

LIGHT BUCKET ASTRONOMY

Low-Cost Fixed and Bimorph Correctors

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Agenda

- ◆ Fixed Correctors
 - ◆ Spherical
 - ◆ Aspherics
 - ◆ Projection lenses
- ◆ Bimorph Secondary Project

Fixed Element Correctors

- ◆ Spherical aberration problem: LBTs may be $f/4$, $f/2$, even $f/1$
- ◆ One & two spherical lens designs (off-the-shelf) considered
- ◆ Slumped meniscus
- ◆ Projection lenses with aspherics

Dave Rowe's 1-m, f/4 Corrector

<input type="button" value="Optimize"/> Statistics 437/7281 Error 19.116 um	Curvature <input type="text" value="1e-5"/> SC <input type="text" value="0.001"/> Spacing <input type="text" value="0.2"/> Corrector <input type="text" value="0.002"/>	<input type="button" value="Trace"/> <input checked="" type="checkbox"/> Auto Focus Polychromatic	EFL 4046.5 f/D 4.047	Wavelengths (nm) Red <input type="text" value="750"/> Green <input type="text" value="550"/> Blue <input type="text" value="420"/>	FOV <input type="text" value="0.2"/> <input type="button" value="Auto Scale"/> 1.02" per
0 Object Distance <input type="text" value="1e20"/> Diameter <input type="text" value="1000"/> Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt	4 Focal Surface Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt				Off-axis Angle (deg) <input type="text" value="0"/> Off-axis Distance <input type="text" value="0"/> Trans (%) 100 RMS Size 4.004e-4 Optimizer Weight <input type="text" value="1"/>
1 Mirror Radius <input type="text" value="7950"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="1000"/> Spacing <input type="text" value="3700"/> <input type="checkbox"/> Opt				Off-axis Angle (deg) <input type="text" value="0.05"/> Off-axis Distance 3.546 Trans (%) 100 RMS Size 0.01993 Optimizer Weight <input type="text" value="1"/>	
2 Lens BK7 Radius 1 <input type="text" value="-139.98"/> <input checked="" type="checkbox"/> Opt Thickness <input type="text" value="5"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="-228.803"/> <input checked="" type="checkbox"/> Opt Diameter <input type="text" value="75"/> Spacing <input type="text" value="1"/> <input type="checkbox"/> Opt				Off-axis Angle (deg) <input type="text" value="0.0715"/> Off-axis Distance 5.068 Trans (%) 97.79 RMS Size 0.03702 Optimizer Weight <input type="text" value="1"/>	
3 Lens BK7 Radius 1 <input type="text" value="80.2317"/> <input checked="" type="checkbox"/> Opt Thickness <input type="text" value="6"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="98.4438"/> <input checked="" type="checkbox"/> Opt Diameter <input type="text" value="75"/> Spacing <input type="text" value="269.833"/> <input type="checkbox"/> Opt					

Tong Liu's f/4 design on f/2 8"

<input type="button" value="Optimize"/>		Curvature <input type="text" value="1e-6"/> SC <input type="text" value="0.001"/> Spacing <input type="text" value="0.05"/> Corrector <input type="text" value="0.002"/>	<input type="button" value="Trace"/>	EFL <input type="text" value="407.24"/> f/D <input type="text" value="2.036"/>	Red <input type="text" value="750"/> nm Green <input type="text" value="550"/> nm Blue <input type="text" value="420"/> nm	FOV <input type="text" value="0.15"/>	<input type="button" value="Auto Scale"/>	<input type="text" value="7.6"/> per
Stats <input type="text" value="1/351"/> Error <input type="text" value="19.494 um"/>		<input type="checkbox"/> Auto Focus Polychromatic				Angle (deg) <input type="text" value="0"/>		
0 Object Distance <input type="text" value="1e20"/> Diameter <input type="text" value="200"/> Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt		Optical Layout <input type="button" value="Fit On Screen"/> <input checked="" type="checkbox"/> Angle0 <input checked="" type="checkbox"/> Angle1 <input checked="" type="checkbox"/> Angle2		Rays <input type="text" value="10"/>		Distance <input type="text" value="0"/>		
1 Mirror Radius <input type="text" value="800"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="200"/> Spacing <input type="text" value="348.38"/> <input checked="" type="checkbox"/> Opt				Weight <input type="text" value="0.7"/>		RMS Diam <input type="text" value="0.02576"/>		
2 Lens BK7 Radius 1 <input type="text" value="-64.6"/> <input type="checkbox"/> Opt Thickness <input type="text" value="5"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="1e20"/> <input type="checkbox"/> Opt Diameter <input type="text" value="50"/> Spacing <input type="text" value="0.5"/> <input type="checkbox"/> Opt				Angle (deg) <input type="text" value="0.05"/>	Distance <input type="text" value="0.3725"/>			
3 Lens BK7 Radius 1 <input type="text" value="64.6"/> <input type="checkbox"/> Opt Thickness <input type="text" value="10"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="1e20"/> <input type="checkbox"/> Opt Diameter <input type="text" value="50"/> Spacing <input type="text" value="43.683"/> <input checked="" type="checkbox"/> Opt				Angle (deg) <input type="text" value="0.07"/>	Distance <input type="text" value="0.5214"/>			
4 Focal Surface Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt						Trans (%) <input type="text" value="100"/>		
						RMS Diam <input type="text" value="0.03893"/>		
						Weight <input type="text" value="1"/>		
						RMS Diam <input type="text" value="0.04831"/>		
						Weight <input type="text" value="1"/>		

