Final Design Review: Independent Project

Submerged Interferometer Diverger

The University of Arizona

College of Optical Sciences

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Requirements

F/.615

Focal space in solution

Corrected for FOV of +/- 0.1 degrees

Entrance Pupil diameter of 20mm

Working distance in solution of at least 8mm

Better than 1/2 wave RMS wavefront error on axis

Better than 2 wave RMS wavefront error at .25 degrees

4 or 5 lens design

Color corrected over 640 to 680nm

Better than 1/10 wave PV color correction over 20nm band

Final surface as glass-solution interface

Final surface is flat

All performance metrics are after tolerance and assembly

Lenses can be removed from assembly if needed

Will be used for reverse ray tracing so knowing what the lens looks like is important

Interface with a 2” diameter mirror mount

Allow a container to seal against final surface to create glass-saline transition (oversized CA)

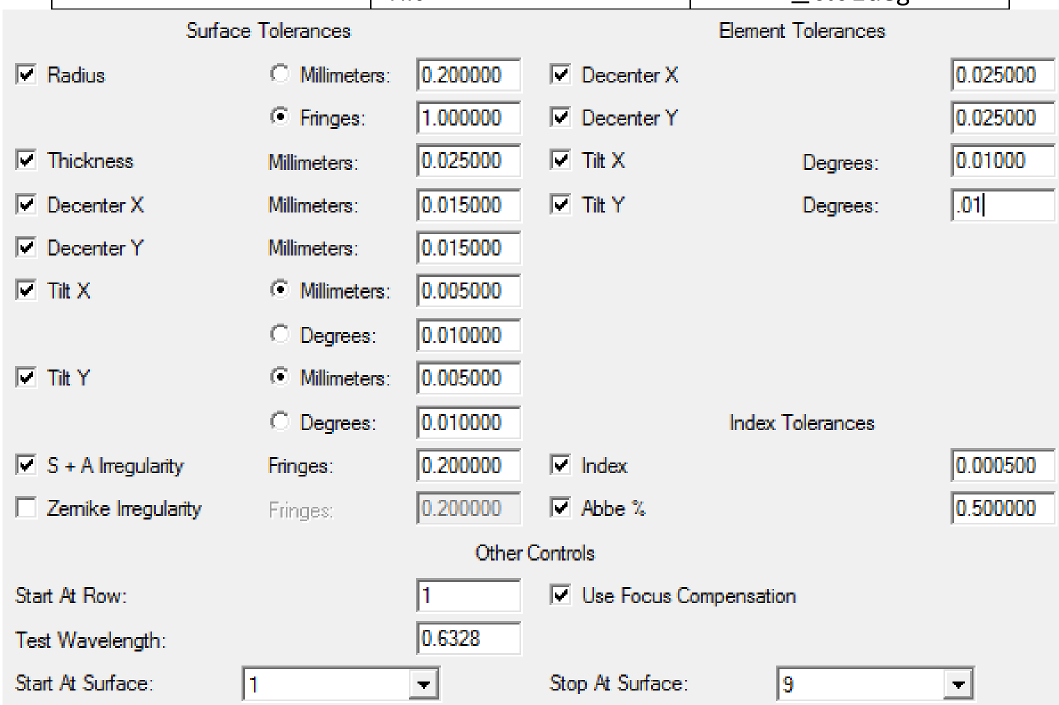
Introduction

Since knowing what the design looks like is important, the tightest tolerances possible will be held on manufacturing the lenses. The rest of the error in the system will come from errors in machining the mechanical parts. This will be the focus of the study. The mechanical errors will result in misalignment that will cause performance degradation. Some design forms will perform better nominally than others, but may be more sensitive to alignment errors. Several design forms will be looked at and their sensitivity analyzed through Monte Carlo simulations. The different design forms will also allow different mounting schemes to be used to constrain the lenses. This will also be considered when tolerancing the designs. Extremely steep surfaces will have loose tolerances on their radii since it is harder to measure. Plano-convex lenses will be easier to mount as well as cheaper and easier to make to tight tolerance. These aspects will contribute to the decision of the best system.

Control variables

Each of the designs will need to have the same parameters to be able to compare them. They will have the same focal ratio, focal length and working distance. They will all come to focus in the same solution. Higher index glasses will be allowed, but their increased cost will be weighed against the increase in performance. Also to keep the comparison fair, the same tolerances will be held for each design. As was mentioned before, the lenses will have tight tolerances which are given in the table below.

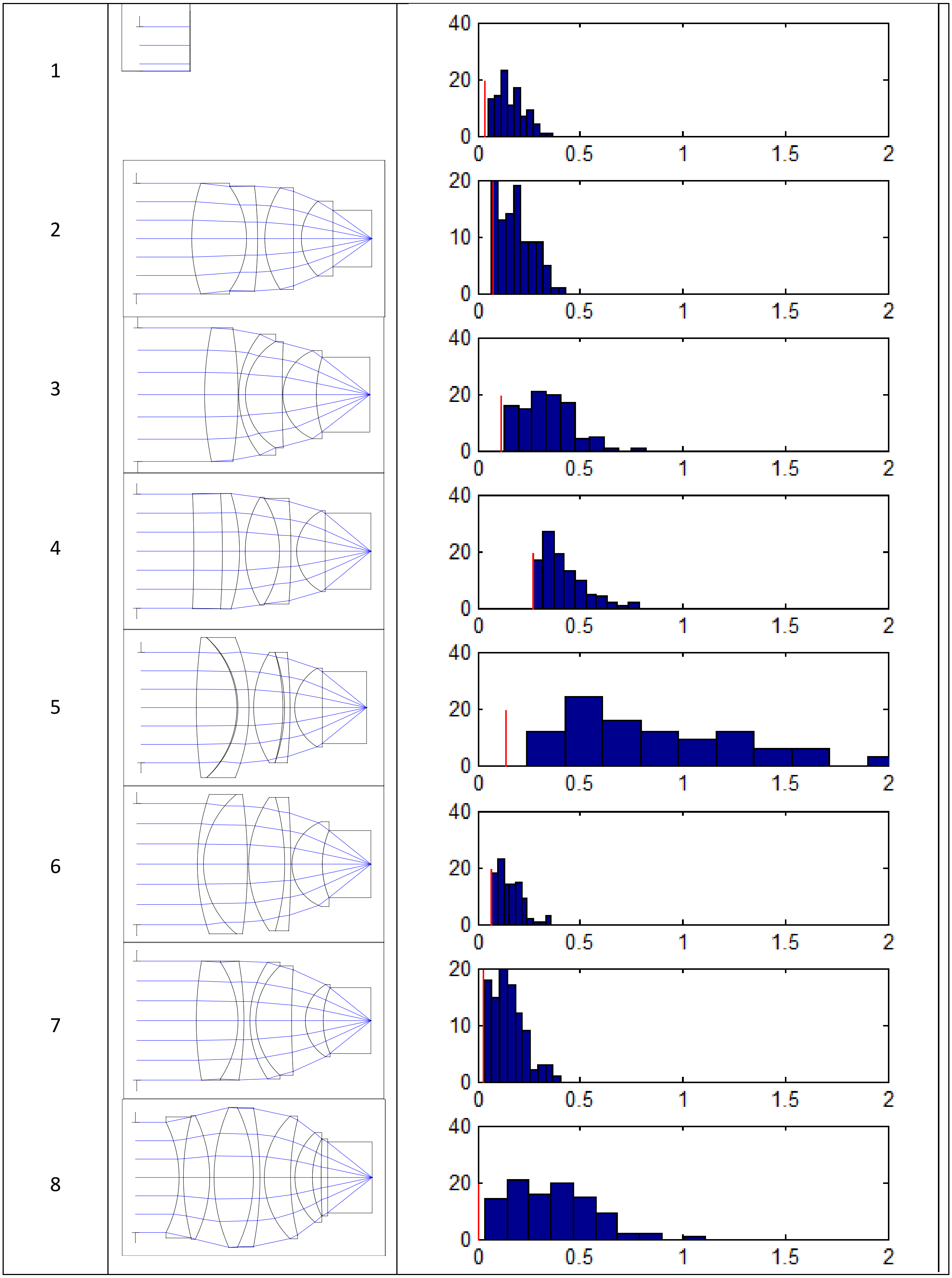
		Tolerance (mm)
Lens Tolerances	Thickness	$\pm .025$
	Diameter	$+0.00/-0.015$
	Wedge (ETD)	0.005
	Radius	0.05% or 1 fringe
	Index	± 0.0005
	Abbe number	$\pm 0.5\%$
Barrel Tolerances	Decenter	± 0.025
	Spacing	± 0.025
	Tilt	± 0.01deg



The above figure shows the default tolerances that were set for each design. What is not seen above is the radius tolerance. The radius can either be measured by an interferometer or test plate. Most of the surfaces in these designs will be too fast for an interferometer. Typically the best tolerance that can be placed on a spherical surface is either 1 fringe, or .05% of the radius. For long radius surfaces, the 1 fringe will be more restrictive while short radii surfaces will be restricted more by the .05% of the radius. For each surface, using the radius and the clear aperture, the more restrictive of the two was found using the following equation.

