Progress Towards Low-Cost Compact Metric Adaptive Optics Systems

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ACTIVE OPTICAL SYSTEMS

Outline

- Introduction & Motivation
- Low-Cost Component Development
  - DMs, Drive Electronics, & AO Controllers
- Optical Setup
- System Demonstrations
  - PC-interfaced System
  - Microcontroller System
- Evaluation of the Microcontroller SPGD
- Conclusions & Future Work

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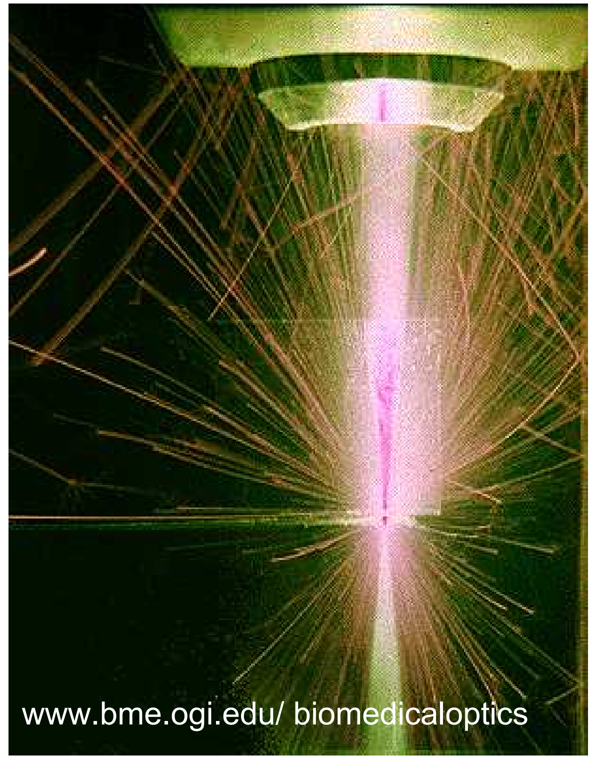
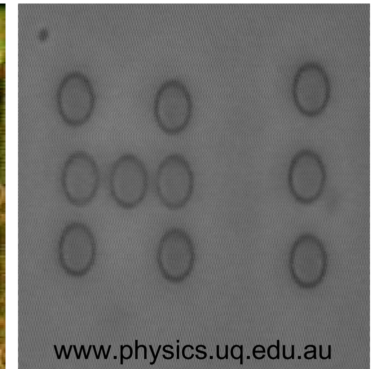
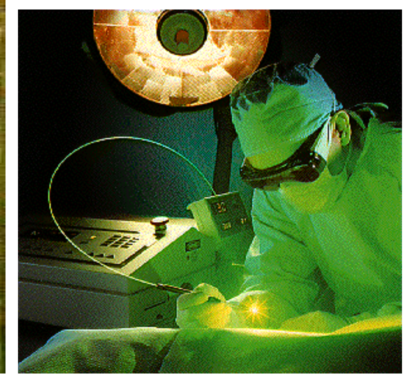
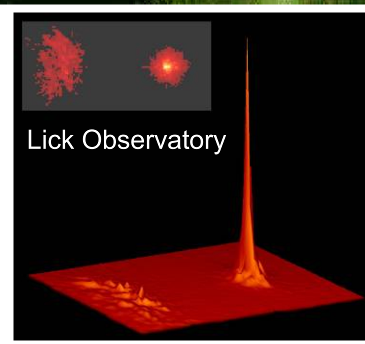
Applications of Adaptive Optics

- Laser Wavefront Control
  - Intensity Profile Shaping
    - Laser Machining
    - Optical Tweezers
  - Atmospheric Aberration Compensation
- Imaging
  - Astronomy
  - Target Inspection
  - Ophthalmology









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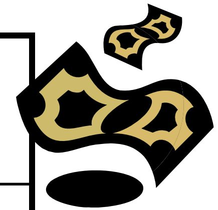
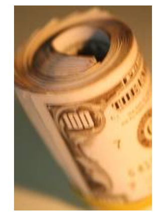
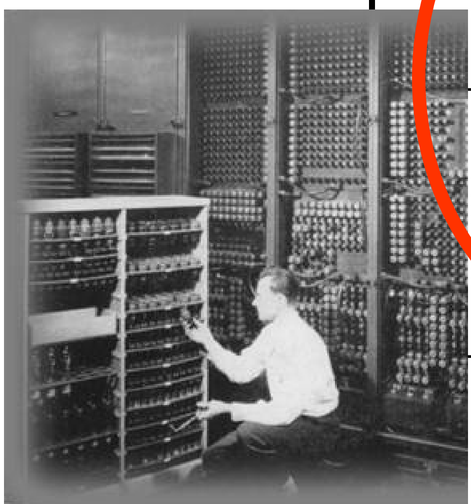
Barriers to Mass Usage







Barrier	Solution
Cost	Implementation via our unique compact low-cost hardware
Complexity	Construction of complete active optical systems
Inertia	AO systems can often relax requirements and increase system functionality

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What is Low Cost?

- Patterson published results of a $25k system in 2000.
  - $30k in today's dollars
- Other vendors are selling:
  - Low Actuator Count DMs for ~$2k
  - Drive Electronics for ~$5k
  - Systems for ~$25k+
- We present here a low-cost metric AO system that is commercially available for $7,500

A low cost adaptive optics system using a membrane mirror

C. Paterson, I. Munro and J. C. Dainty

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carlp@ic.ac.uk

Abstract: A low cost adaptive optics system constructed almost entirely of commercially available components is presented. The system uses a 37 actuator membrane mirror and operates at frame rates up to 800 Hz using a single processor. Numerical modelling of the membrane mirror is used to optimize parameters of the system. The dynamic performance of the system is investigated in detail using a diffractive wavefront generator based on a ferroelectric spatial light modulator. This is used to produce wavefronts with time-varying aberrations. The ability of the system to correct for Kolmogorov turbulence with different strengths and effective wind speeds is measured experimentally using the wavefront generator.

OCIS codes: (010.1080) Adaptive optics; (010.1330) Atmospheric turbulence

References and links

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Patterson et al, Optics Express 6, No. 9, 175-85

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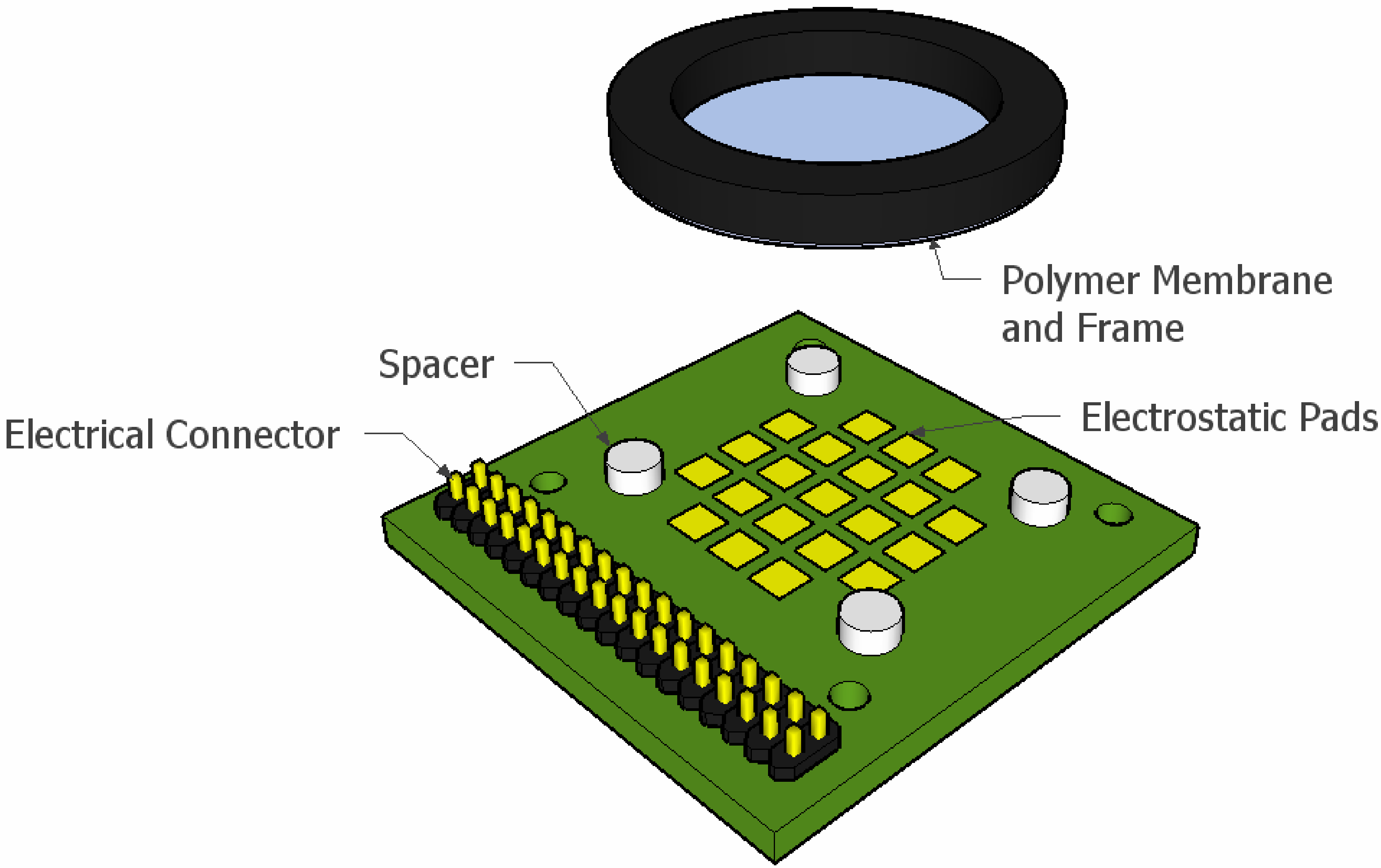
Low-Cost Polymer Deformable Mirrors



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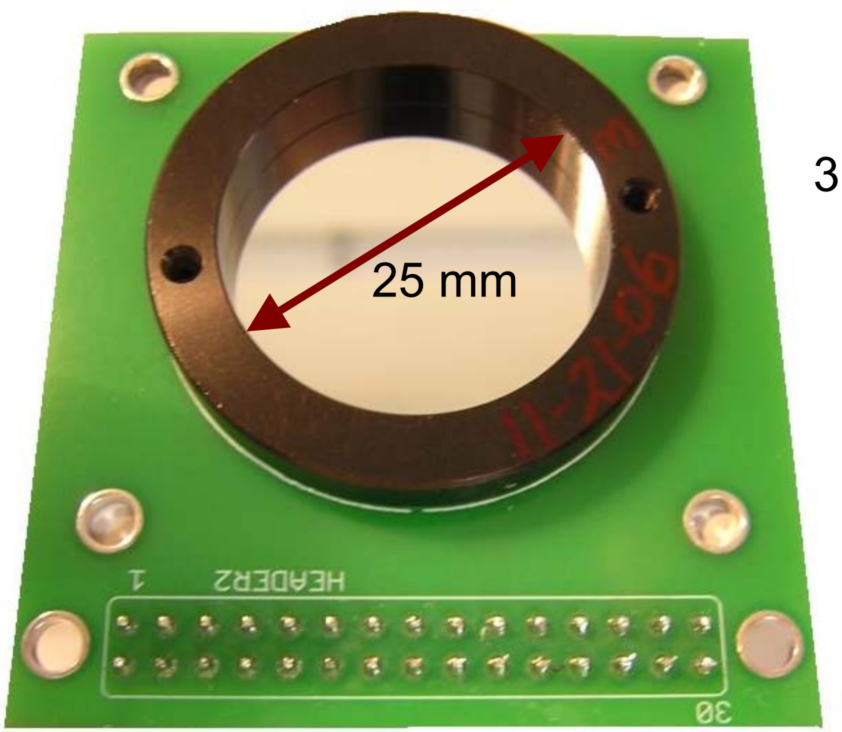
Polymer Deformable Mirror



DM Prior to Packaging

Packaged DM

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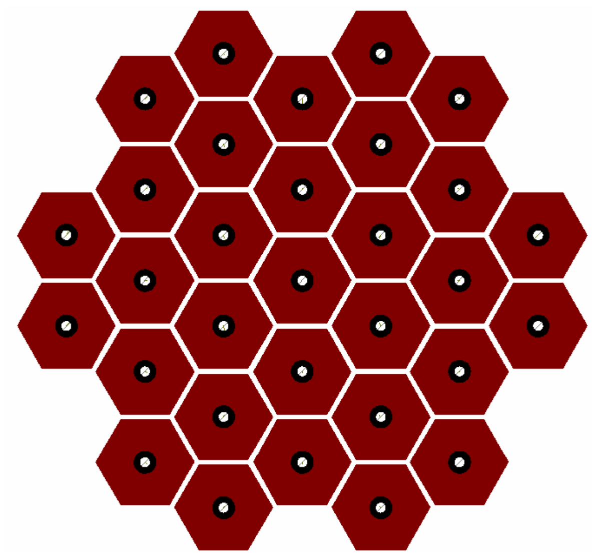
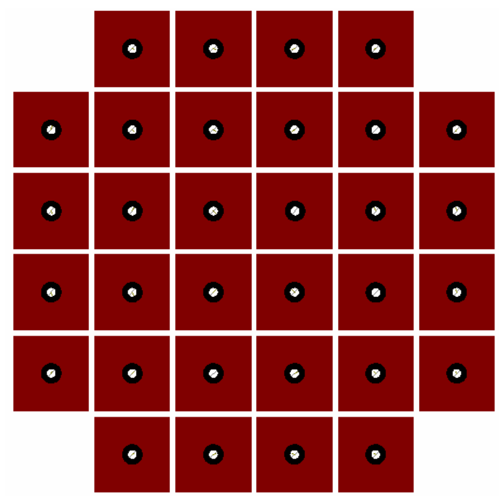
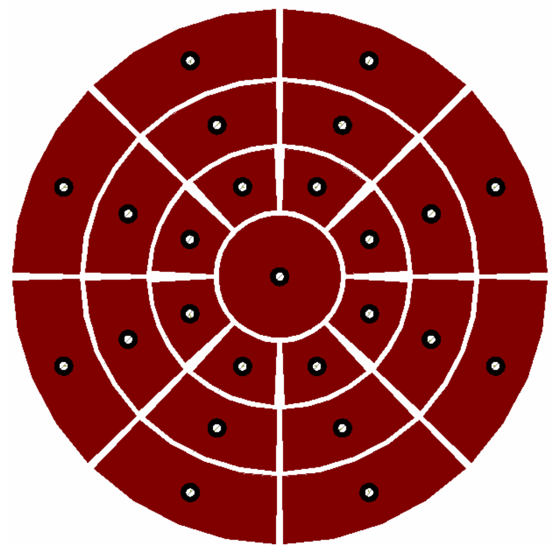
Actuator Patterns