1-m f/4 BK4

Optimize	Curvature <input type="text" value="1e-6"/> SC <input type="text" value="0.001"/> Spacing <input type="text" value="0.05"/> Corrector <input type="text" value="0.002"/>	Trace <input type="checkbox"/> Auto Focus Polychromatic	EFL 5159.9 f/D 5.16	Red <input type="text" value="750"/> nm Green <input type="text" value="550"/> nm Blue <input type="text" value="420"/> nm	FOV <input type="text" value="0.2"/> Auto Scale 0.799" per	
Stats 54/41486 Error 25.081 um					Angle (deg) <input type="text" value="0"/> Distance <input type="text" value="0"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.03611"/> Weight <input type="text" value="0.7"/>	
0 Object Distance <input type="text" value="1e20"/> Diameter <input type="text" value="1000"/> Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt	<div style="border: 1px solid gray; padding: 5px;"> Optical Layout <div style="display: flex; justify-content: space-between; align-items: center;"> Fit On Screen <input checked="" type="checkbox"/> Angle0 <input checked="" type="checkbox"/> Angle1 <input checked="" type="checkbox"/> Angle2 Rays </div> </div>					
1 Mirror Radius <input type="text" value="7950"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="1000"/> Spacing <input type="text" value="3721.47"/> <input checked="" type="checkbox"/> Opt					Angle (deg) <input type="text" value="0.05"/> Distance <input type="text" value="4.531"/> Trans (%) <input type="text" value="96.08"/> RMS Diam <input type="text" value="0.04475"/> Weight <input type="text" value="1"/>	
2 Conic Lens BK7 Radius 1 <input type="text" value="-37.0143"/> <input checked="" type="checkbox"/> Opt SC 1 <input type="text" value="-0.715204"/> <input checked="" type="checkbox"/> Opt Thickness <input type="text" value="10.3015"/> <input checked="" type="checkbox"/> Opt Radius 2 <input type="text" value="-42.2732"/> <input checked="" type="checkbox"/> Opt SC 2 <input type="text" value="-0.666619"/> <input checked="" type="checkbox"/> Opt Diameter <input type="text" value="80"/> Spacing <input type="text" value="351.79"/> <input checked="" type="checkbox"/> Opt					Angle (deg) <input type="text" value="0.07"/> Distance <input type="text" value="6.343"/> Trans (%) <input type="text" value="92.65"/> RMS Diam <input type="text" value="0.0654"/> Weight <input type="text" value="1"/>	
3 Focal Surface Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt					Angle (deg) <input type="text" value="0.07"/> Distance <input type="text" value="6.343"/> Trans (%) <input type="text" value="92.65"/> RMS Diam <input type="text" value="0.0654"/> Weight <input type="text" value="1"/>	

1-m f/4 Plastic

<p>Optimize</p> <p>Statistics 0/122 Error 77.051 um</p>	<p>Curvature <input type="text" value="1e-5"/></p> <p>SC <input type="text" value="0.001"/></p> <p>Spacing <input type="text" value="0.2"/></p> <p>Corrector <input type="text" value="0.002"/></p>	<p>Trace</p> <p><input type="checkbox"/> Auto Focus Polychromatic</p>	<p>EFL 4706 f/D 4.706</p>	<p>Wavelengths (nm)</p> <p>Red <input type="text" value="656.3"/></p> <p>Green <input type="text" value="587.6"/></p> <p>Blue <input type="text" value="486.1"/></p>	<p>FOV <input type="text" value="1"/> Auto Scale 4.38" per </p>
<p>0 Object</p> <p>Distance <input type="text" value="1e20"/></p> <p>Diameter <input type="text" value="1000"/></p> <p>Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt</p>	<div style="border: 1px solid gray; padding: 5px;"> <p>Optical Layout</p> <p>Fit On Screen <input checked="" type="checkbox"/> Angle0 <input checked="" type="checkbox"/> Angle1 <input checked="" type="checkbox"/> Angle2</p> </div>			<p>Off-axis Angle (deg) <input type="text" value="0"/></p> <p>Off-axis Distance <input type="text" value="0"/></p> <p>Trans (%) <input type="text" value="100"/></p> <p>RMS Size 0.06108</p> <p>Optimizer Weight <input type="text" value="1"/></p>	
<p>1 Mirror</p> <p>Radius <input type="text" value="7950"/> <input type="checkbox"/> Opt</p> <p>SC <input type="text" value="0"/> <input type="checkbox"/> Opt</p> <p>Diameter <input type="text" value="1000"/></p> <p>Spacing <input type="text" value="3705.32"/> <input checked="" type="checkbox"/> Opt</p>				<p>Off-axis Angle (deg) <input type="text" value="0.05"/></p> <p>Off-axis Distance <input type="text" value="4.191"/></p> <p>Trans (%) <input type="text" value="100"/></p> <p>RMS Size 0.09321</p> <p>Optimizer Weight <input type="text" value="0.5"/></p>	
<p>2 Lens PBH3</p> <p>Radius 1 <input type="text" value="-140"/> <input type="checkbox"/> Opt</p> <p>Thickness <input type="text" value="20"/> <input type="checkbox"/> Opt</p> <p>Radius 2 <input type="text" value="-160"/> <input type="checkbox"/> Opt</p> <p>Diameter <input type="text" value="150"/></p> <p>Spacing <input type="text" value="324.624"/> <input checked="" type="checkbox"/> Opt</p>				<p>Off-axis Angle (deg) <input type="text" value="0.1"/></p> <p>Off-axis Distance <input type="text" value="8.385"/></p> <p>Trans (%) <input type="text" value="100"/></p> <p>RMS Size 0.156</p> <p>Optimizer Weight <input type="text" value="0.1"/></p>	
<p>3 Focal Surface</p> <p>Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt</p>					