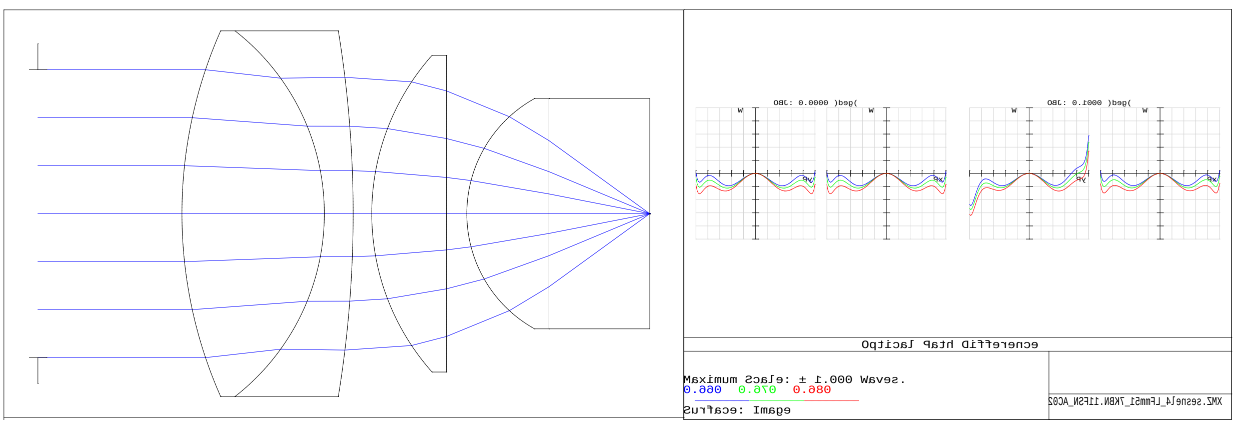
$$\#\ of\ fringes = \frac{0.0005\left(\frac{D}{2}\right)^2}{\lambda R}$$

If the resulting number of fringes is less than 1, the tolerance is left as plus or minus one fringe. Otherwise the resulting number of fringes for 0.05% of the radius is used. Below is the output distribution for a Monte Carlo simulation.


1
2
3
4
5
6
7
8
40
20
10
0
0.5
1
1.5
2

For this simulation, 100 realizations of the perturbed lens had its focus re-optimized with damped least squares to simulate actual focus compensation. The red line on each of the plot represents the nominal performance and the results of the simulations are binned to the right of this line showing performance degradation from element misalignments. It is interesting to note that some of the designs many have better nominal performance, but its final as built performance would be worse. Some of the designs are more sensitive to alignment errors. While all of this is extremely interesting, analyzing why this happens is not the purpose of this paper. The systems that perform close to their nominal criteria and only use four lenses are the first and second designs. Two of the lenses in the second design are plano-convex. This means that they will be easier to mount than other complex lens shapes. The design before this one is the same concept with 4 lenses except the last two elements are meniscus shaped. This allows further reduction of the nominal wave front error of the system. The as built performances between the two however are nearly the same. The second design is chosen over the first because the lens shape should allow the tolerances to be tightened even further than what was used in the previous simulation.

Optical Design

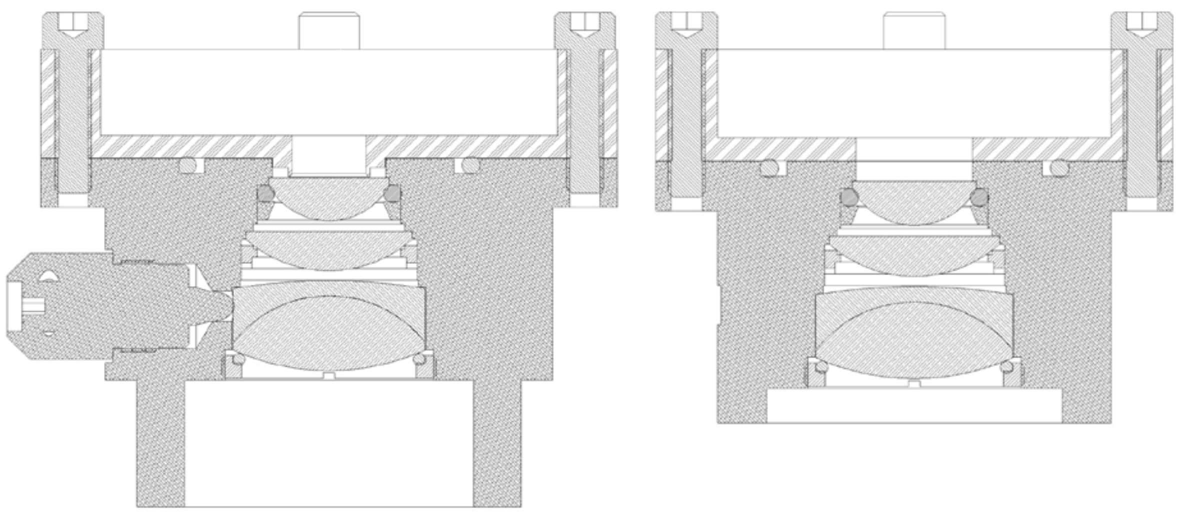


The selected design is shown above with its wave fans. The design nominally meets the half wave RMS requirement on axis. The nominal performance is actually about 1/20th wave RMS. The Monte Carlo simulation has shown that this performance will deteriorate with manufacturing tolerances but is not predicted to drop less than half a wave. It should be possible to keep performance better than 1/10 wave if a compensator is added.

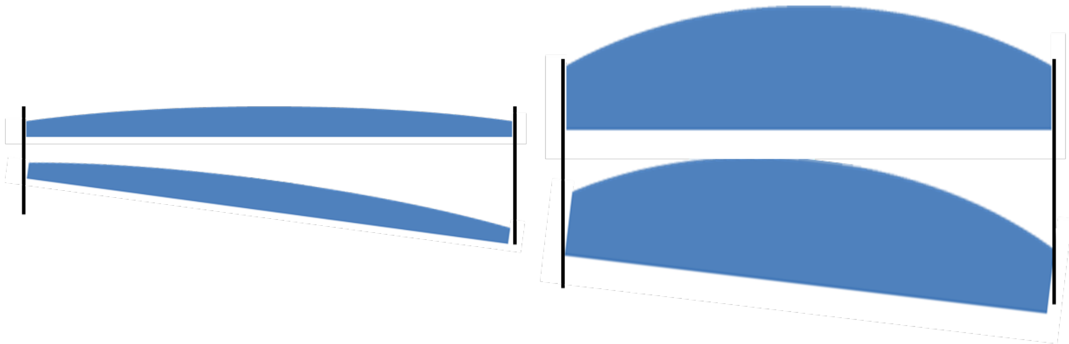
Satisfying Requirements

The studies in the previous sections show that the selected lens design will meet the performance requirements if the tolerances used in the study are met. The tolerances are tight and will require caution, especially since the lens assembly may need to be taken apart and cleaned frequently. It would also be nice if the assembly and realignment of the system is considered during the mechanical design. It would be nice to have a quick method for safely putting the lenses back in the barrel and aligning the diverger to the interferometer. The requirements that are not performance based (dimensions and lens parameters) are met by the selected design shown above. The other requirements that have not been considered will be the interfaces both between the optical mount and the saline.