Hexagonal	Square	Segmented Annular







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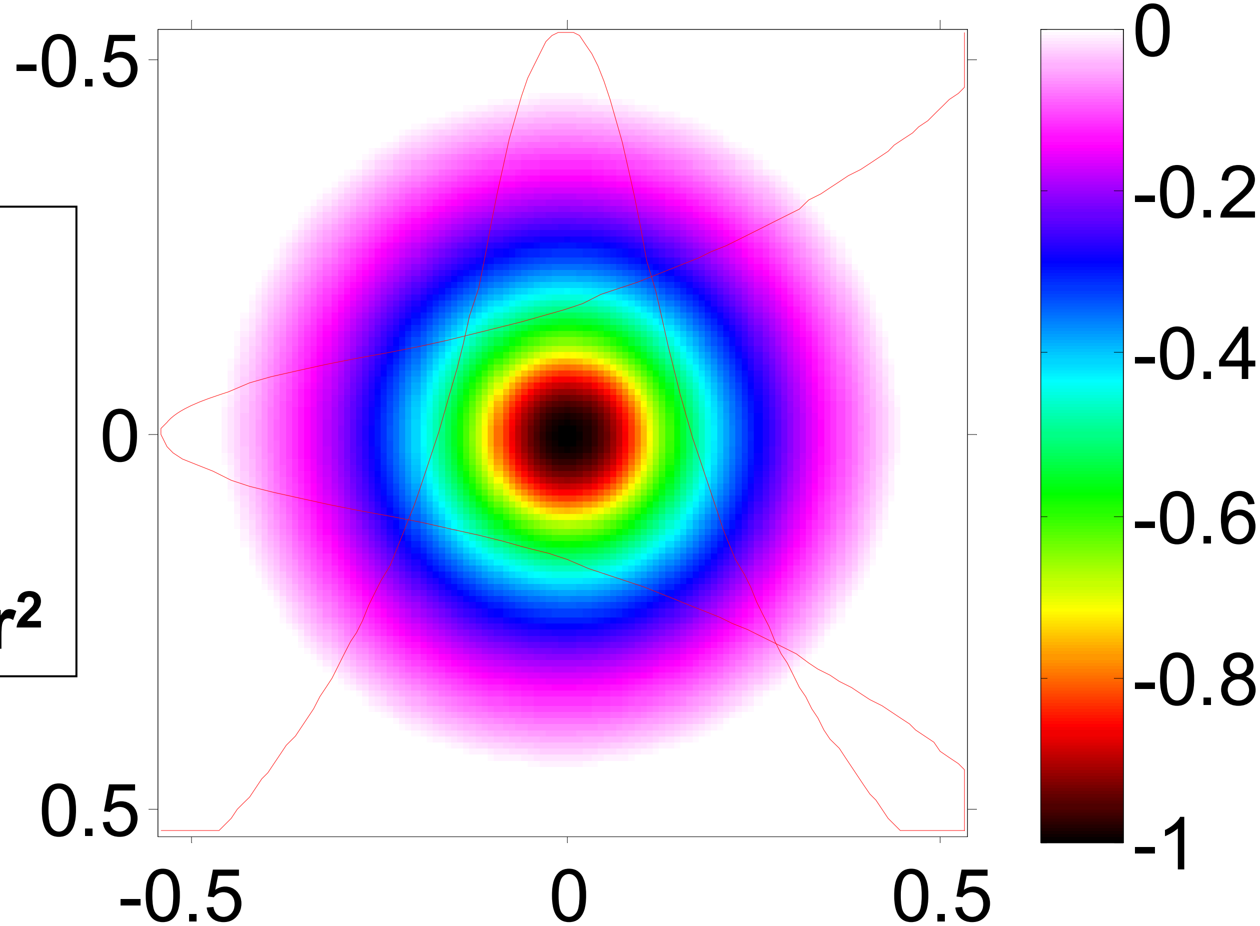
Membrane Influence Functions (IFs)

Ability to achieve high spatial frequencies falls off as ~1/r²



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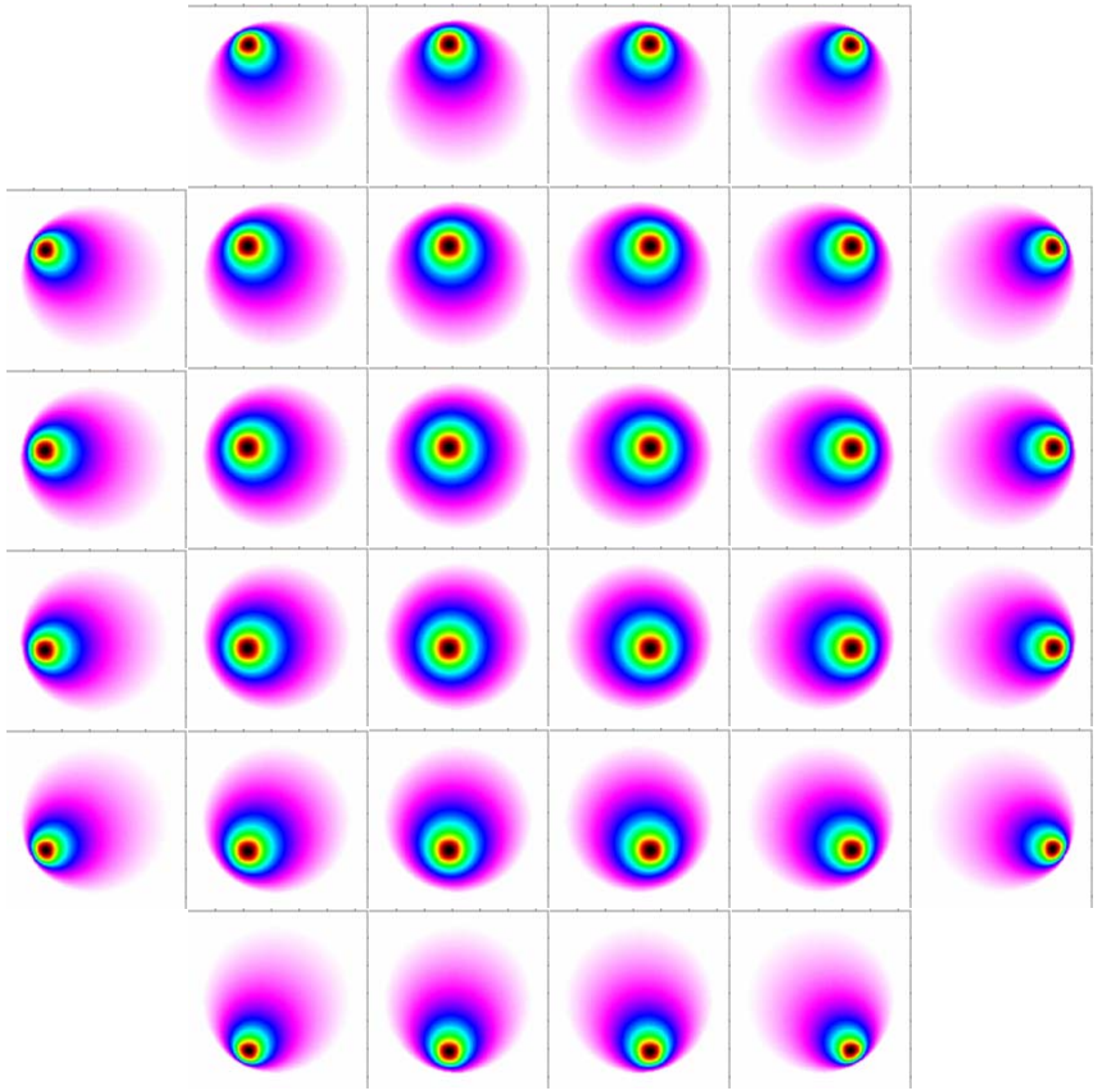
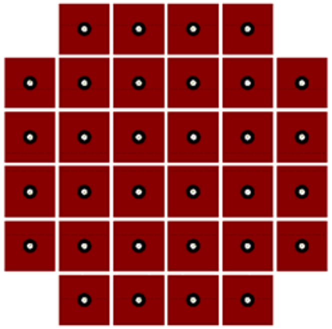
Square Grid Influence Functions





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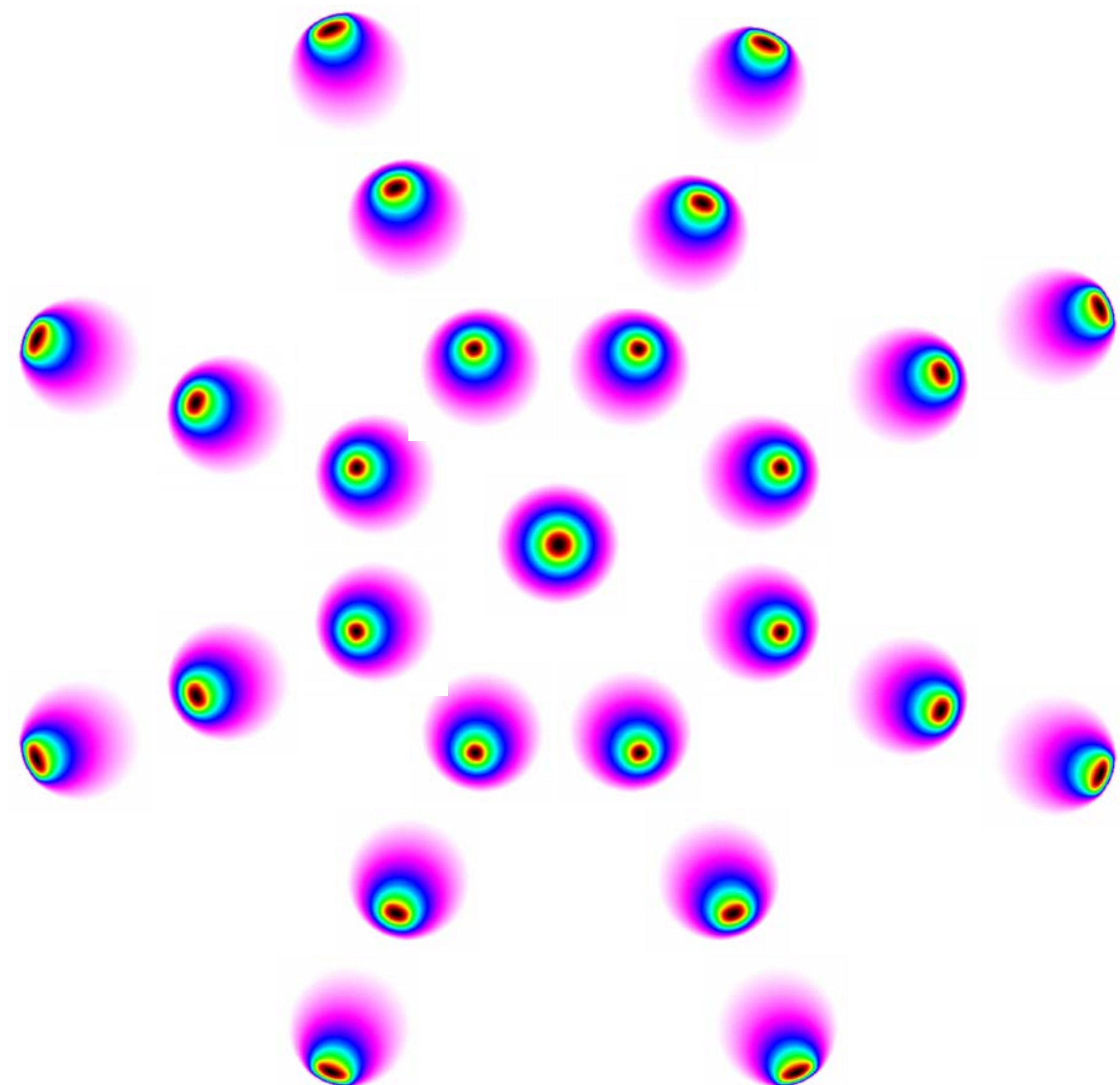
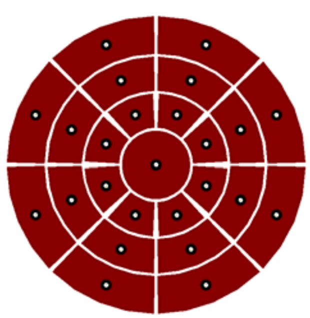
Annular Influence Functions