1-m f/2 Plastic

<input type="button" value="Optimize"/>		Curvature <input type="text" value="1e-5"/> SC <input type="text" value="0.001"/> Spacing <input type="text" value="0.2"/> Corrector <input type="text" value="0.002"/>	<input type="button" value="Trace"/>	<input checked="" type="checkbox"/> Auto Focus Polychromatic	EFL <input type="text" value="2435"/> f/D <input type="text" value="2.435"/>	Wavelengths (nm) Red <input type="text" value="656.3"/> Green <input type="text" value="587.6"/> Blue <input type="text" value="486.1"/>	FOV <input type="text" value="1.5"/> <input type="button" value="Auto Scale"/> 12.7" per
Statistics <input type="text" value="170/558"/> Error <input type="text" value="101.94 um"/>						Off-axis Angle (deg) <input type="text" value="0"/> Off-axis Distance <input type="text" value="0"/> Trans (%) <input type="text" value="100"/> RMS Size <input type="text" value="0.1019"/> Optimizer Weight <input type="text" value="1"/>	
0 Object Distance <input type="text" value="1e20"/> Diameter <input type="text" value="1000"/> Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt	Optical Layout <input type="button" value="Fit On Screen"/> <input checked="" type="checkbox"/> Angle0 <input checked="" type="checkbox"/> Angle1 <input checked="" type="checkbox"/> Angle2 Rays <input type="text" value="7"/> <input type="button" value="Repl"/>					Off-axis Angle (deg) <input type="text" value="0.05"/> Off-axis Distance <input type="text" value="2.269"/> Trans (%) <input type="text" value="100"/> RMS Size <input type="text" value="0.1646"/> Optimizer Weight <input type="text" value="0"/>	
1 Mirror Radius <input type="text" value="4000"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="1000"/> Spacing <input type="text" value="1827.17"/> <input checked="" type="checkbox"/> Opt						Off-axis Angle (deg) <input type="text" value="0.1"/> Off-axis Distance <input type="text" value="4.539"/> Trans (%) <input type="text" value="100"/> RMS Size <input type="text" value="0.2788"/> Optimizer Weight <input type="text" value="0"/>	
2 Lens PBH3 Radius 1 <input type="text" value="-120"/> <input type="checkbox"/> Opt Thickness <input type="text" value="25"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="-145"/> <input type="checkbox"/> Opt Diameter <input type="text" value="150"/> Spacing <input type="text" value="211.248"/> <input checked="" type="checkbox"/> Opt							
3 Focal Surface Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt							

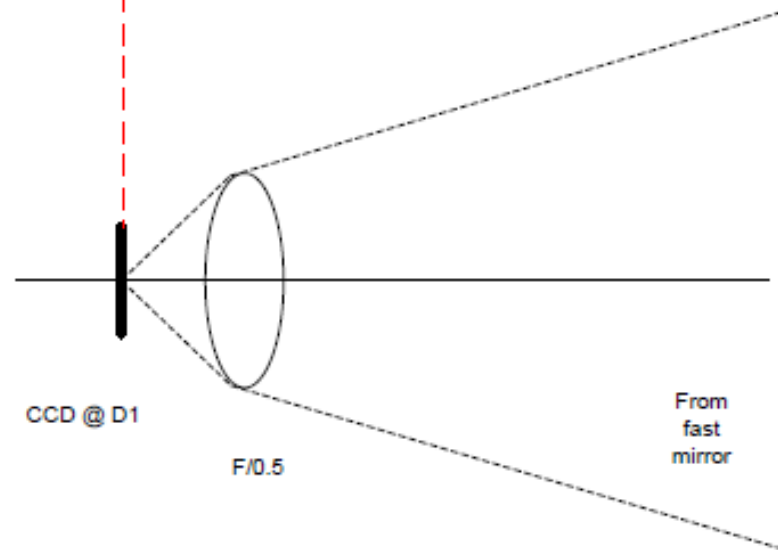
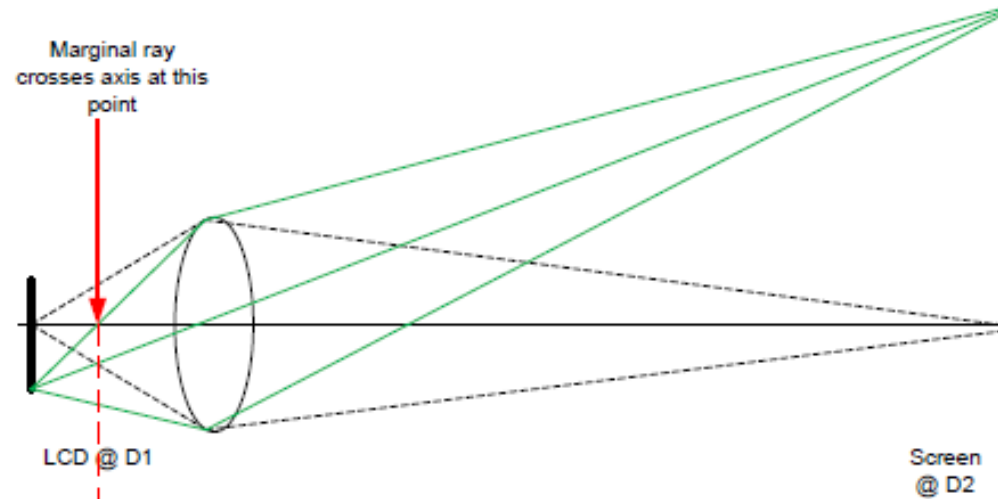
1-m f/4 Meniscus

Optimize	Curvature <input type="text" value="1e-5"/>	Trace	EFL <input type="text" value="3964.5"/>	Red <input type="text" value="750"/> nm	FOV <input type="text" value="1"/> Auto Scale 5.2" per
Stats 118/2049	SC <input type="text" value="0.001"/>	<input type="checkbox"/> Auto Focus	f/D <input type="text" value="3.964"/>	Green <input type="text" value="550"/> nm	Angle (deg) <input type="text" value="0"/>
Error 56.47 μ m	Spacing <input type="text" value="0.2"/>	Polychromatic		Blue <input type="text" value="420"/> nm	Distance <input type="text" value="0"/>
	Corrector <input type="text" value="0.002"/>				Trans (%) <input type="text" value="100"/>

0 Object Distance <input type="text" value="1e20"/> Diameter <input type="text" value="1000"/> Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt		Angle (deg) <input type="text" value="0"/> Distance <input type="text" value="0"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.02886"/> Weight <input type="text" value="1"/>
1 Mirror Radius <input type="text" value="7950"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="1000"/> Spacing <input type="text" value="3646.03"/> <input checked="" type="checkbox"/> Opt		Angle (deg) <input type="text" value="0.05"/> Distance <input type="text" value="3.525"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.1278"/> Weight <input type="text" value="1"/>
2 Lens BK7 Radius 1 <input type="text" value="-90"/> <input type="checkbox"/> Opt Thickness <input type="text" value="2.3"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="-92.3"/> <input type="checkbox"/> Opt Diameter <input type="text" value="100"/> Spacing <input type="text" value="1"/> <input type="checkbox"/> Opt		Angle (deg) <input type="text" value="0.0715"/> Distance <input type="text" value="5.042"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.1822"/> Weight <input type="text" value="1"/>
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4 Focal Surface Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt		