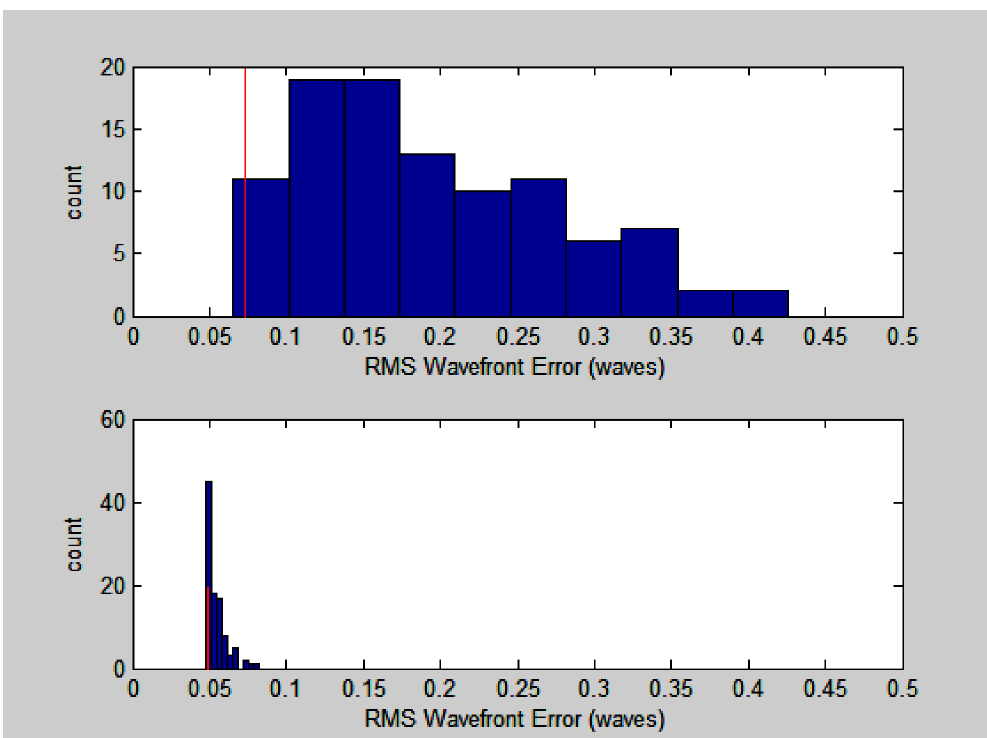
Method for Mounting Lenses



The lenses from Optimax will have their diameters cut to a tolerance of +0 and -15 microns. The mechanical axis of the lenses will be constrained to 7.5 microns of the center axis of the lens barrel. The flat surfaces will be the faces that locate the plano-convex lenses. The edge thickness tolerance on these lenses will be 5 microns. For the size of these lenses, that corresponds to a tilt of the optical axis relative to the mechanical axis of the lens by 0.00025 radians or 0.015 degrees. This is only a tilt of the spherical surface since the flat surface will be located perpendicular to the optical and mechanical axis to the accuracy that the lathe can make cuts perpendicular to its axis of rotation. The decenter of the spherical surface will only be 7.5 microns plus the oversized radius of the lens seats. This will be 25 microns on the diameter making the total decenter only 20 microns. This small clearance will make fitting the lenses into their seats difficult since small tilt will cause the lens to bind. For this reason, the edges of the plano-convex lenses were made only a millimeter thick. A chamfer of .2mm was placed on the edges to keep the lens from chipping during assembly. The maximum allowable lens tilt that can happen when inserting the lens into its seat will be .02/.9=0.022radians, which is similar to inserting a lens with 4.5mm edge thickness into a standard lens tube with diameter oversized by 200 microns (.1/4.5=.022). It could be a tight fit but it will not be a nightmare.



To mount the doublet precisely will take a bit more work. The doublet will be larger and the most sensitive surface is buried in the middle making it impossible to use it for mounting. Some people have solved this problem by over sizing one of the lenses and mounting to the cemented face of this lens. The other lens would then be supported by the cemented interface and the other lens is then constrained. For this particular design, the two plano-convex lenses are highly constrained and are the least sensitive elements. Since only a few of these are to be built, some alignment could be done on the doublet. The easiest active alignment is to interface one of the external faces of the doublet with the lens barrel and allow the doublet to be adjusted transverse to the optical axis. The face of the doublet that mates with the barrel will always have its center of curvature on the mechanical axis of the barrel. The wedge allowed in each of the individual lens elements for the doublet is specified at .005mm of edge thickness difference. After cementing the two together, the edge thickness difference will also be .005mm for the entire doublet. Even with these tight tolerances, a majority of the system performance degradation is still from the doublet. Allowing the doublet to be shifted slightly perpendicularly to the optical axis helps a lot with this.

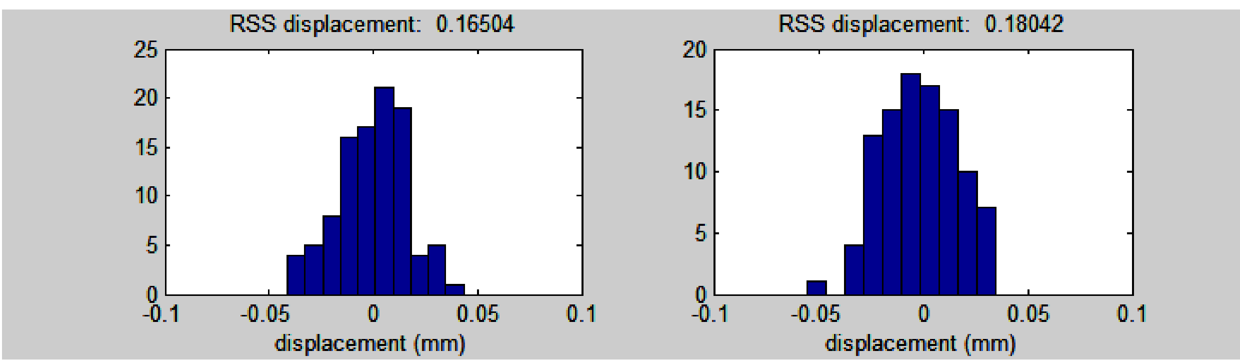


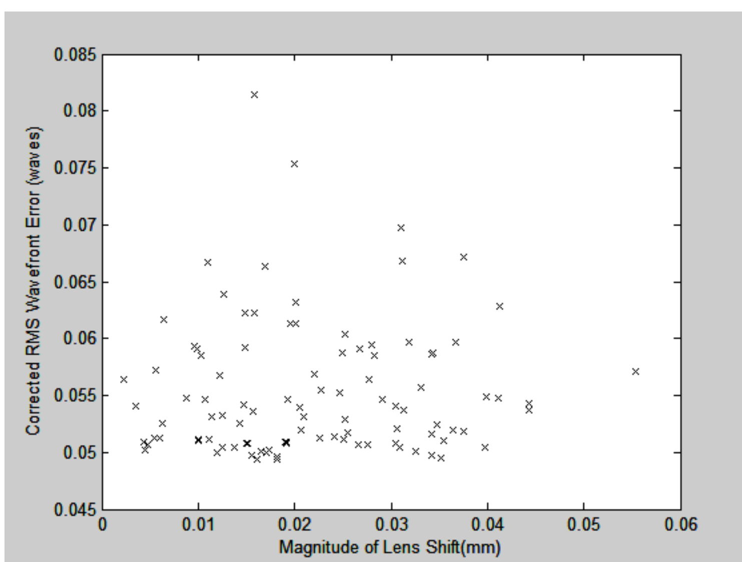
The compensation will be provided by two set screws driving the lens in two perpendicular directions. A third set screw will allow the lens to be locked. A retaining ring will press a 3/32 inch soft Buna-N o-ring against the doublet for preload. The lens will have a small range of adjustment perpendicular to the optical axis and will only displace the o-ring slightly.

$$\Delta z = \frac{(x + \Delta x)^2}{2R} - \frac{x^2}{2R} = \frac{\Delta x(2x + \Delta x)}{2R}$$

The equation above shows how much the o-ring will be compressed for a certain shift perpendicular to the optical axis. The largest adjustment needed in the Monte Carlo simulation shown above was only plus or minus 50 microns. For a 100 micron translation of the lens, the o-ring will be compress/decompressed by .0398mm which is 1.7% of the cross sectional area of the o-ring. If the lens is translated by half a millimeter, the o-ring will be compressed by 8.5% of its cross sectional area.