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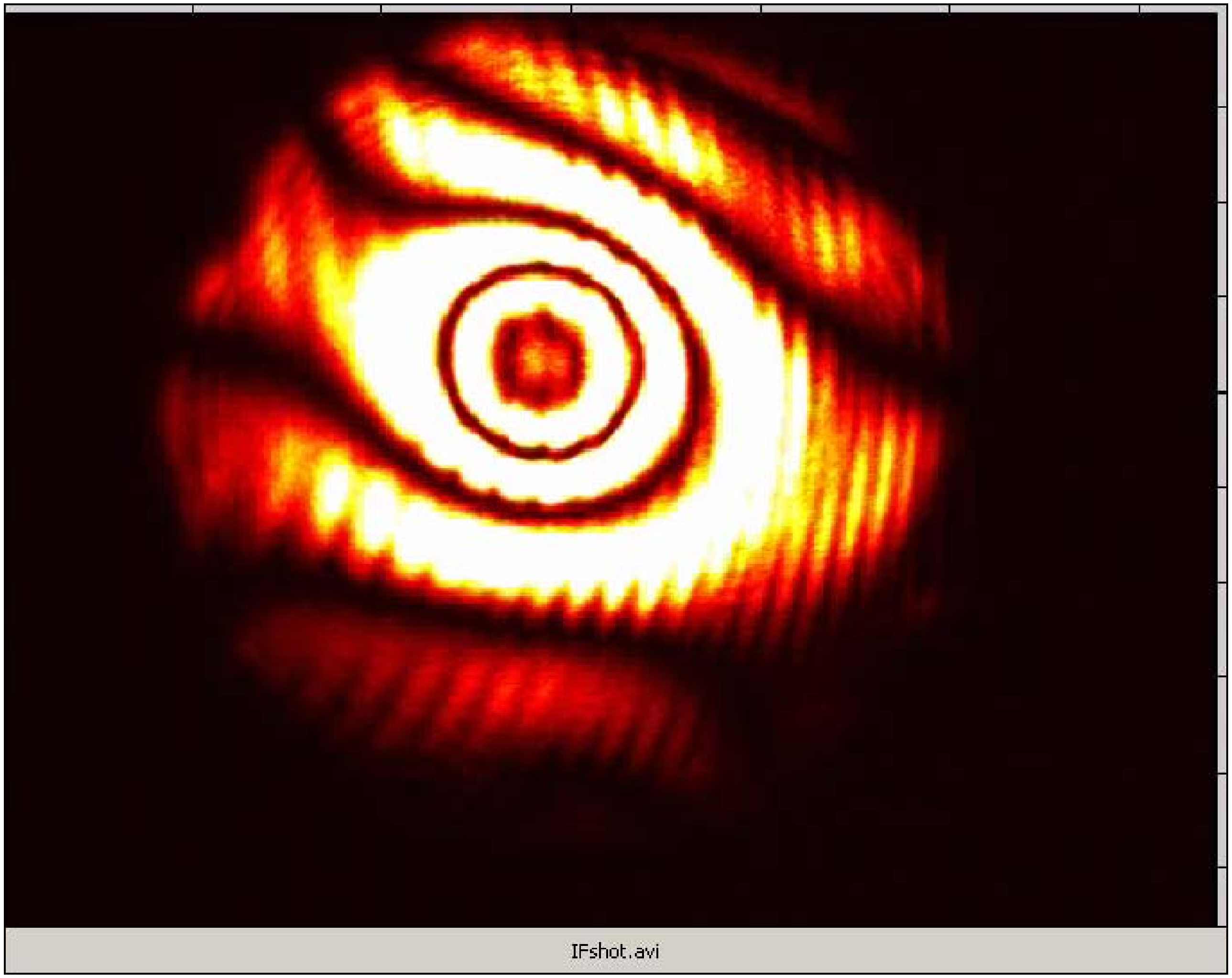
Measured Influence Functions



Each Actuator at ~300V Produces ~1 wave at 633nm

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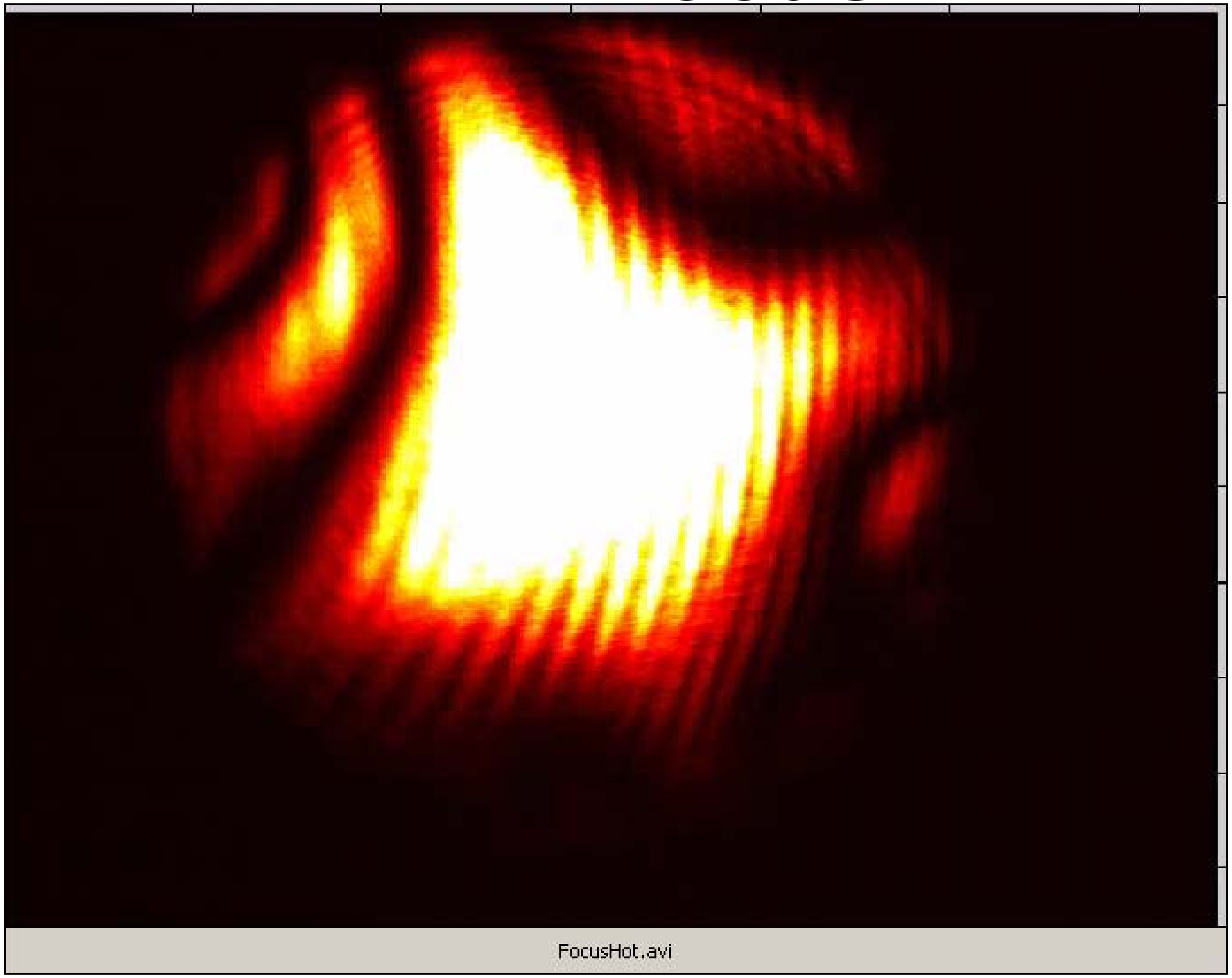
DM in Focus



NOTE: Imager is not exactly in the image plane.

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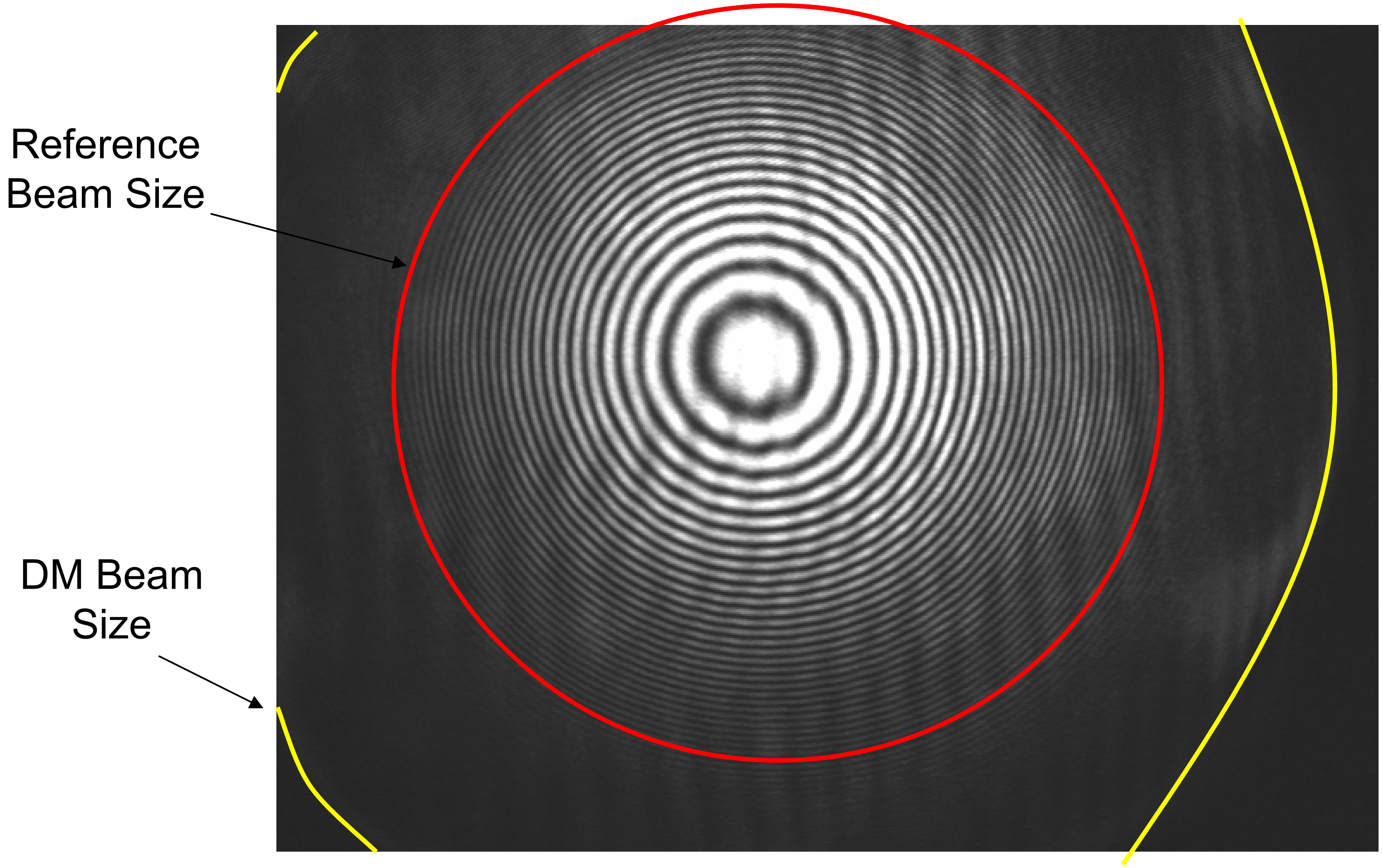
DM Max Focus



Estimated >20 µm of throw

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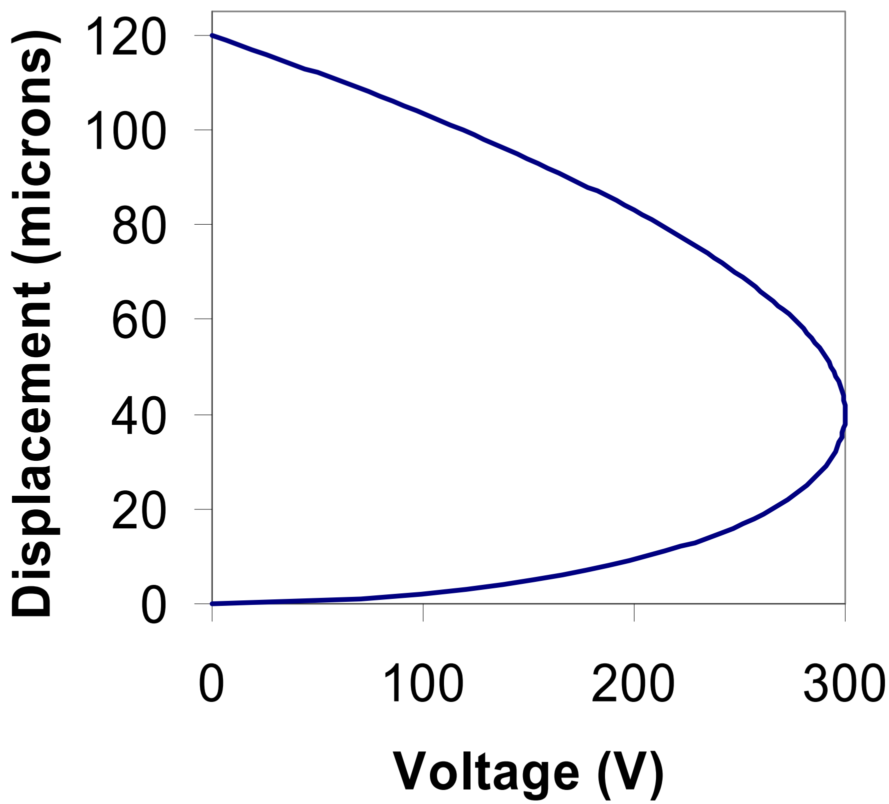
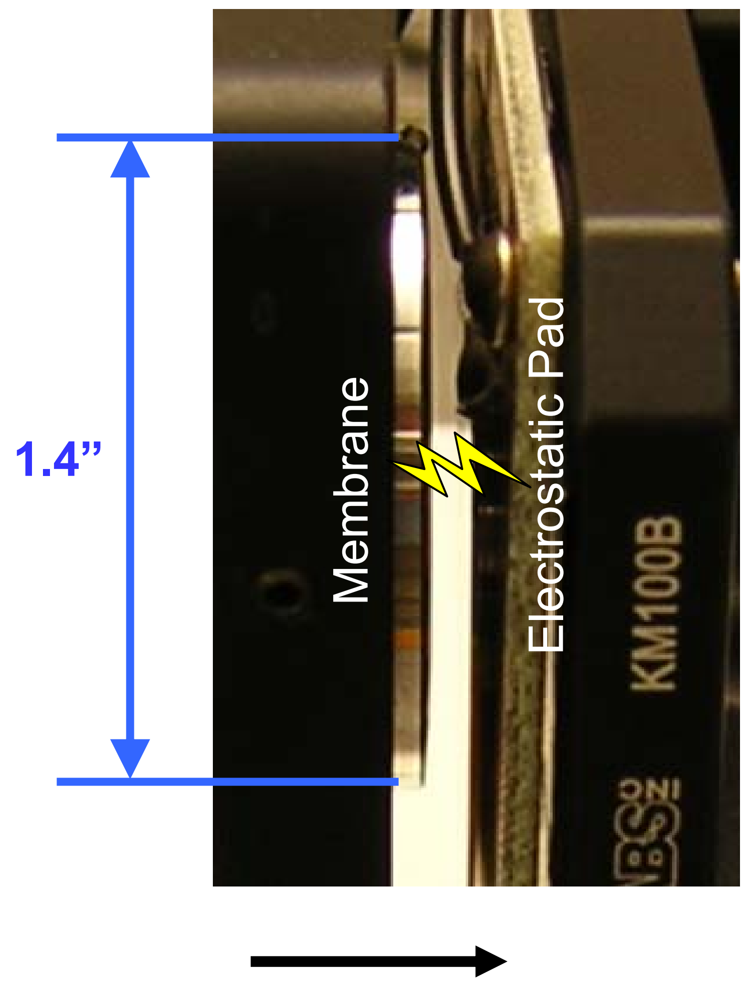
Electrostatic Snap-Down