Aspherics

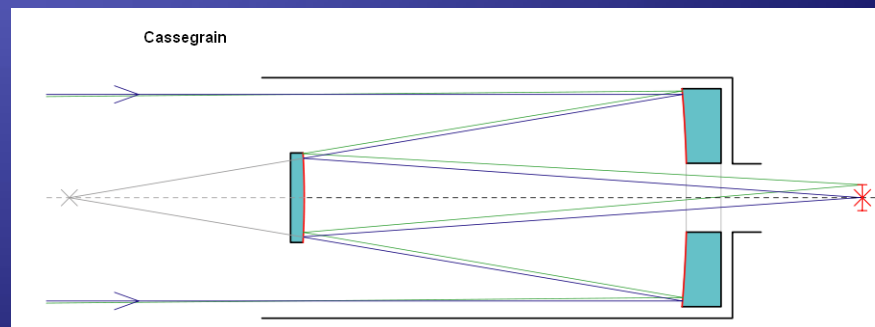
- ◆ Olive3 is out-of-date
- ◆ Projection lenses
 - ◆ Movie
 - ◆ LCD $\sim f/2$
 - ◆ Rear Proj. TV $\sim f/1$



Telescope
 $1/f = 1/D1 + 1/D2$, D2 negative

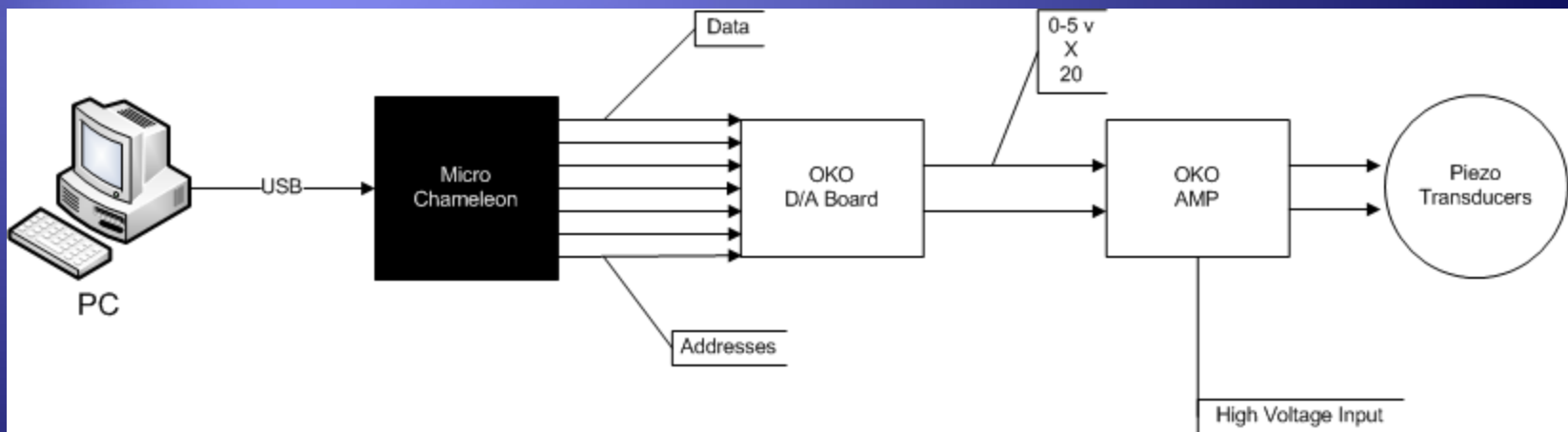
Bimorph Secondary Project

- ◆ Goals
 - ◆ Active, not adaptive, correction for LBTs
 - ◆ Low-cost & replicable
 - ◆ Explore relationship between prediction and experiment
- ◆ Current State
 - ◆ Deformable Cass-like secondary (not 45° Newt.)
 - ◆ 40 actuators