The resolution for this compensation of the doublet will need to be very fine. The maximum motion that was needed to compensate errors in assembly of the system was 50 microns, but the standard deviation of the required offset was 16 to 18 microns.





The compensating adjustment on the doublet will be very sensitive. A simple set screw will not be enough to achieve these

Saline Tank

The interface between the lens barrel and saline tank is also defined in this report. It is preferred that the seal be between the plastic tank and the flat surface of the last lens before focus to prevent any metal from coming in contact with the solution. The smallest o-ring cross section for this diameter clear aperture is 1/16 inches. The gland needs to be ___ inches for this size o-ring which drives the diameter and thickness of this last lens. It drives it to becoming nearly a hemisphere of glass to maximize the clear aperture for sealing the tank to the lens. The other option is to seal the tank against the lens barrel and rely on a seal inside the barrel against the last lens. The seal on the inside of the barrel is a good idea whether or not it is actually needed. It will consist of a larger 3/32 inch soft Buna-N o-ring. The steep curvature of the last lens and sides of the lens barrel will form the gland. A retaining ring will press the o-ring into the gland to preload the lens as well as seal the lens against the barrel. The tank can then either interface with the last surface of the lens or with the barrel. An o-ring gland will be cut on the exterior of the lens barrel.

The tank needs to be removable without the entire assembly being disassembled. This will allow the last surface of the lens group to be cleaned without having to realign everything. For this reason the screws that attach the tank to the barrel will be accessible from the top.

Lens Barrel

The lens barrel will be milled on a lathe from a single piece of aluminum. The important features are the location of the lens seats relative to each other, diameter of the lens seats, and their centricity and parallelism. The centricity is tolerance to 5 microns, which should be achievable on a lathe since each cut can be made without re-blocking the part. The parallelism was held to 5 microns which matches the tilt tolerance used in Zemax. The outer diameter is toleranced to plus 25 microns and minus 0 which will give a total element centration uncertainty of 20 microns. The table below shows the stack up of tolerances and how that compares to the tolerances used in the Zemax simulation.

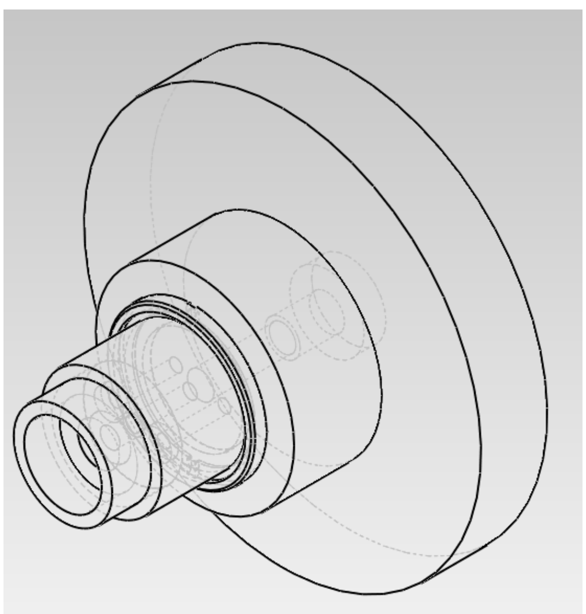
Lens	Parralelism(mm)	Diameter(mm)	Actual Tol	Zemax Tol
L4	0.01	16	0.00125	0.01
L3	0.01	17	0.001176	0.01
L1/L2	0.01	18	0.001111	0.01
	Diameter Tol(mm)	Seat Centration(mm)		
L4	0.02	0.005	0.020616	0.05
L3	0.02	0.005	0.020616	0.05
	Seat location Tol(mm)	Lens Thickness Tol(mm)		
Surf2	0.025	0	0.025	0.025
Surf1	0.025	0.025	0.035355	0.025

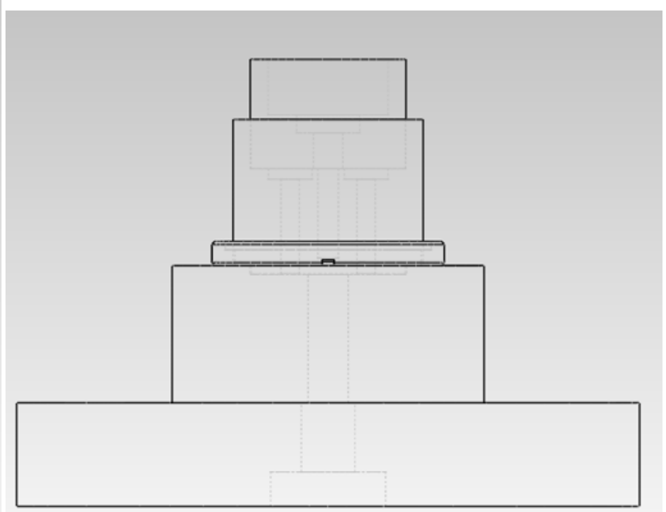
The tolerances that will be held on the lenses are close to what was simulated. The only parameter that the table shows outside of the tolerance is the location of one of the lens surfaces. This is based on the two errors compounding, but Zemax compensates the lens thickness error with the air space between lenses. This is the same as what we will see when the system is built.

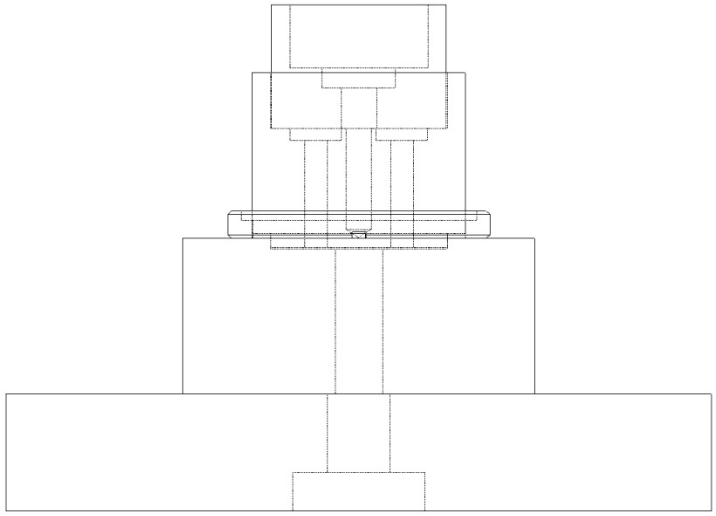
Parts List

Part Number	Vendor	Description	Qty	Price (all qty)
L1.V2	OptiMaxSi	Positive Doublet Element	1	$1,932.50
L2.V2	OptiMaxSi	Negative Doublet Element	1	$1,932.50
L3.V2	OptiMaxSi	Low Power Plano	1	$1,877.50
L4.V2	OptiMaxSi	High Power Plano	1	$1,867.50
RR4	CUSTOM	Custom retaining ring for o-ring seal	1	TBD
EO85-556	Edmund Optics	OTS retaining ring for 20mm optics	2	$19.95
EO85-596	Edmund Optics	OTS retaining ring for 1inch optics	2	$19.95
TANK	CUSTOM	Custom saline tank	1	TBD
BARREL.V2.1	CUSTOM	Custom high precision lens barrel	1	TBD
BHC17.04	Newport	Hex adjustment heads	2	$239.98
SN200-F2K	Newport	2 inch mirror mount	1	$189.99
2418T126	McMaster Carr	020 Soft Buna-N o-ring	60	$10.00
2418T138	McMaster Carr	113 Soft Buna-N o-ring	80	$9.60
2418T148	McMaster Carr	126 Soft Buno-N o-ring	30	$8.40
			TOTAL PRICE	$8,107.87