Parallel Plate Snap-Down



Experiment



Translated under Bias

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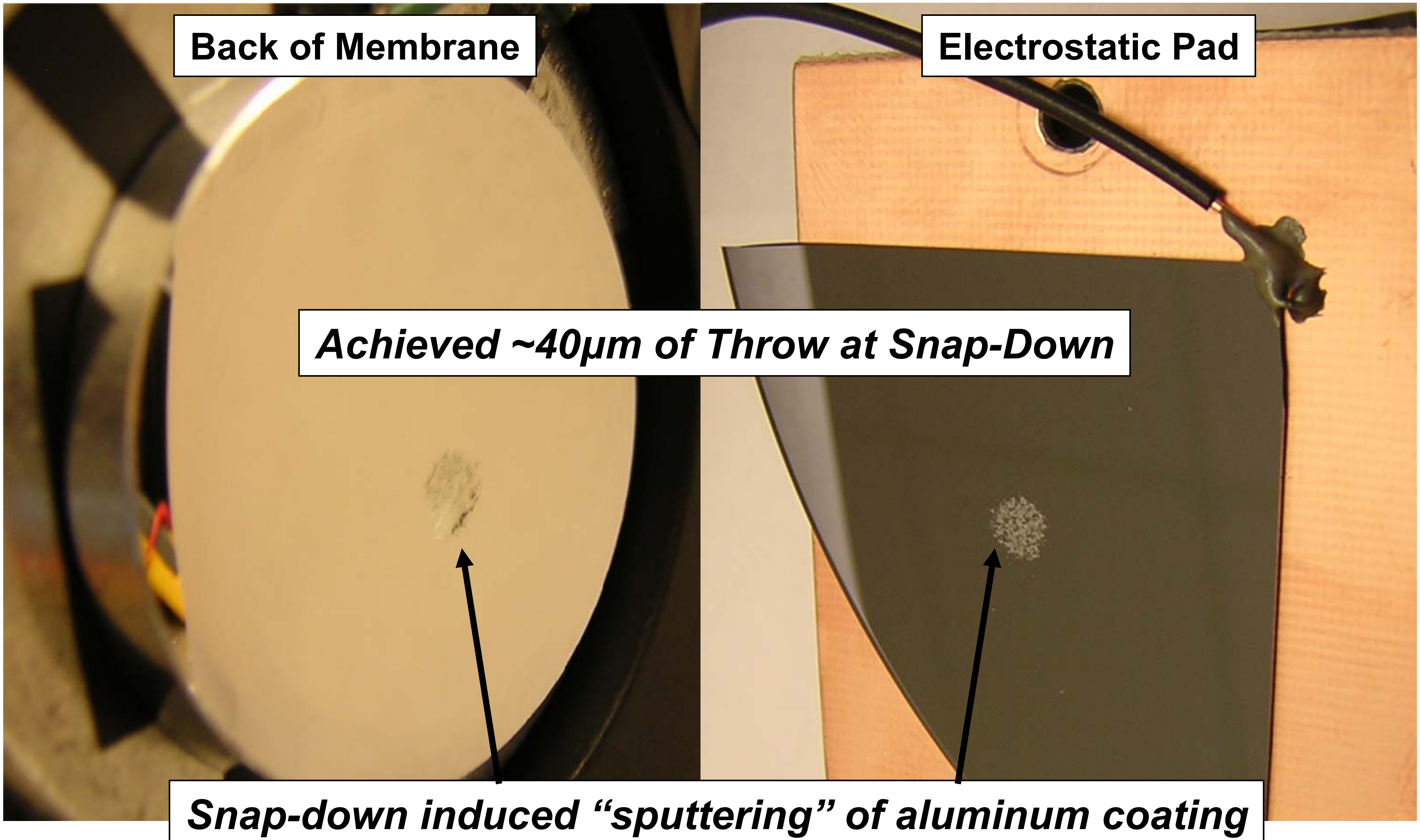
Snap-Down Results



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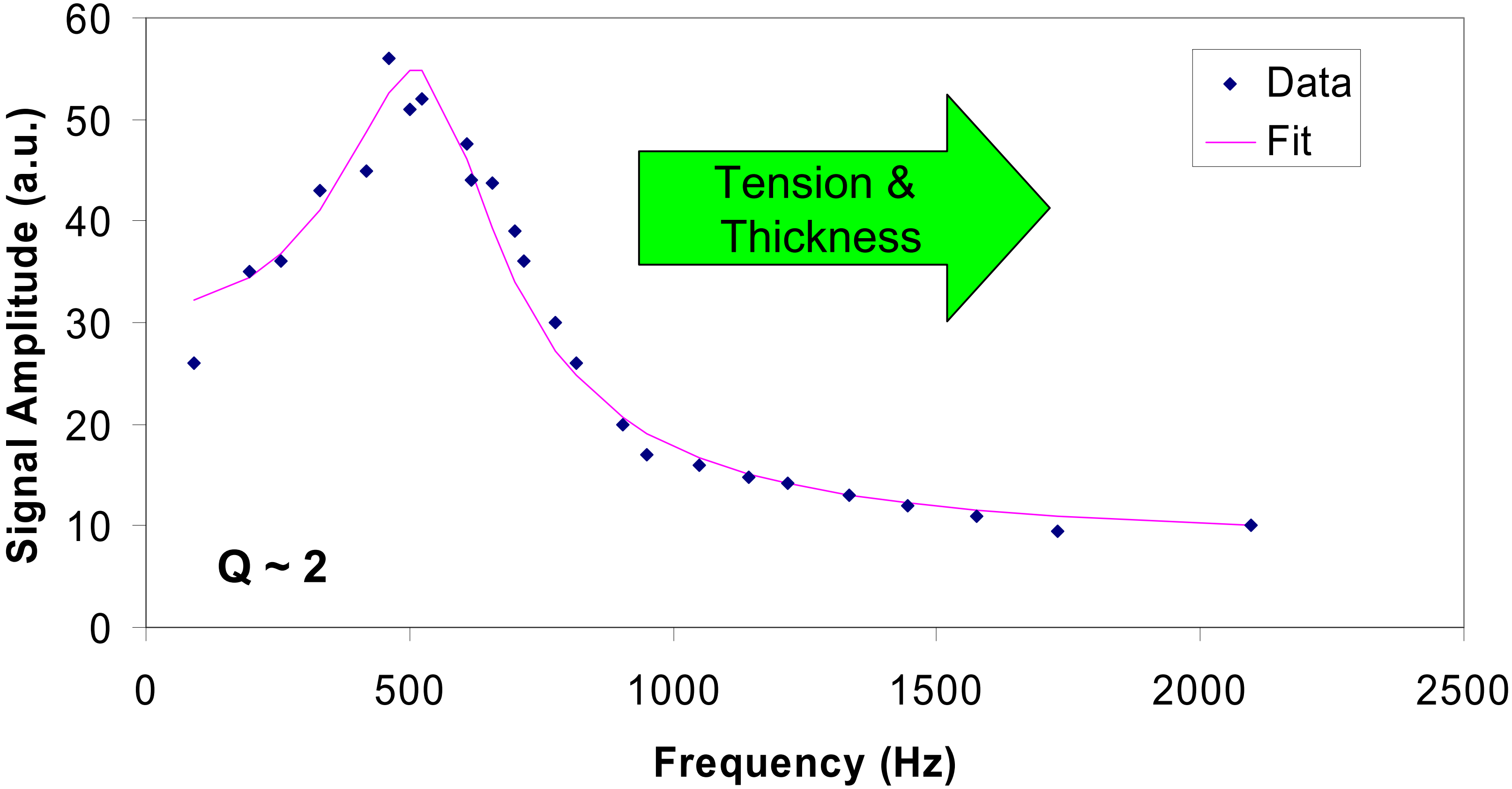
Resonance Frequency



Because the polymer membranes are currently hand assembled, the resonance frequency changes from device to device.

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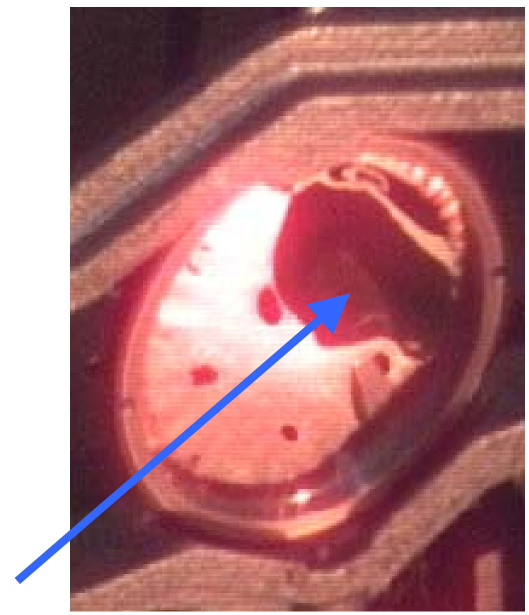
Pellicle Characteristics

- Wavefront Quality : λ/2 per inch
  - mostly in an astigmatic term
- Demonstrated high reflectivity coatings
  - Q-Switched damage at 3.3 J/cm^2 (235 MW/cm^2)
  - HR coated membrane demonstrated survivability under 12 kW CW 1064nm
- Available COTS up to 6" in Diameter

Polymer Membrane Under 12 kW CW 1-µm Light



Thermally Induced Distortion at 1s

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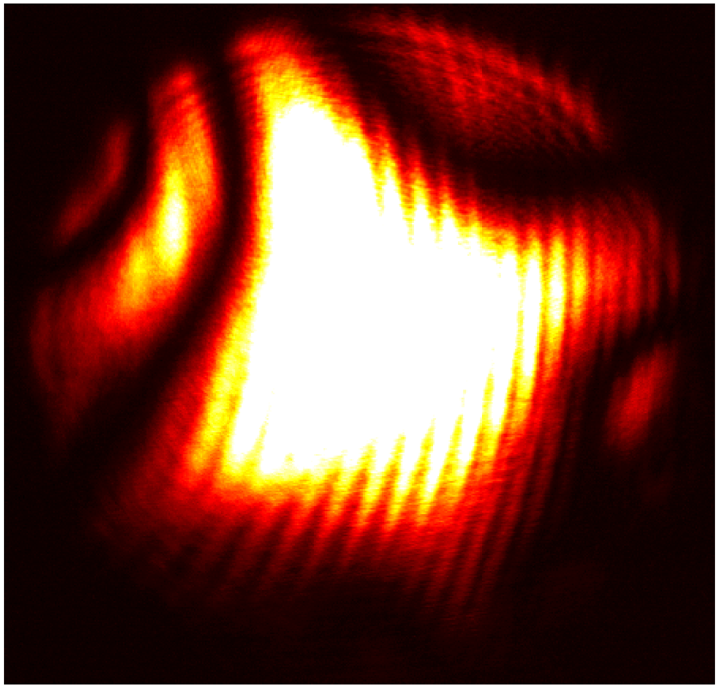
Static Aberrations

- Mounting the pellicle to the substrate can be tricky.
  - See Dave Dayton's results from yesterday
- We have developed a new mounting process at AOS that has dramatically reduced the aberration amplitude created by this process.



