquid crystal response times by a factor of up to 8x through use of the transient nematic effect, phase wrapping, and regional calibrations. The base technology is the transient nematic effect, utilizing intermediate transition voltages beyond the target voltage needed to achieve the desired phase value. The second technology development is the use of phase wrapping, which is based on the cyclical nature of light wherein adding or subtracting 2π from any phase value in a hologram results in an equivalent hologram. Often times it is faster to switch from phase1 → phase2 ± 2π instead of switching from phase1 → phase2. ODP automatically implements the faster of the two transitions, based on the calibration data. The third technology development is the utilization of regional calibrations of an SLM. Because most optical applications require precision on the order of a fraction of a wavelength, nearly all SLMs will have some inherent phase errors across the aperture that may impact the performance of the optical system. OverDrive Plus utilizes the phase modulation capabilities of the SLM to calibrate these errors out of the reflected wave, while also utilizing the regional calibrations when determining the length of time required for the transient nematic effect on a pixel by pixel basis.

OverDrive Plus for Ultra-High Speed Modulation



512 x 512Analog Spatial Light Modulator Specifications

Resolution: 512 x 512
Fill Factor: 83.4 - 100%
Array Size: 7.68 x 7.68 mm
Pixel Pitch: 15 x 15 µm
Zero-Order Diffraction Efficiency*: 61 - 95%
Controller: PCIe 8-bit, PCIe 16-bit, DVI 16-bit

Wavelength	Wavefront Distortion	Liquid Crystal Response Time (Standard Efficiency / High Efficiency)			AR Coatings (Ravg <1%)
		P512/PDM512	HSP512/HSPDM512	ODP512/ODPDM512	
405 nm	λ/5	25 ms / 33.3 ms	N/A	3 ms / 4 ms	400 – 850 nm
532 nm	λ/7	33.3 ms / 45 ms	7 ms / 10 ms	3.5 ms / 4.5 ms	400 – 850 nm

DVI 16-bit

PCIe 8-bit

PCIe 16-bit

512 x 512 Controller Models

Model	PCIe 8-bit	PCIe 16-bit	DVI 16-bit
Controller Phase Levels	256 / 8-bits	65,536 / 16-bits	65,536 / 16-bits
CPU to Controller Transfer Time (Computer Dependent)	0.6 ms	2.1 ms	16.7 ms

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