Assembly/Alignment Procedure

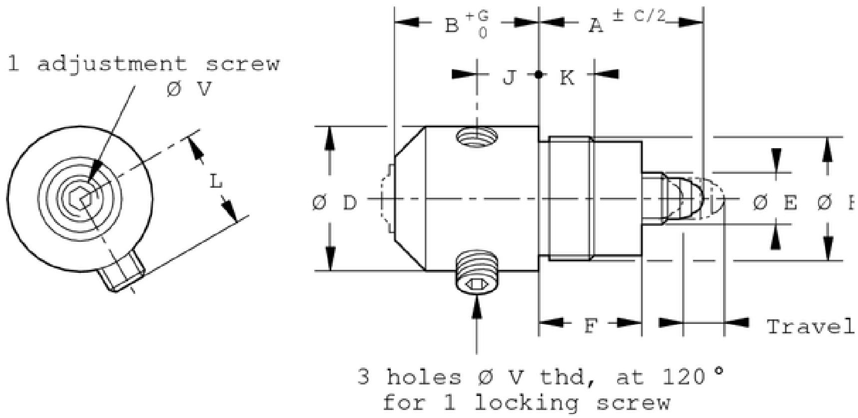




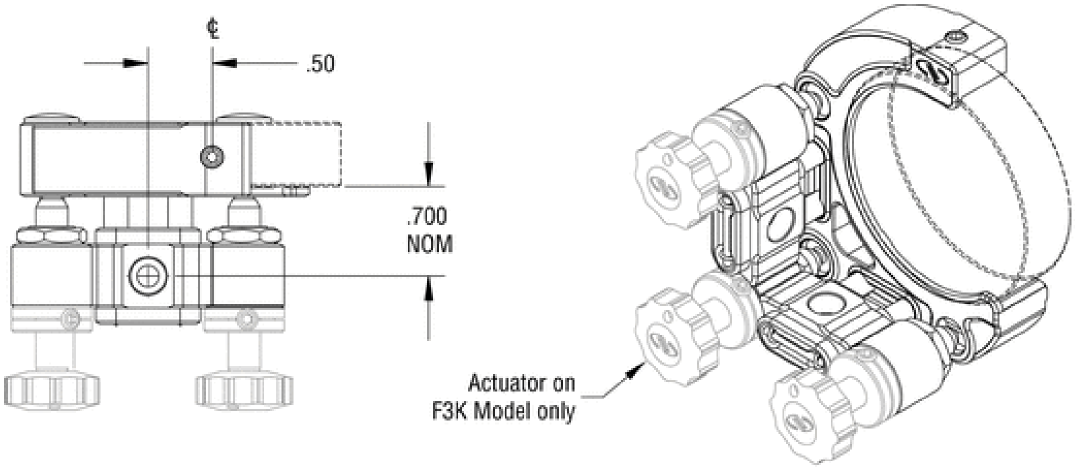


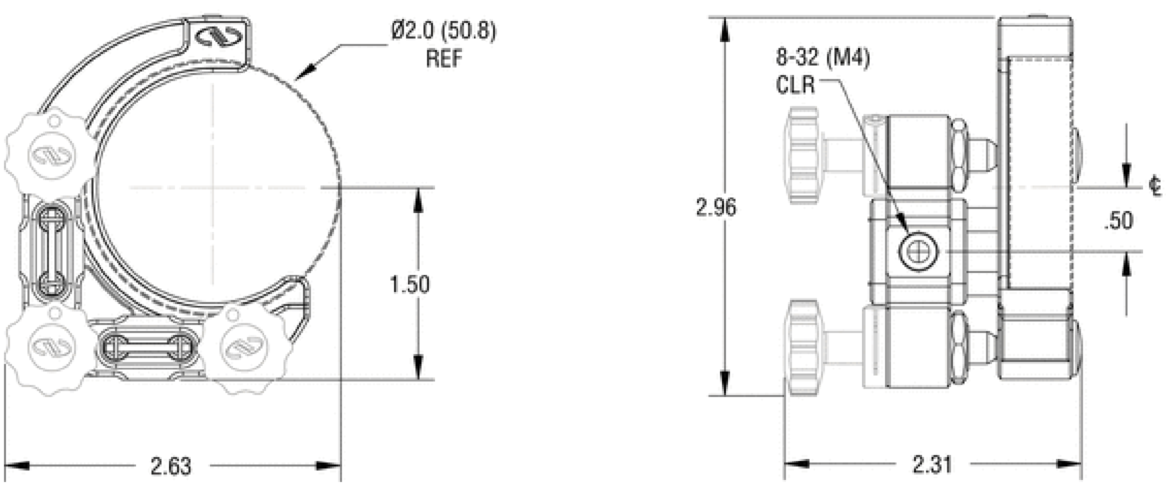
- L4 is the first lens to be inserted into the barrel and can be identified as the plano convex lens with the steepest curvature. The spherical surface can be placed atop the loading post.
- The lens barrel is then set carefully guided over the top. The loading post will center L4 into its seat. The edge of L4 should be visible from the top and the technician can make sure the lens is not binding by tapping on the flat surface of the lens.
- When the lens is seated, the barrel/loading post assembly can be flipped over and the loading post removed.
- The o-ring is then inserted and can be pressed into position again using the loading post.
- Retaining ring RR4 is then tightened against the o-ring to secure and seal the lens tube. Now would be a good time to check the seal to make sure it is not leaking.
- The top section of the loading post can be removed and lens L3 can now be placed on top. The barrel now with L4 is lowered over the post guiding L3 into its seat. When the end of the barrel touches the spacer, we know the lens is in the correct position.
- The assembly can be flipped over and the L3 retaining ring threaded against L3 to secure it.
- The Saline tank can be mounted to the top of the barrel assembly with the o-ring placed in the gland on top of the barrel.
- The Hex adjustment micrometer heads should be threaded into the sides of the lens barrel at this point.
- The barrel will then be placed into the interferometer and aligned to a ball bearing. There will be ~20 waves of spherical from the incomplete diverger lens, but it can be adjusted until coma is minimized. At this point we know that the two plano convex lenses are aligned to the optical axis.
- The second section of the loading post can be removed and the doublet retaining ring, preload o-ring, and doublet can be stacked on top. Using the loading post, the stack can be loaded into the bottom of the barrel and the retaining ring tightened.
- The hex adjustment screws on the side of the barrel can then be used to null out the remainder of the aberrations in the interferometer.