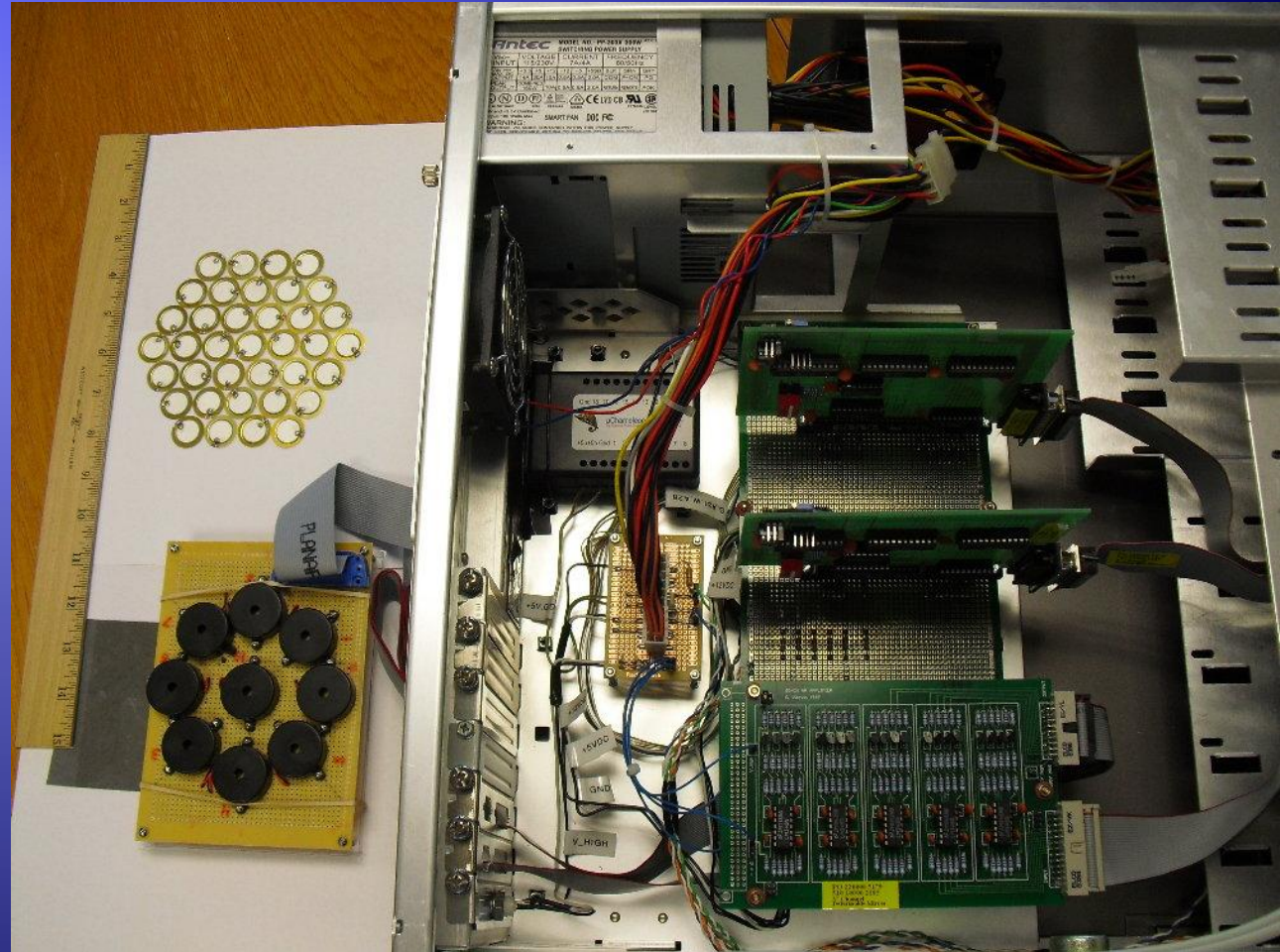
Bimorph Secondary II

- ◆ Controller



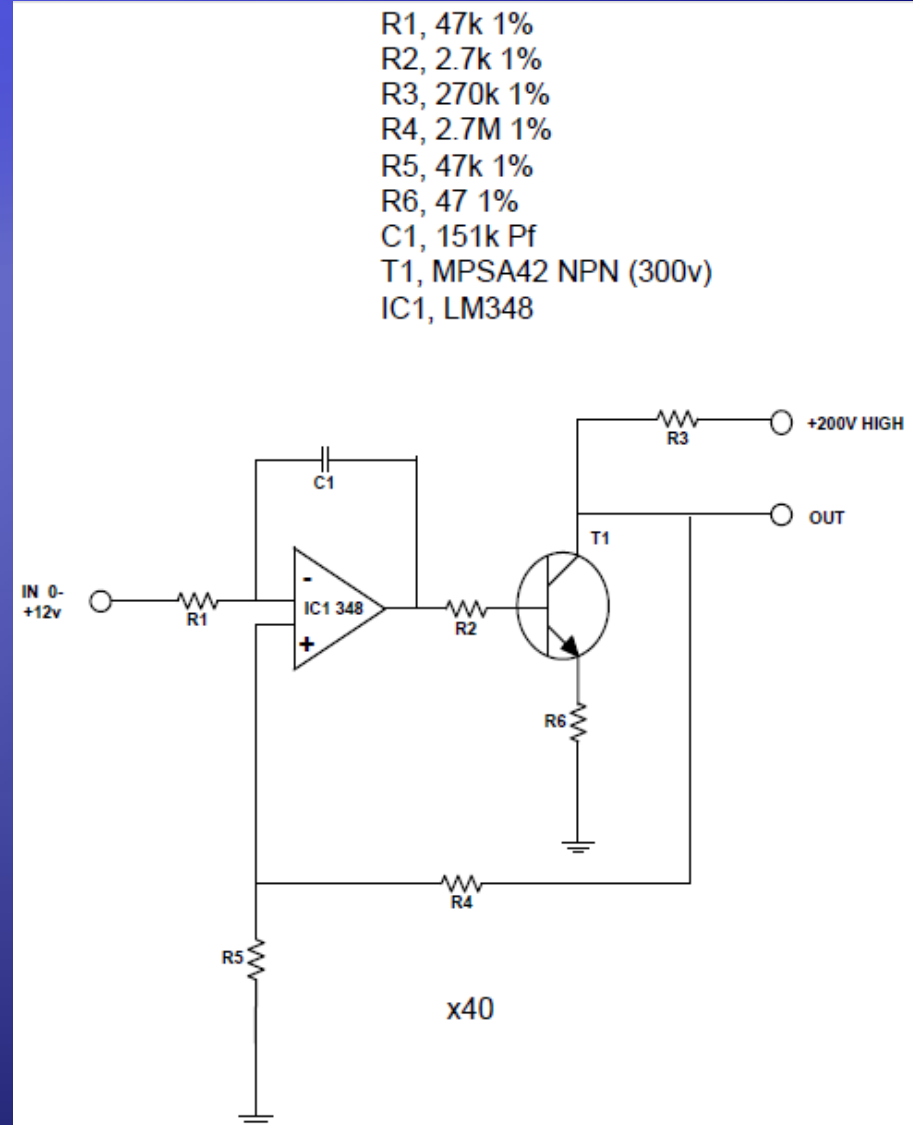
Bimorph Secondary III

- ◆ Re-used old ISA OKO boards
- ◆ USB μ Chameleon
- ◆ 500Hz update rate
- ◆ 40-channel
- ◆ 0-200V Out