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Summary of Polymer Membrane DMs

Characteristic	Value
Resonance	~500 Hz
Throw	~40 µm (330VDC at Snap-Down)
Size	6” COTS Parts
Coatings	Metal & Dielectric Stacks (12kW cw 1064nm survived, 3.3 J/cm^2 Damage Threshold for Q-Switched)

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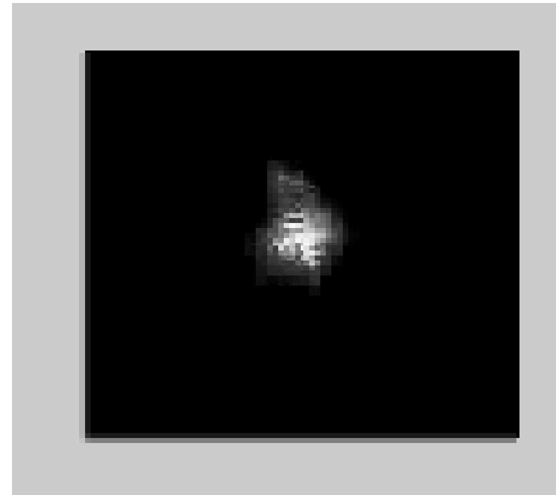
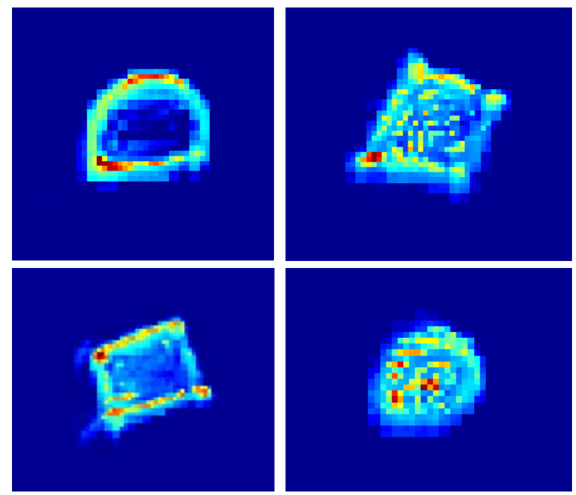
Potential Applications for Polymer Membrane DMs

- Good for:
  - Low-Order Quasi-Static Imaging and Laser Aberration Compensation
    - Telescopes, Microscopes, Laser Machining, etc.
  - Basic Laser Beam Shaping
- Maybe good for:
  - Vertical Path Atmospheric (Astronomy)
- Probably not good for:
  - Large Telescopes
  - Megawatt Class Lasers
  - Long Path Free-Space Optical Comm.





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Drive Electronics

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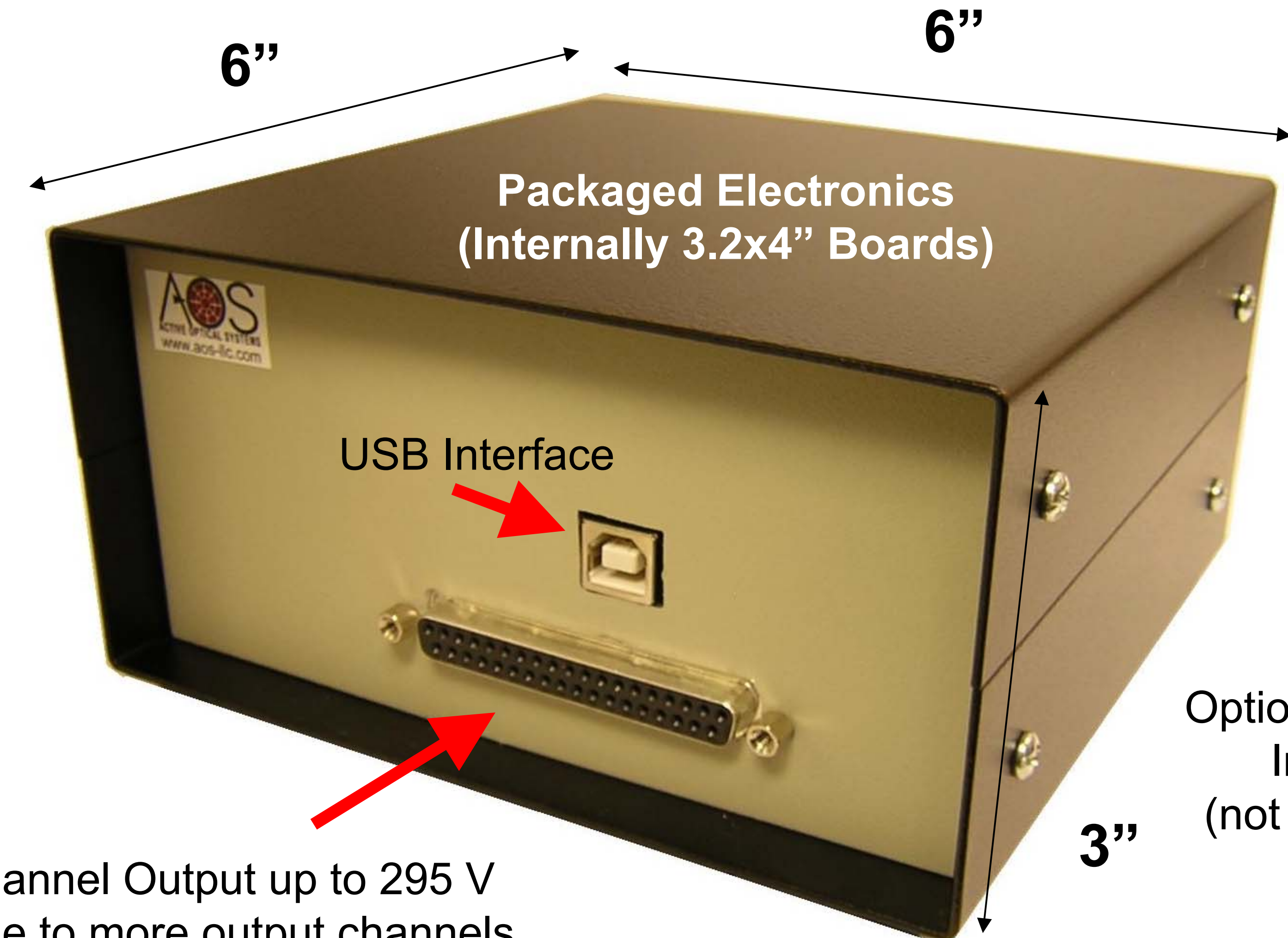
Drive Electronics



Optional BNC
Input
(not shown)

32-Channel Output up to 295 V
(scalable to more output channels
and from 8-bit to 16-bits in 2-bit increments)

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Converting the Drive Electronics into an AO Controller

- The USB interface chip we chose to use was an inexpensive (~$10) microcontroller that was designed for low-cost applications like toys.
- During the development, we discovered that it had integrated ADCs and sufficient computational capability to do metric adaptive optics.

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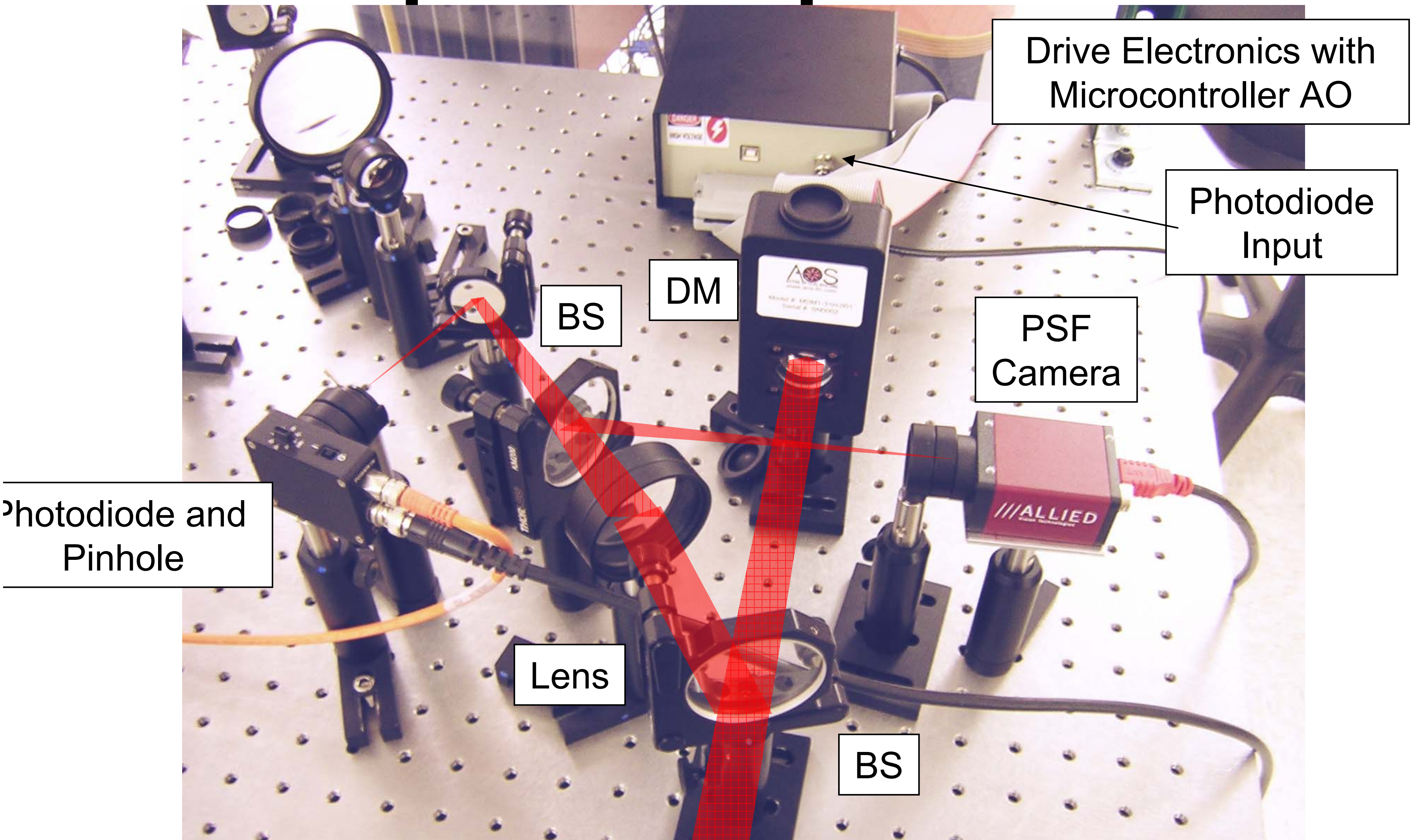
Optical Setup Picture



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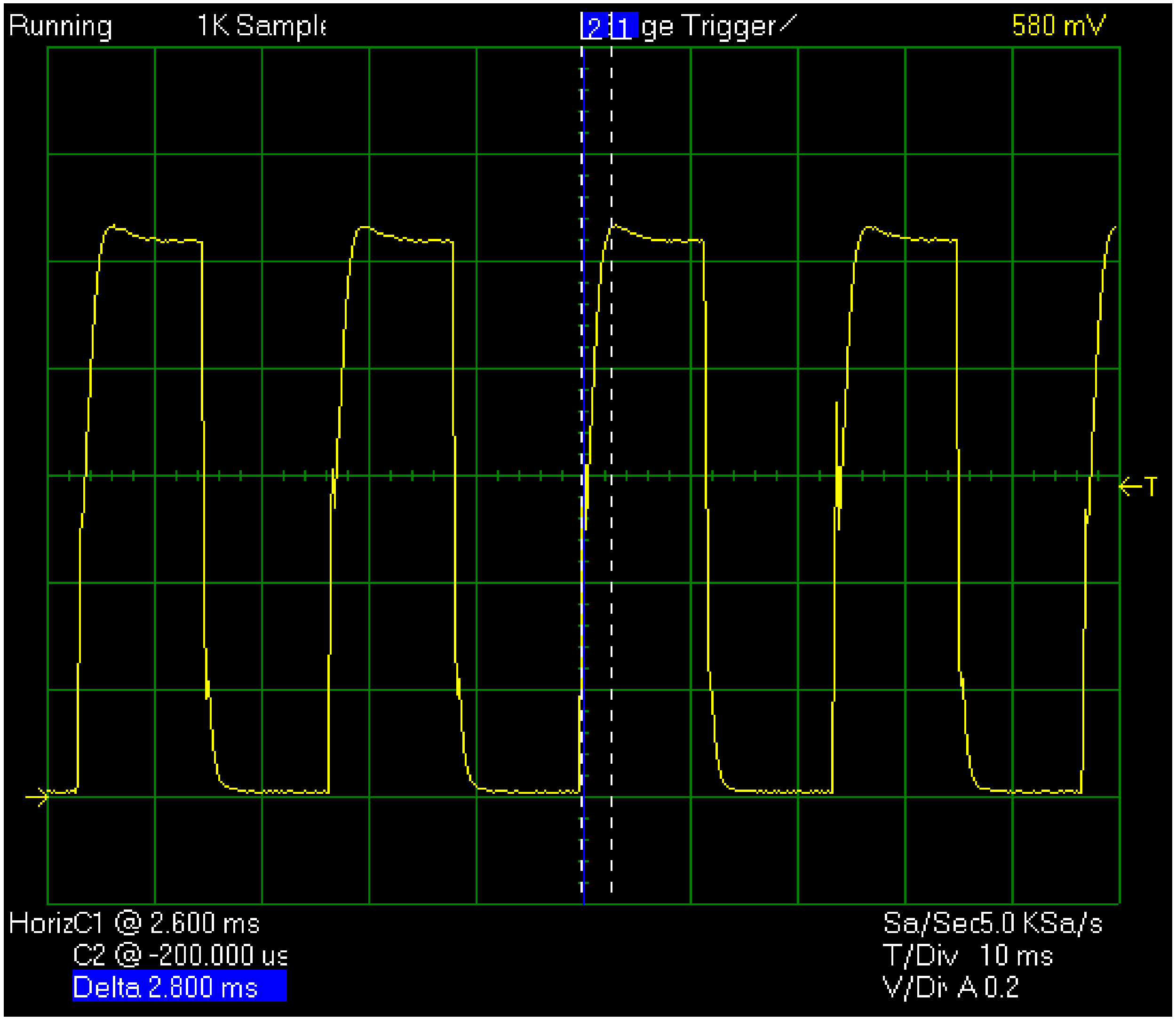
DM Rise and Fall Time