Appendix



BHC17.04: A = 16 mm, B/D = 14 mm, C = 4 mm, E = M5 thread, F/ L = 10 mm, G = 1 mm, H = M12 x 0.50 thread, J = 5.5 mm, K = 6 mm, V = M4 thread





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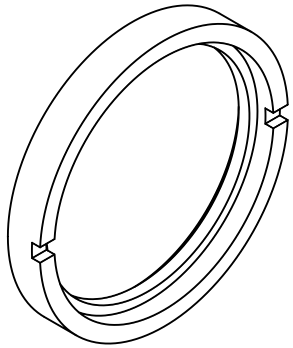
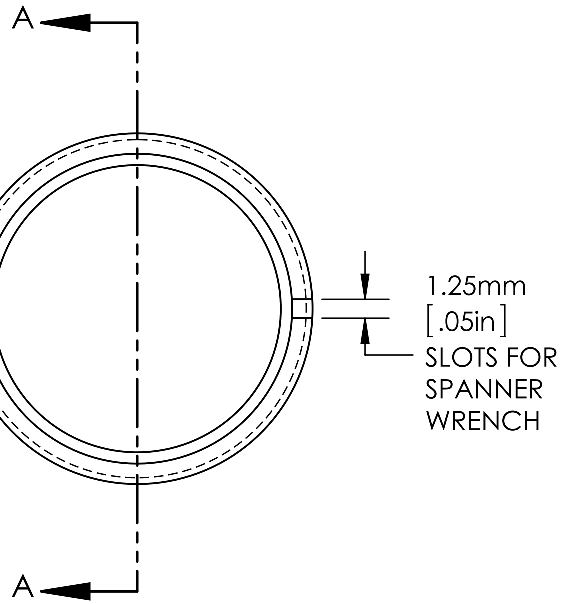
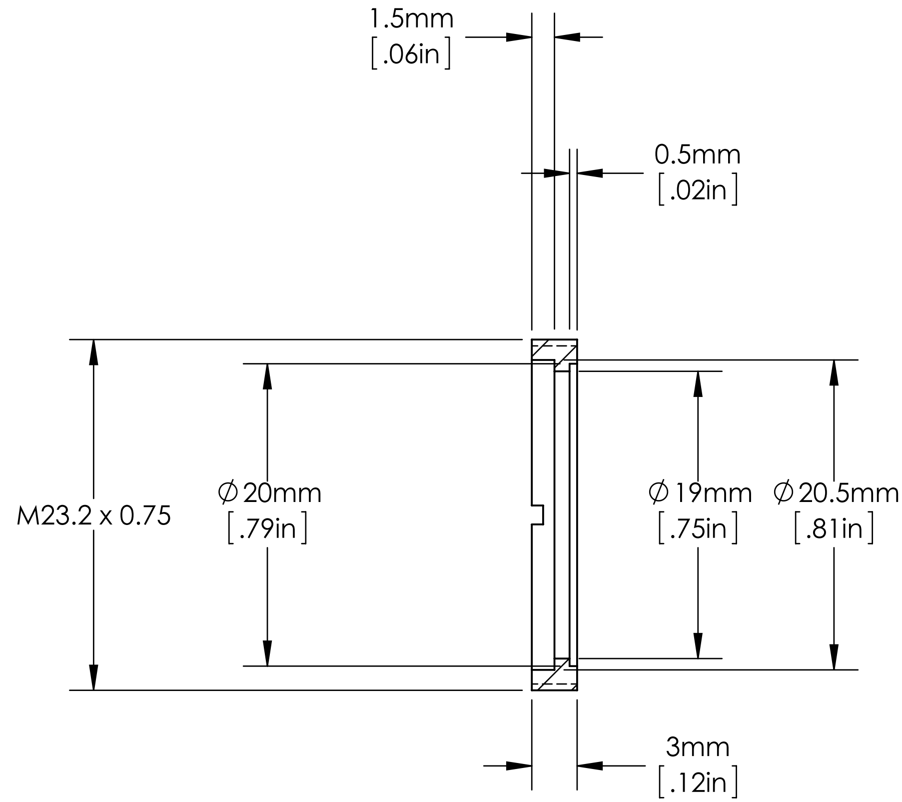
DIMENSIONS ARE IN mm [INCHES]







SECTION A-A

NOTES:

1. RETAINING RINGS SOLD IN PAIRS.

Edmund Optics®

TITLE	M23.2 Retaining Ring Pair for 20mm Diameter Optics						
DWG NO	85556	MATERIAL	BLACK ANODIZED ALUMINUM	SHEET 1 OF 1	REV	000	

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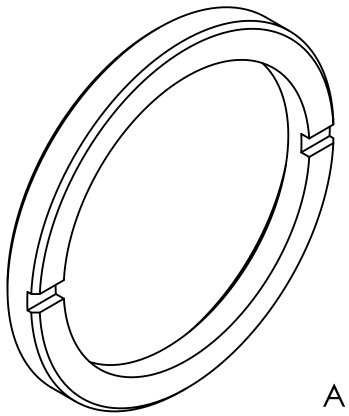
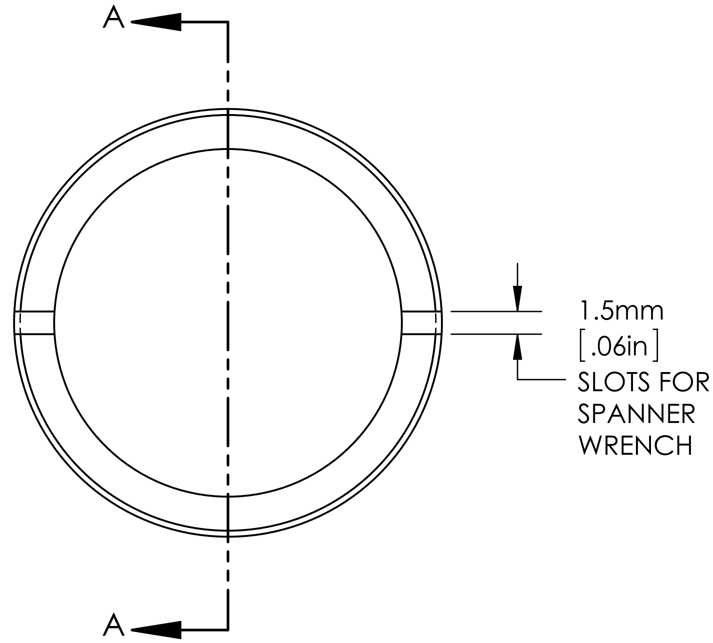
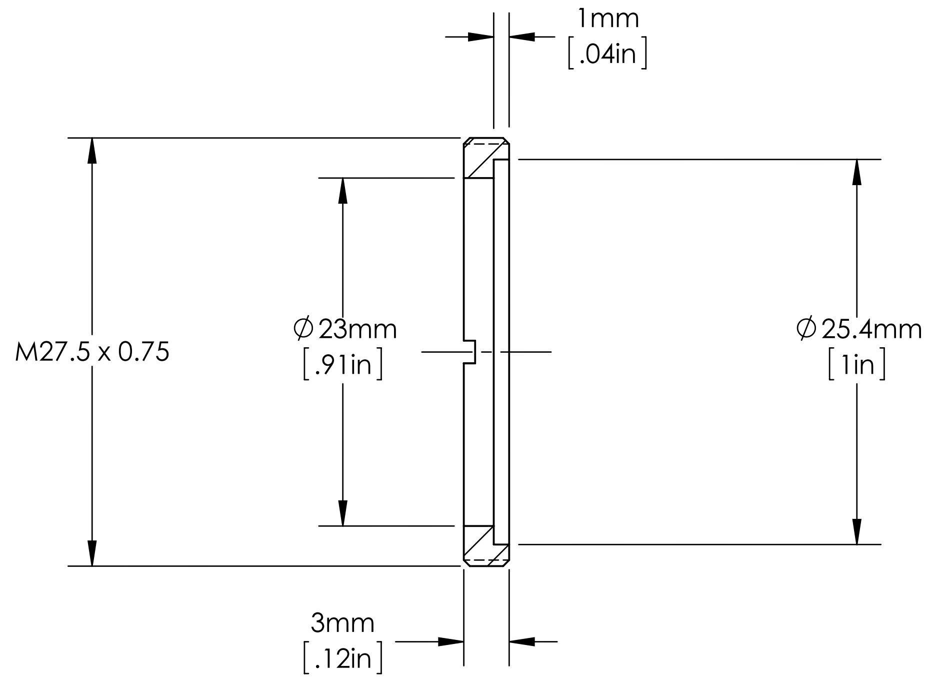
DIMENSIONS ARE IN mm [INCHES]







SECTION A-A

NOTES:

1. RETAINING RINGS SOLD IN PAIRS.

Edmund Optics®

TITLE	M27.5 Retaining Ring Pair for 25.4mm Diameter Optics						
DWG NO	85596	MATERIAL	BLACK ANODIZED ALUMINUM	SHEET 1 OF 1	REV	000	