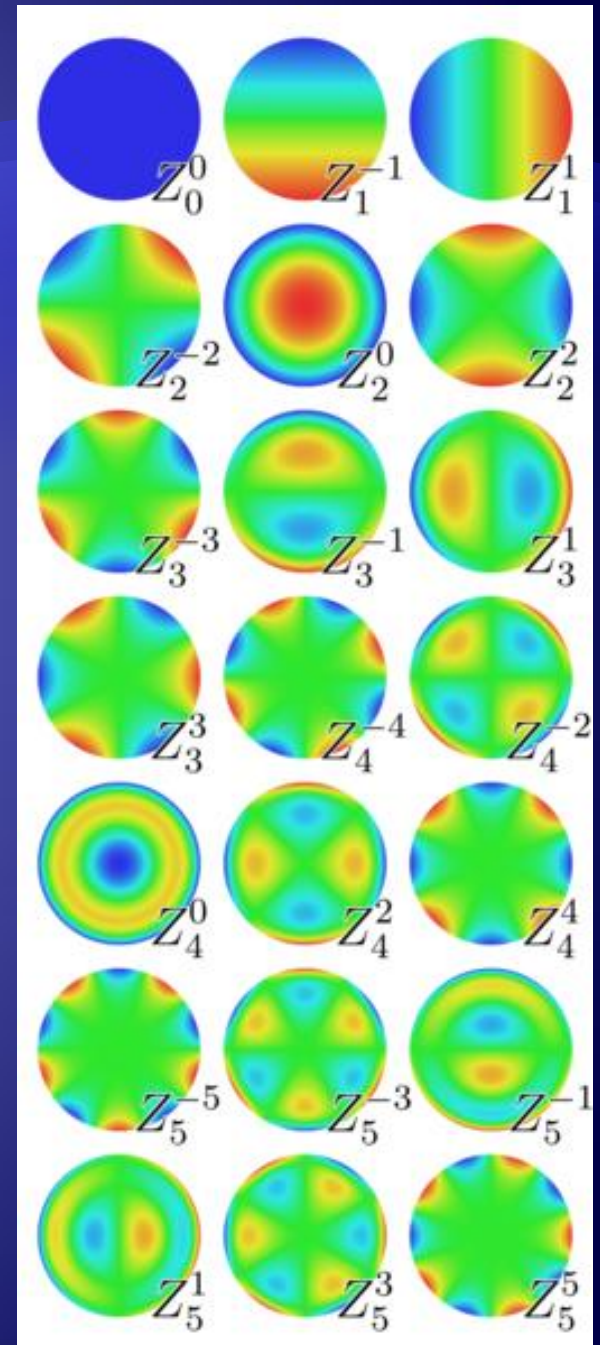
Bimorph Secondary IV

- ◆ HV amp: 0-3v in, 0-200v out
- ◆ 500Hz update rate
- ◆ MPSA42 @ \$0.05ea.
Qty. 2k



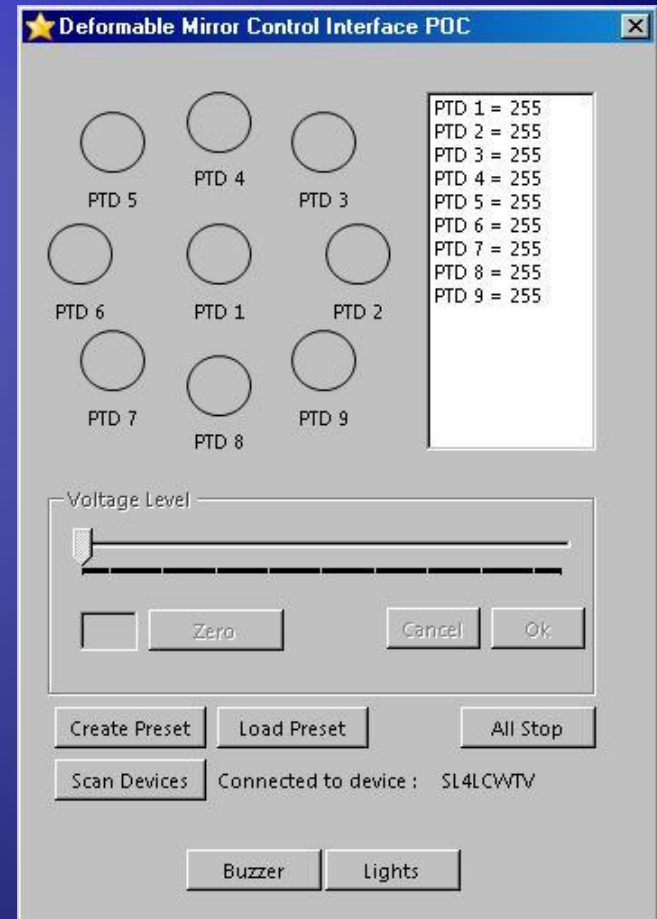
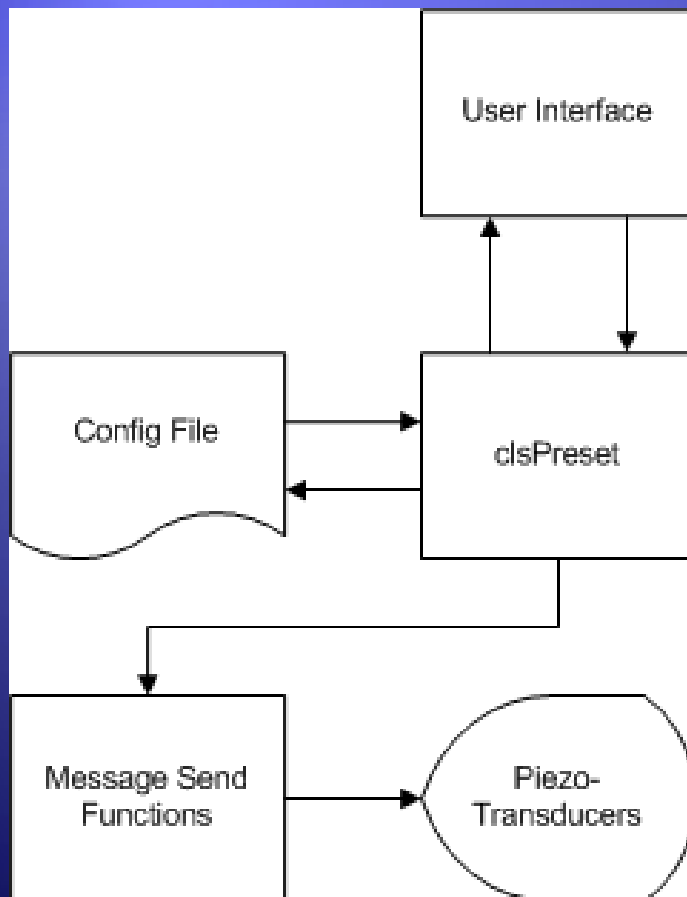
Bimorph Secondary V

- ◆ Zernike orthonormal functions
- ◆ Closed loop
 - ◆ Wavefront sampling
 - ◆ Active correction
- ◆ Open loop
 - ◆ Minimize PSF (simulated annealing)
 - ◆ Lookup table