~2.8 ms
Rise Time



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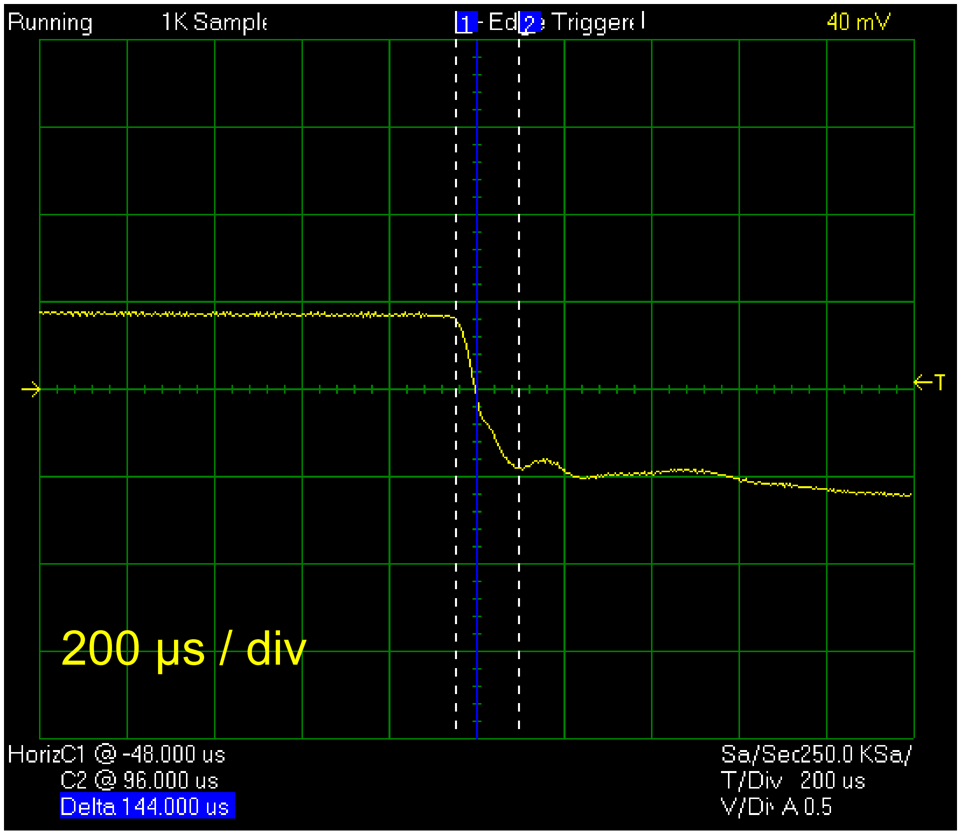
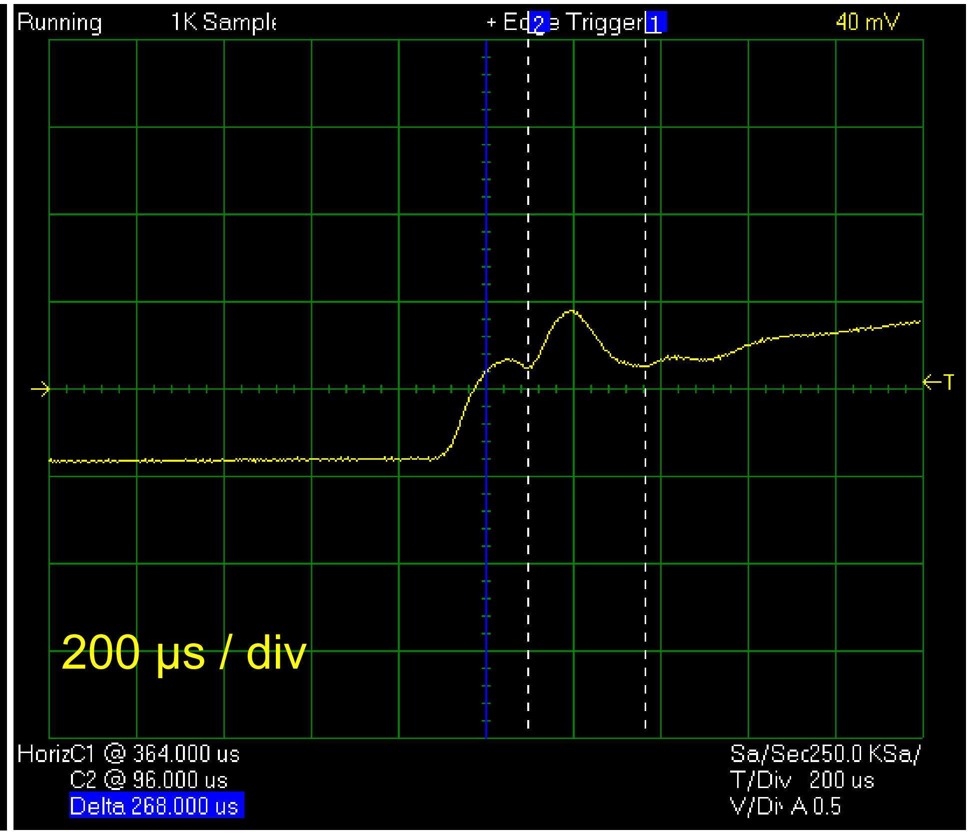
Rise Time



~10% to 90% Fall Time
= 144 µs



Rise Time Oscillation
~3.7 kHz

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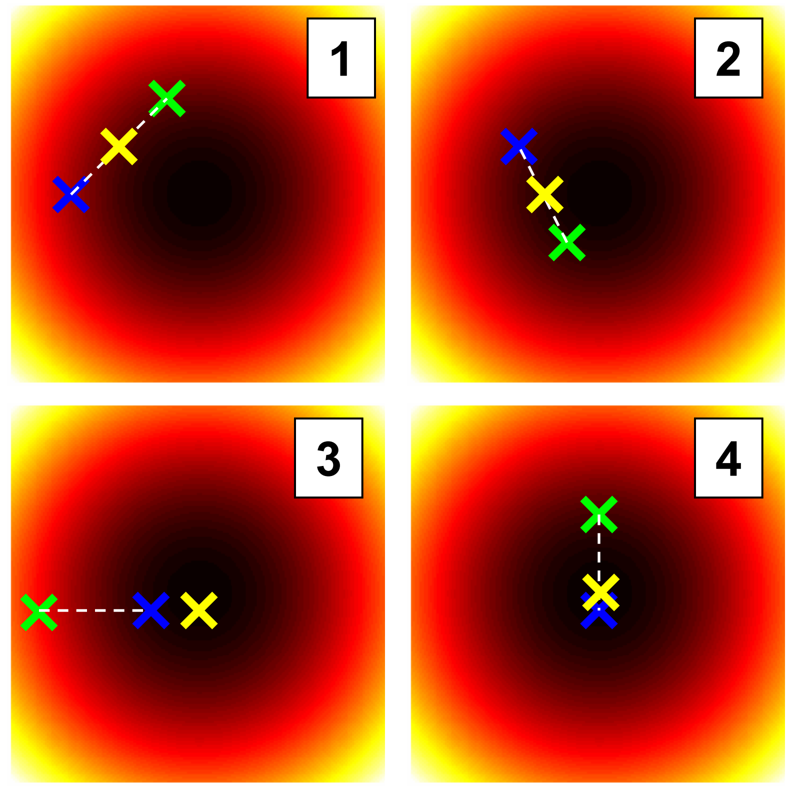
Stochastic Parallel Gradient Descent (SPGD) Algorithm

1. Start with a point in the error space.
2. Take a step in a random direction to another point.
3. Find the "optimum" position based on the gradient.
4. Repeat to 2



Starting Point
Trial Step (V')
Final Position (V'')

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SPGD Algorithm Math

Take a Random Trial Step

$$V' = V + dV$$

Step Size

where $dV = \Delta \bullet rand(N)$,

Δ is the maximum step size,

rand(...) is a random number

vector from -1 to +1, and

N is the number of actuators

Take a Step Based on the Trial Result

$$V'' = V + \eta\left(M_{initial} - M_{step}\right)dV$$

Gain

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Brute-Force Searching Algorithm

- Choose each actuator and scan over the entire 255 count range in 5 count intervals and set it to the best value.
- After scanning all the actuators, repeat the scan.

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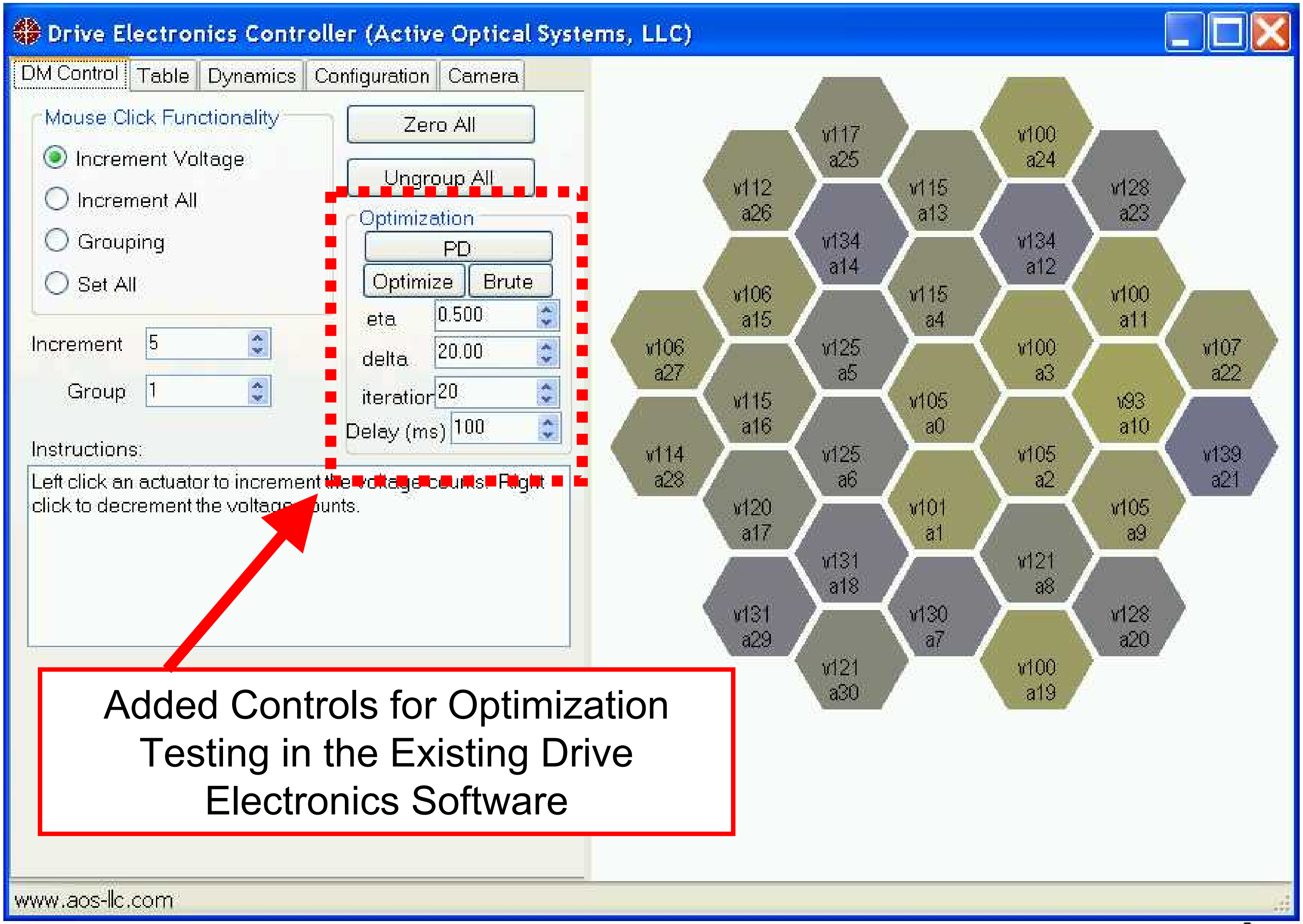
PC-Based Optimization



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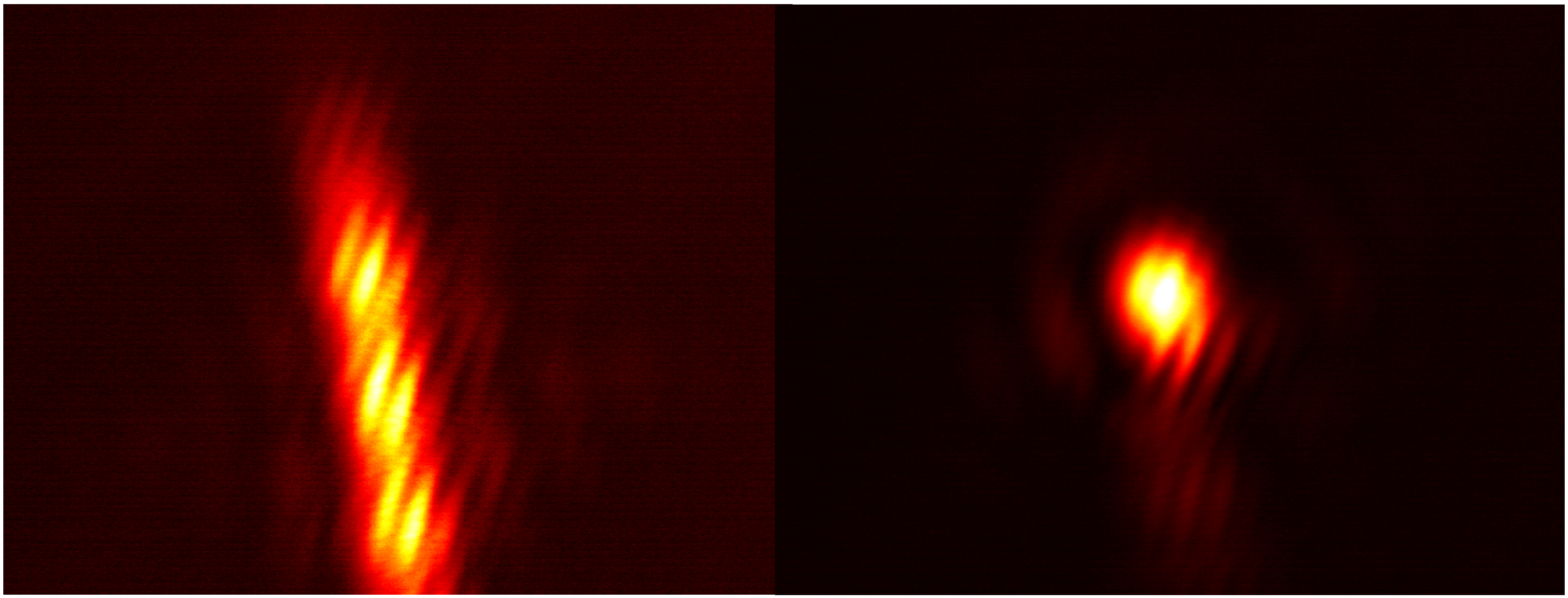
Typical Point Spread Functions