NOTES:
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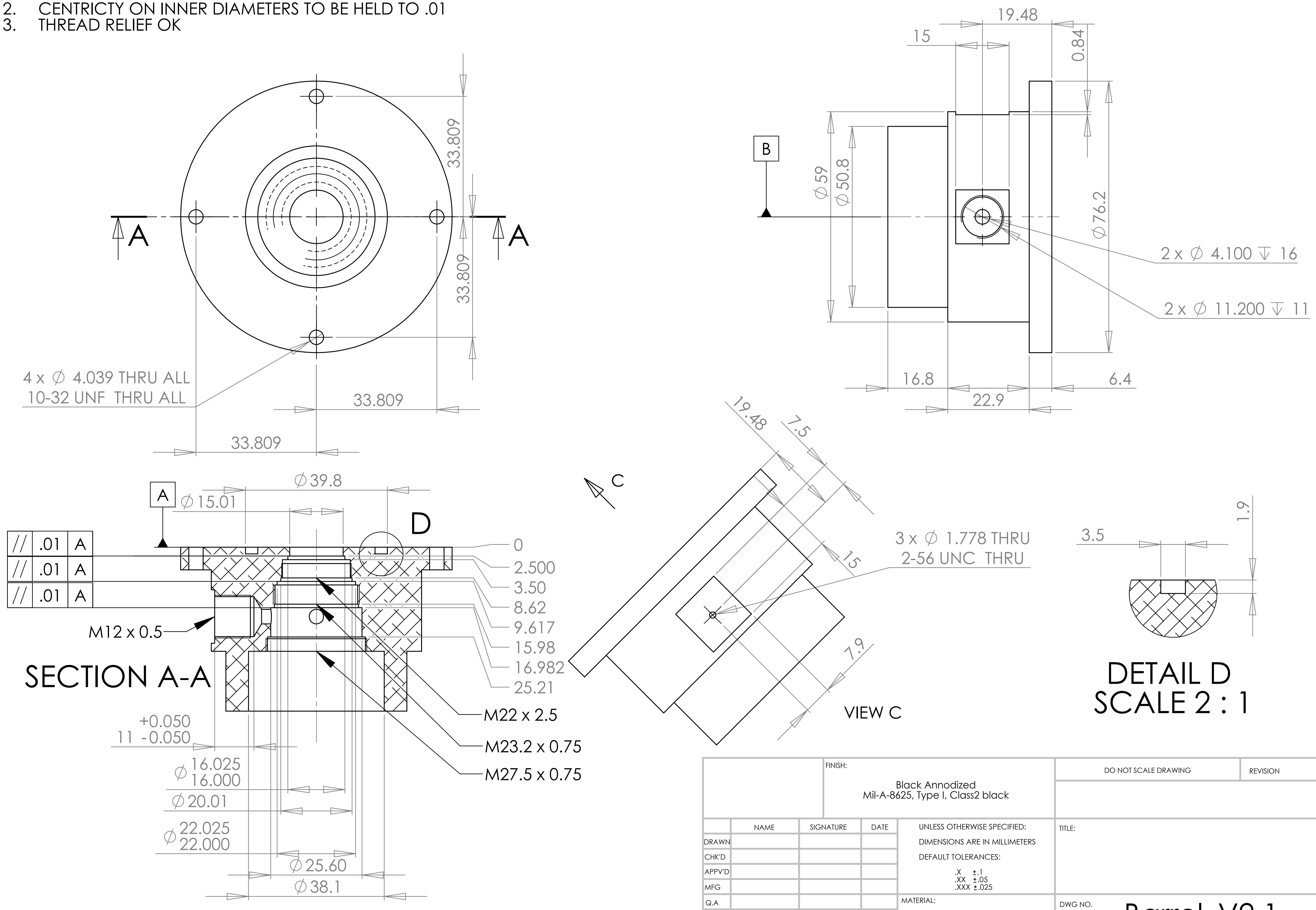
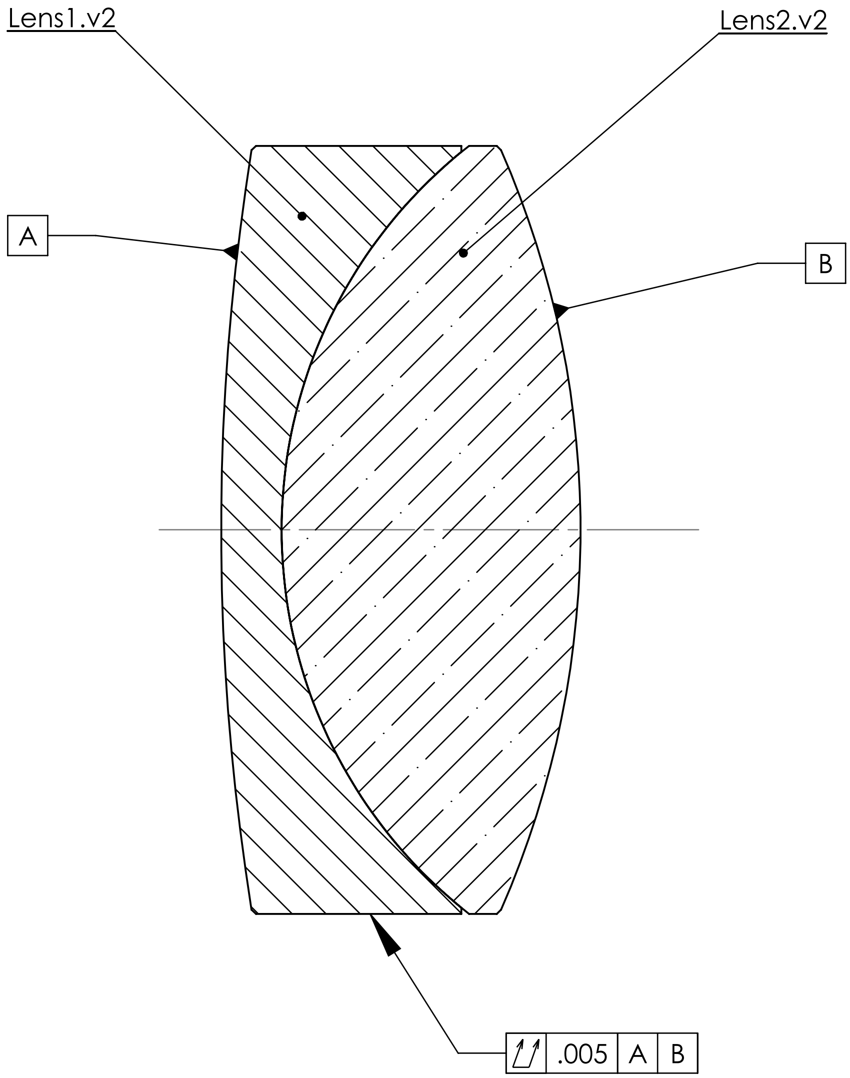
2. CENTRICTY ON INNER DIAMETERS TO BE HELD TO .01
3. THREAD RELIEF OK



		FINISH: Black Annodized Mil-A-8625, Type I, Class2 black		DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS DEFAULT TOLERANCES: .X ±.1 .XX ±.05 .XXX ±.025	TITLE:
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL: Aluminum Alloy 6061	DWG NO. Barrel_V2.1 — A3
				WEIGHT:	SCALE:1:1 — SHEET 1 OF 1



AR COATED at 650nm <0.2%

LEFT SURFACE	MATERIAL	RIGHT SURFACE
		ETD of 0.005

ISO ELEMENT DRAWING INDICATIONS ACCODING TO ISO 10110

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NEXT ASSY	USED ON
APPLICATION	

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SIZE	DWG. NO.	REV.
A	Doublet	