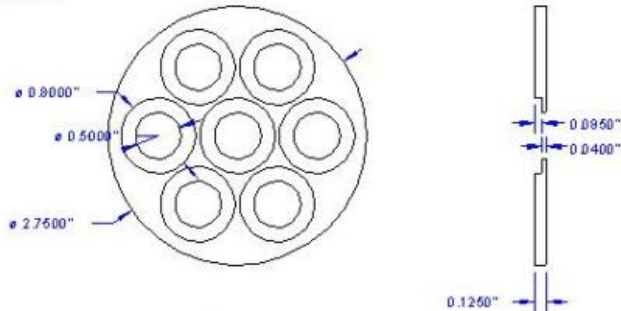
Bimorph Secondary VI

◆ Control Software

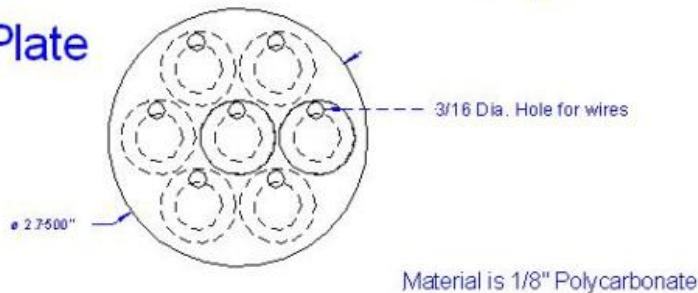


7-piezo prototype I

Base Plate

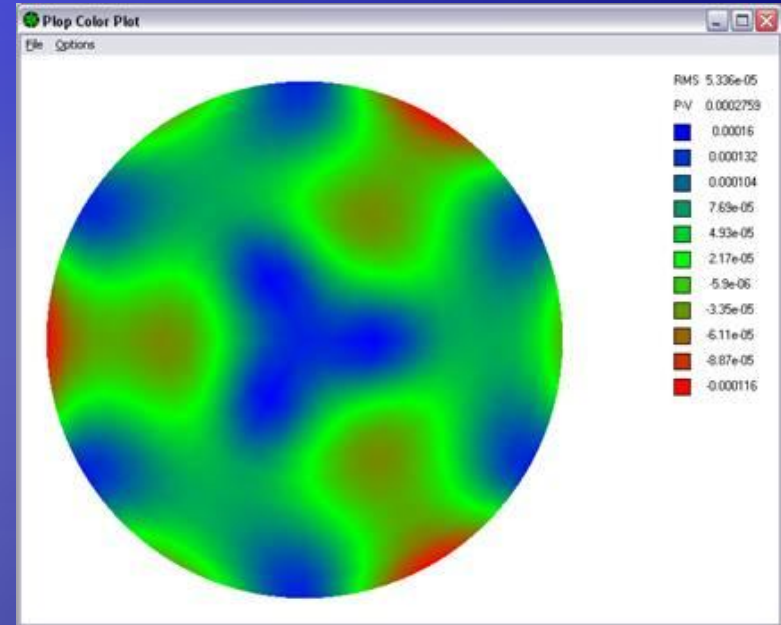
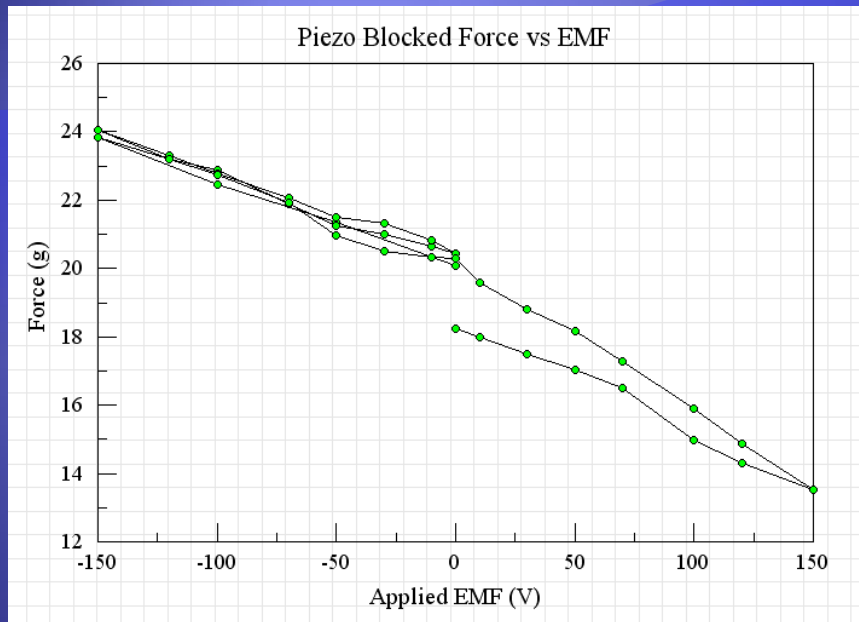