Before AO
(Mirror Under Optimal Focal Bias)

After AO



NOTE: Fringing due to the window on the camera

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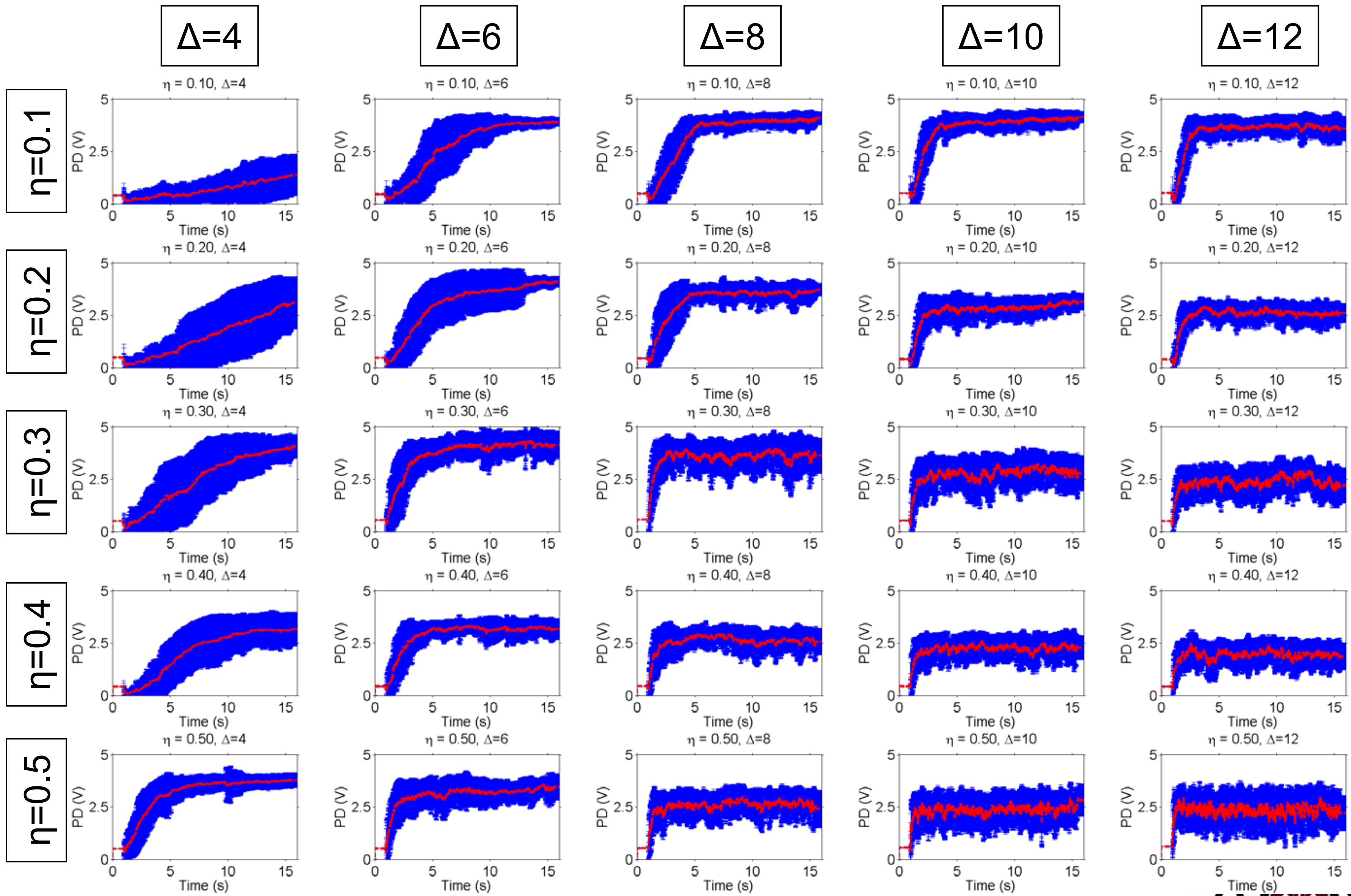
Average Results (30 ms delay, 20 averages, 16s)



Key: Average / Std. Dev.

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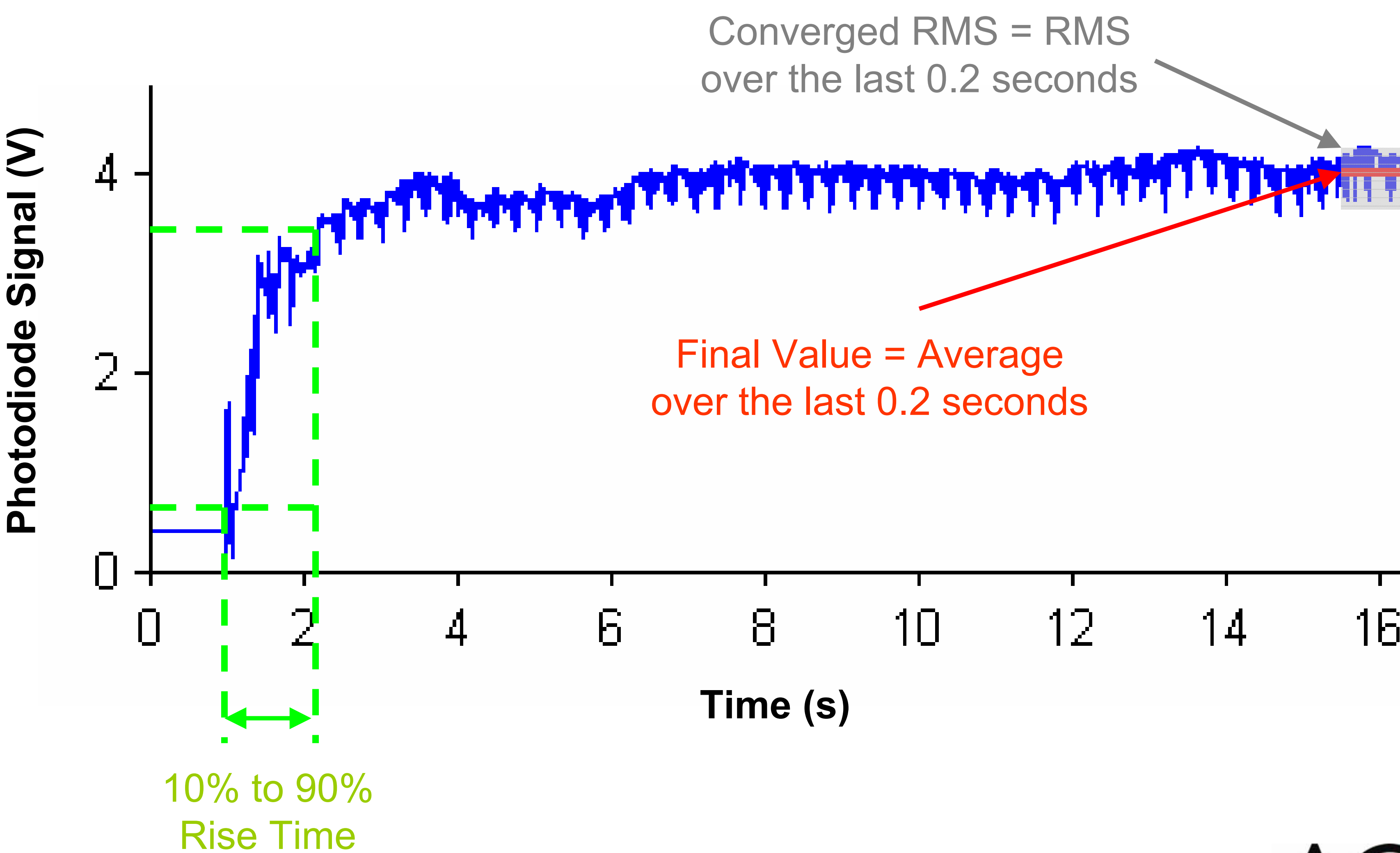
Definition of Output Parametrization



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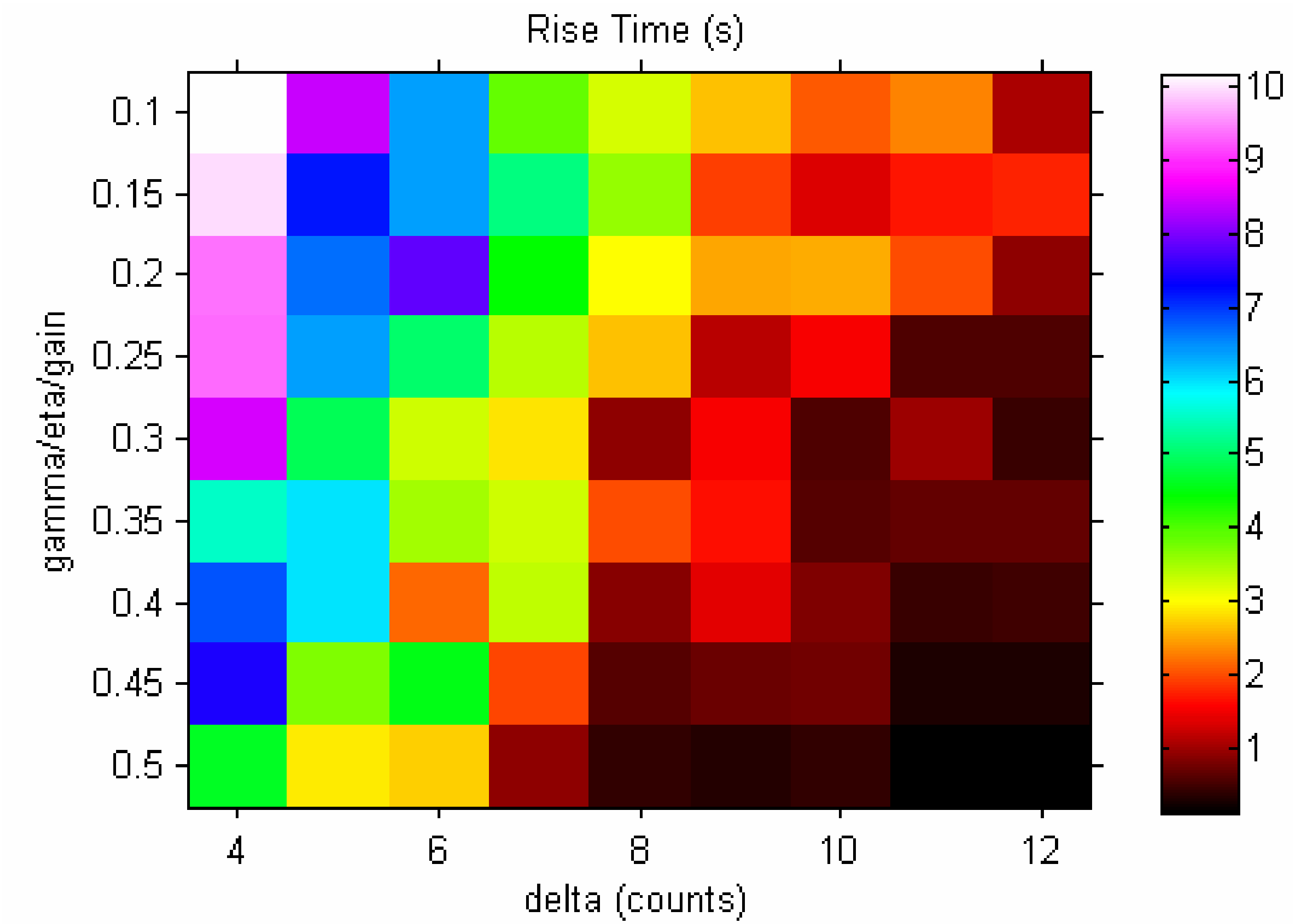
Rise Times (s)