Cover Plate



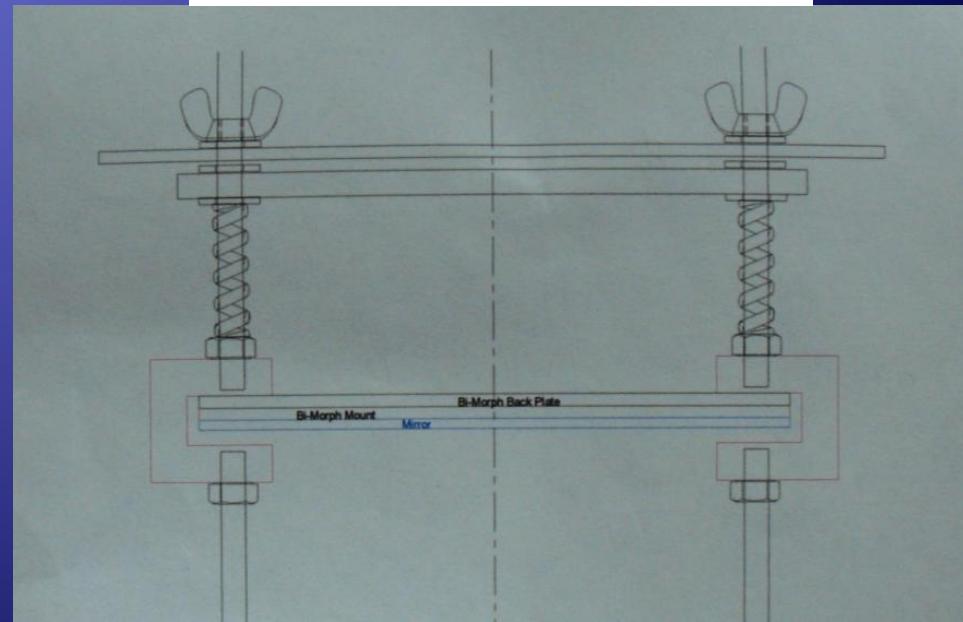
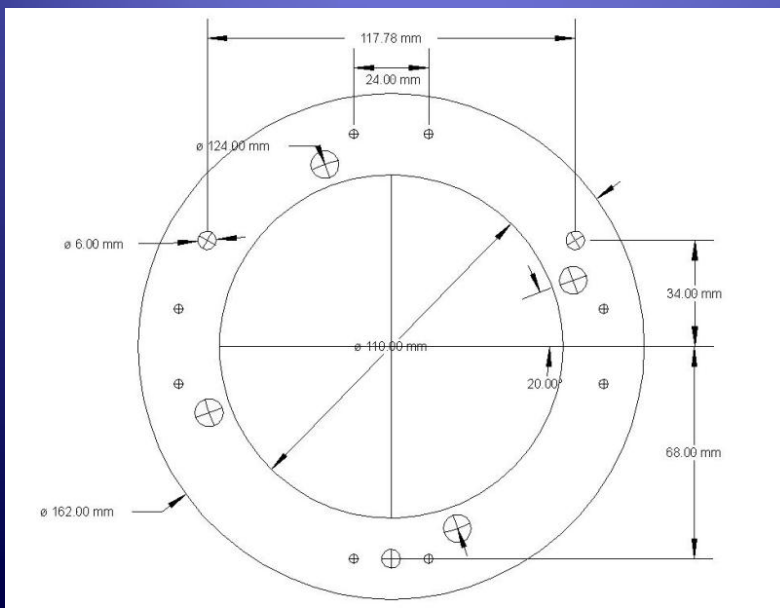
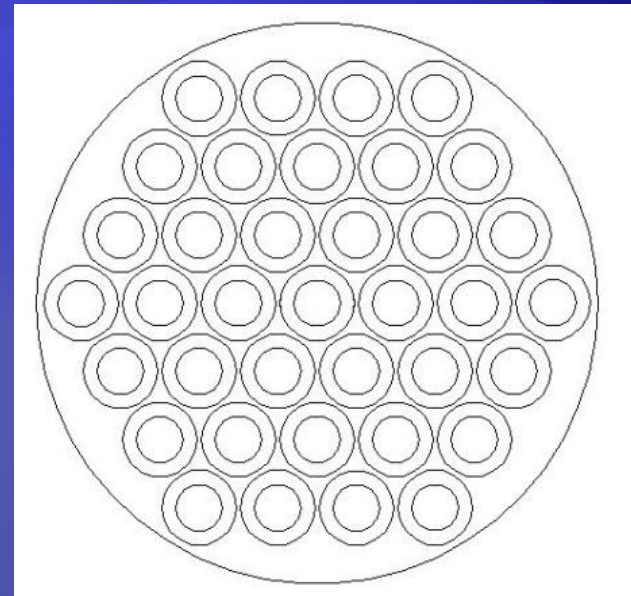
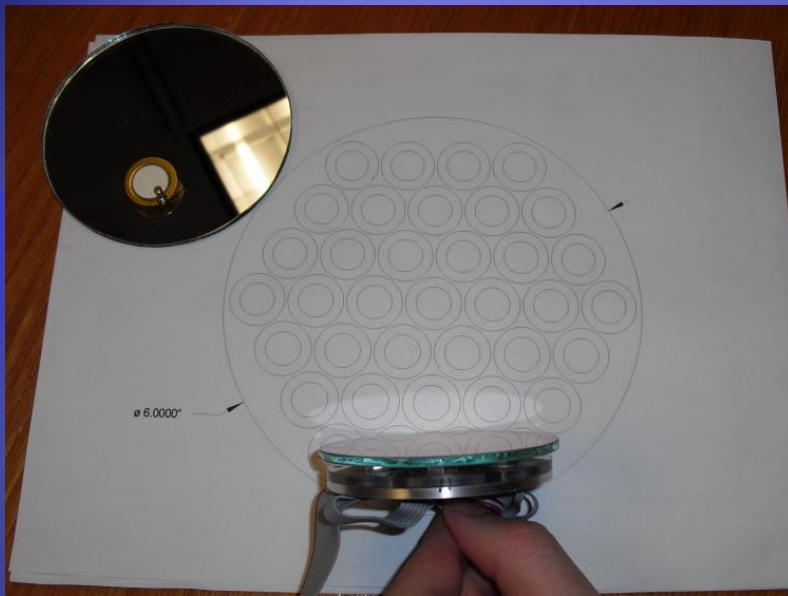
- ◆ Unblocked deflection of ± 35 microns over 120VAC (340Vpp)
- ◆ About 0.2microns/Volt

7-piezo prototype II



- ◆ 10-g swing from +/- 150V
- ◆ Some hysteresis
- ◆ >200V force reversal!
- ◆ Plop for 0.5-mm glass shows 1/5 wave from 0.5-g support

Bimorph Secondary Mount – 37 piezo



Conclusions and further work

- ◆ Low-cost piezos design can deform 3-mm plate glass sufficiently & repeatably
- ◆ Need to finish 37-piezo secondary
- ◆ Test under a variety of circumstances
 - ◆ Determine hysteresis & temperature affects
 - ◆ Try PSF-size feedback

Contact

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- ◆ Initiative Website - www.AltAzInitiative.org
- ◆ Yahoo Discussion Group - <http://groups.yahoo.com/group/AltAzInitiative>

More details:

The Alt-Az Initiative: Telescope, Mirror, & Instrument Developments, eds. Genet, Johnson, & Wallen, (Payson, AZ: Collins Foundation Press) 2010