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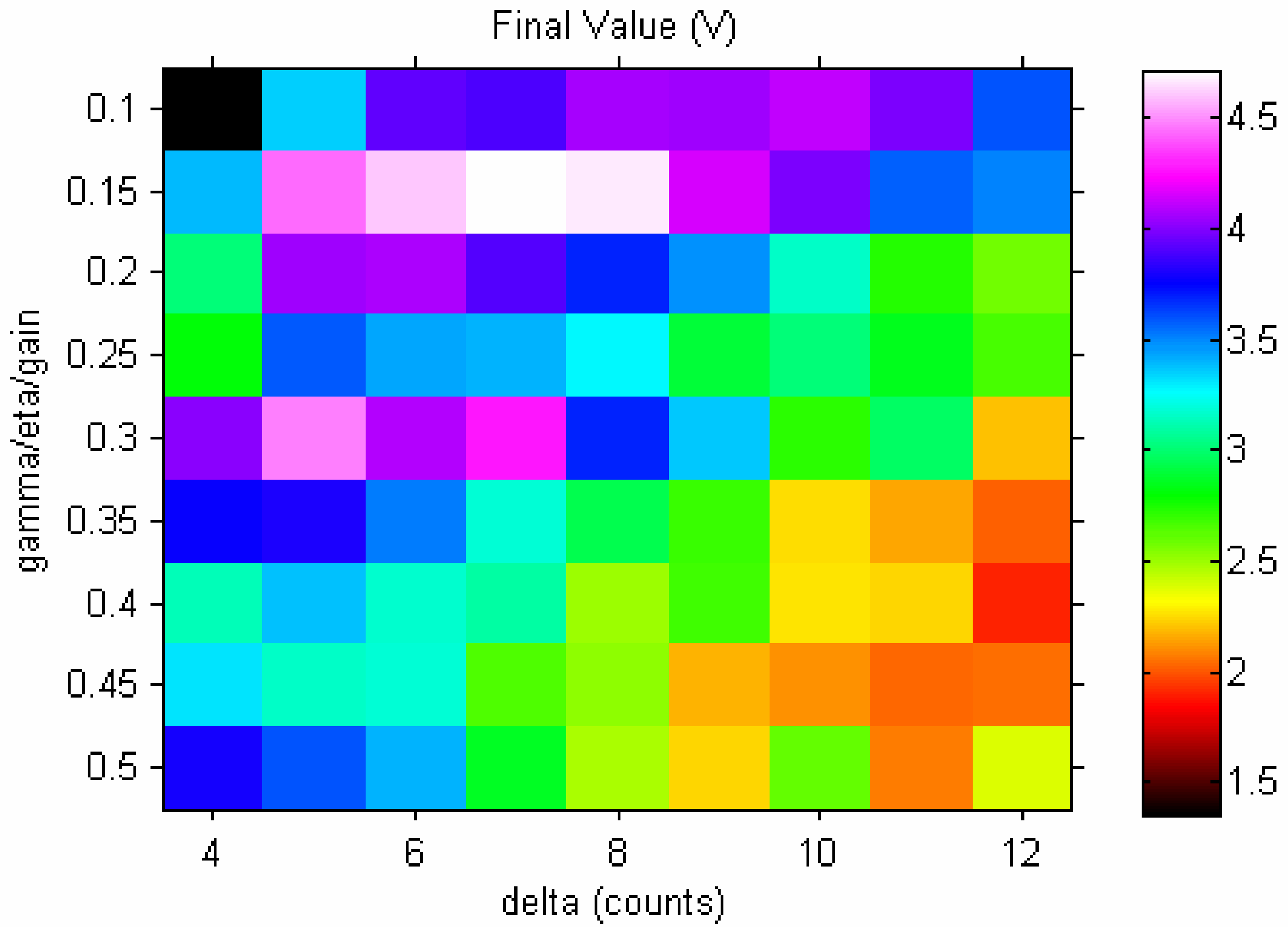
Converged Final Values (V)



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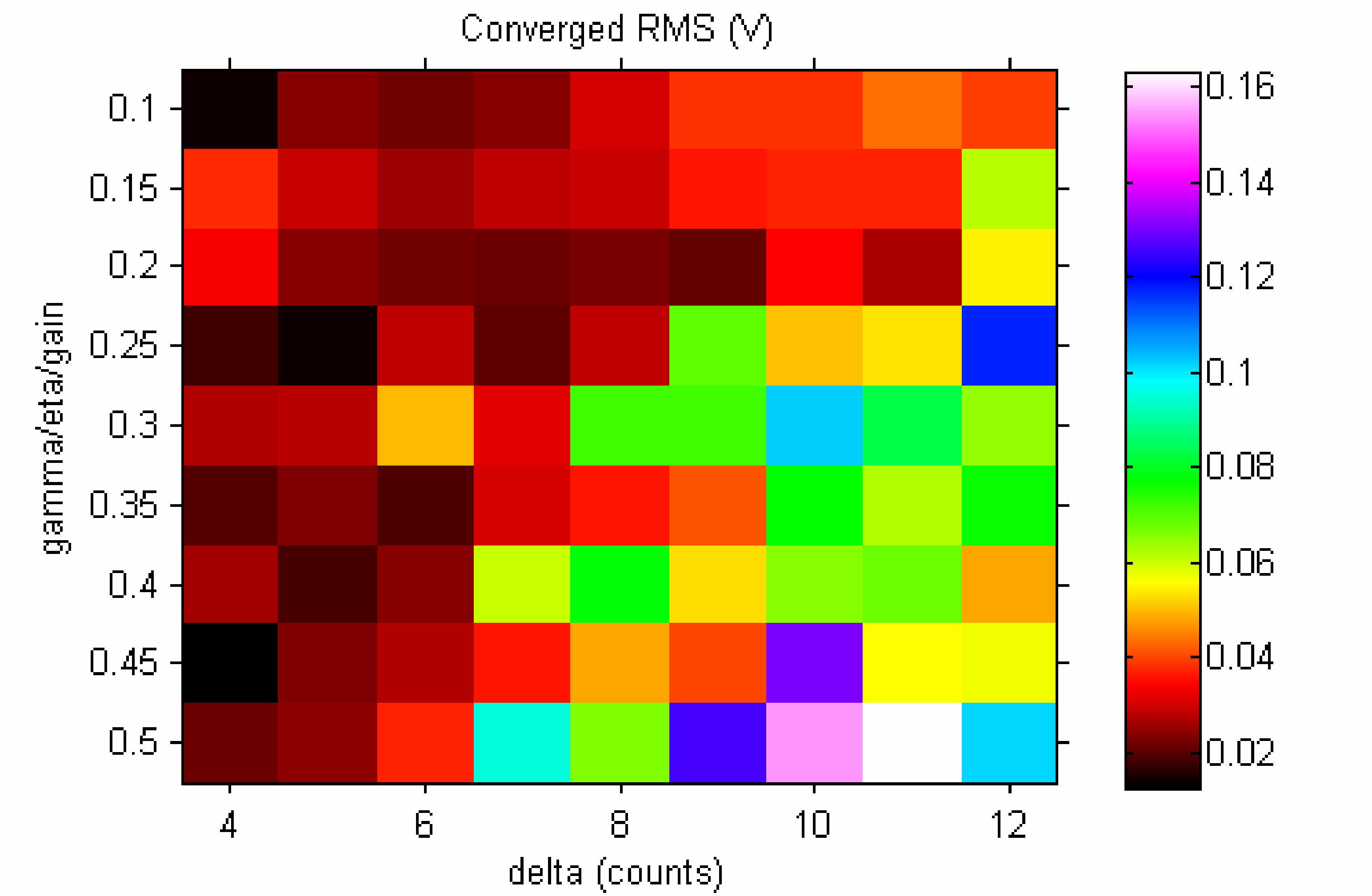
RMS after Converged (V)



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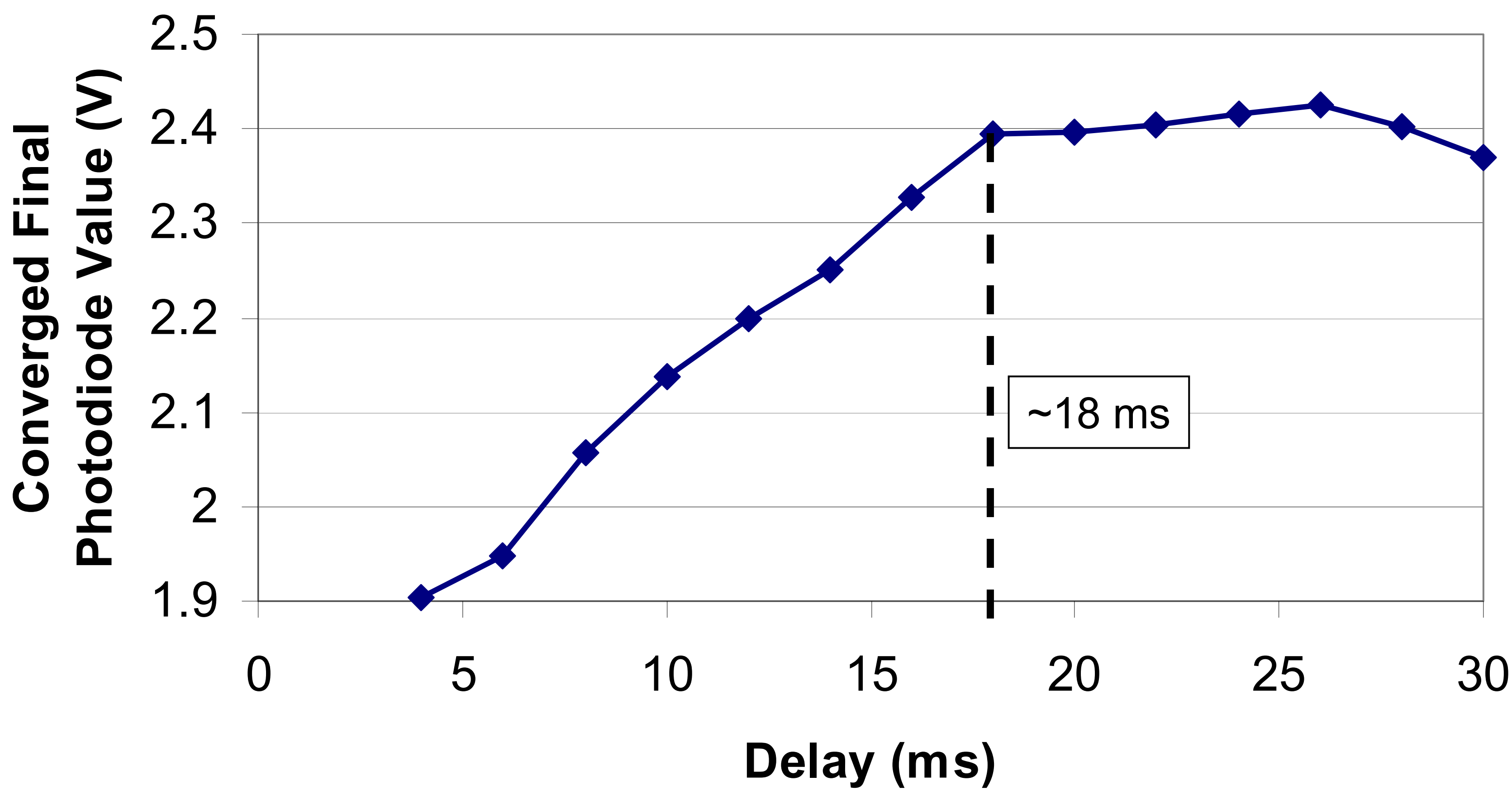
Effect of Sample Delay on Final Value



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Conclusions

- We have developed low cost:
  - DMs ($1,500)
  - USB Interfaced Drive Electronics ($5,000)
  - Metric Adaptive Optics Systems ($7,500)
- We characterized the parameters of our microcontroller SPGD metric AO system to find the effect of
  - the gain (η),
  - the step size (Δ),
  - and the measurement delay.

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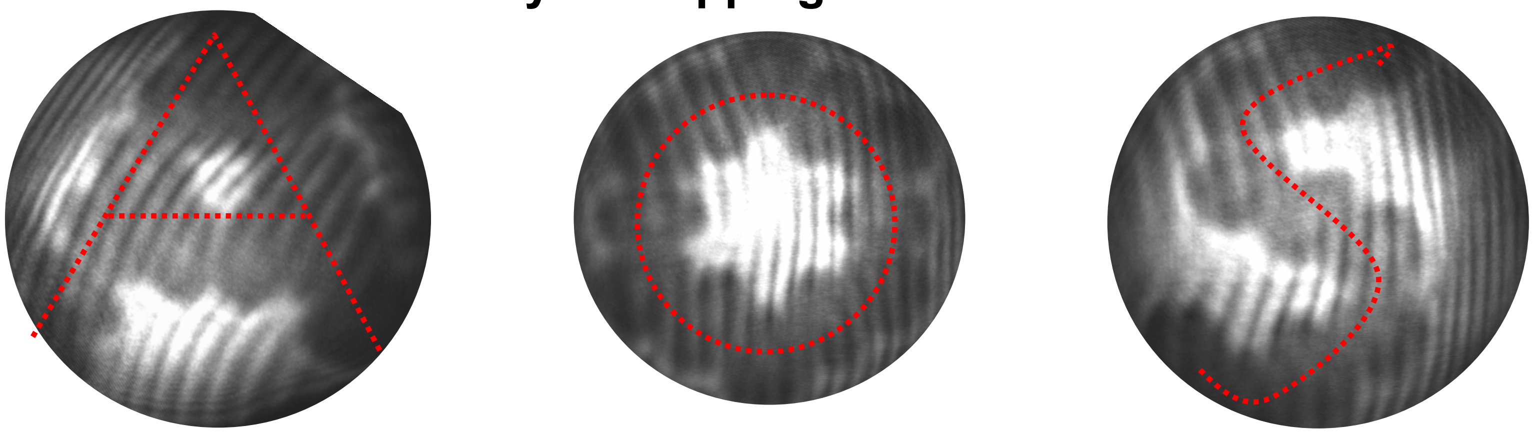
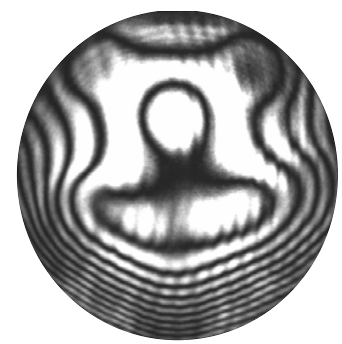
Intensity Remapping Demonstration



Questions?



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