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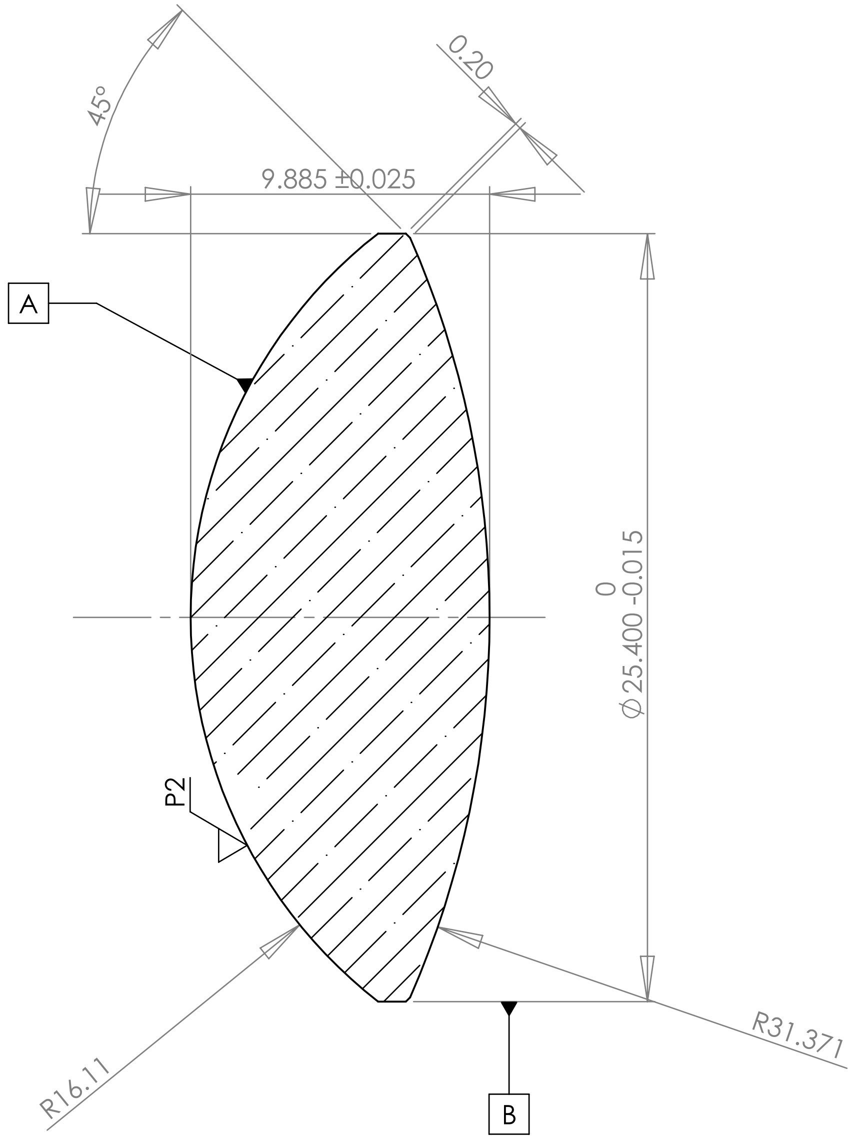


AR COATED at 650nm <0.2%

LEFT SURFACE	MATERIAL	RIGHT SURFACE
∅ 25.4 Prot. Chamfer : 0-0.2 3/ 5.3(0.5) 4/ 0.5' 40-20 Scratch Dig	GLASS: N-BK7 Nd=1.5168;Vd=64.167336 0/ 5 1/ 3 x 0.16 2/ 4;4	∅ 25.4 Prot. Chamfer: 0-0.2 3/ 2.8(0.5) 4/ 0.5' 40-20 Scratch Dig

ISO ELEMENT DRAWING INDICATIONS ACCODING TO ISO 10110

NEXT ASSY	USED ON
APPLICATION	

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

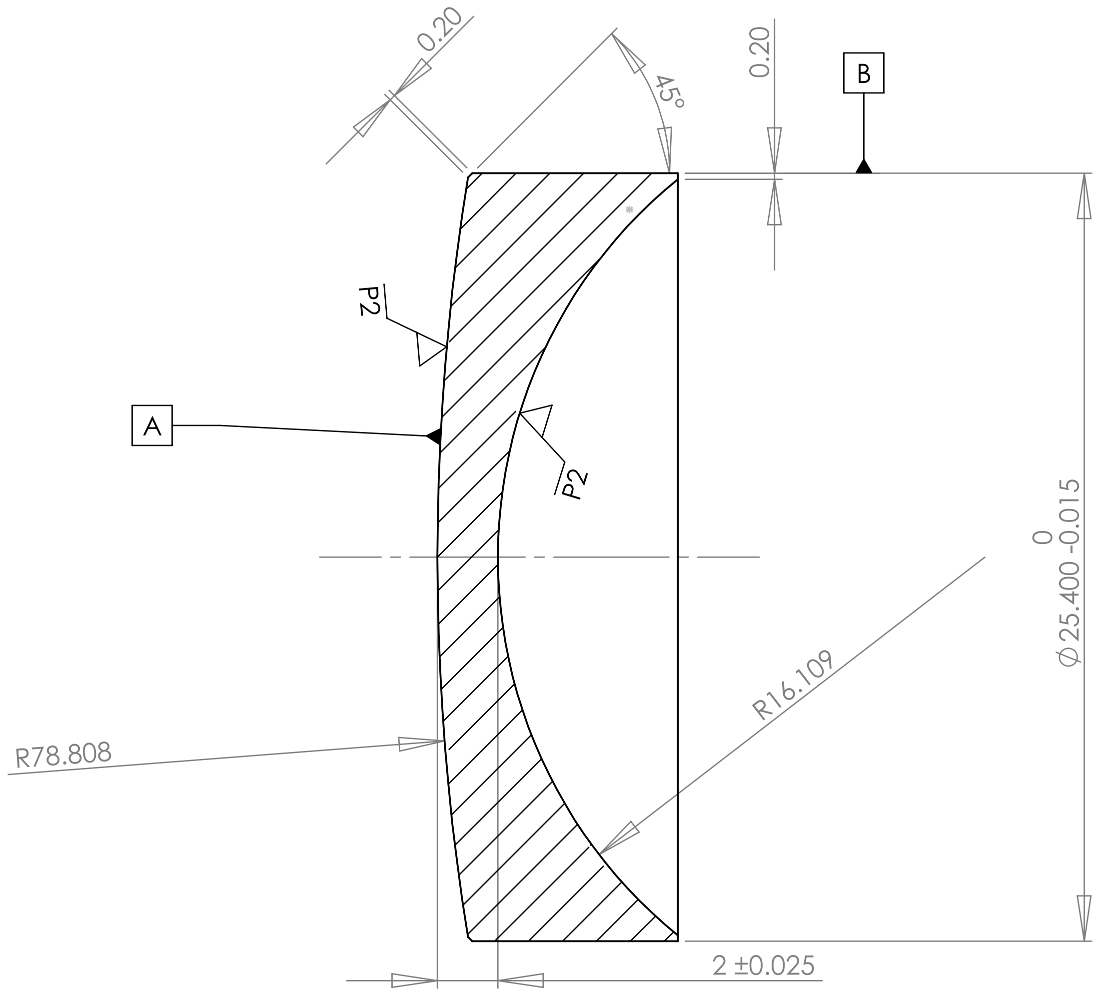
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SIZE	DWG. NO.	REV.
A	L1.v2	

SCALE:4:1 | WEIGHT: | SHEET 1 OF 1



AR COATED at 650nm <0.2%

LEFT SURFACE	MATERIAL	RIGHT SURFACE
Ø 22 CA Prot. Chamfer: 0-0.2 3/ 1(0.5) 4/ 0.5' 40-20 Scratch Dig	GLASS: N-SF11 Nd=1.78472;Vd=25.679998 0/ 5 1/ 3 x 0.16 2/ 4;4	Ø 22 CA Prot. Chamfer: 0-0.2 3/ 4.1(0.5) 4/ 0.5' 40-20 Scratch Dig

ISO ELEMENT DRAWING INDICATIONS ACCODING TO ISO 10110

NEXT ASSY	USED ON
APPLICATION	

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

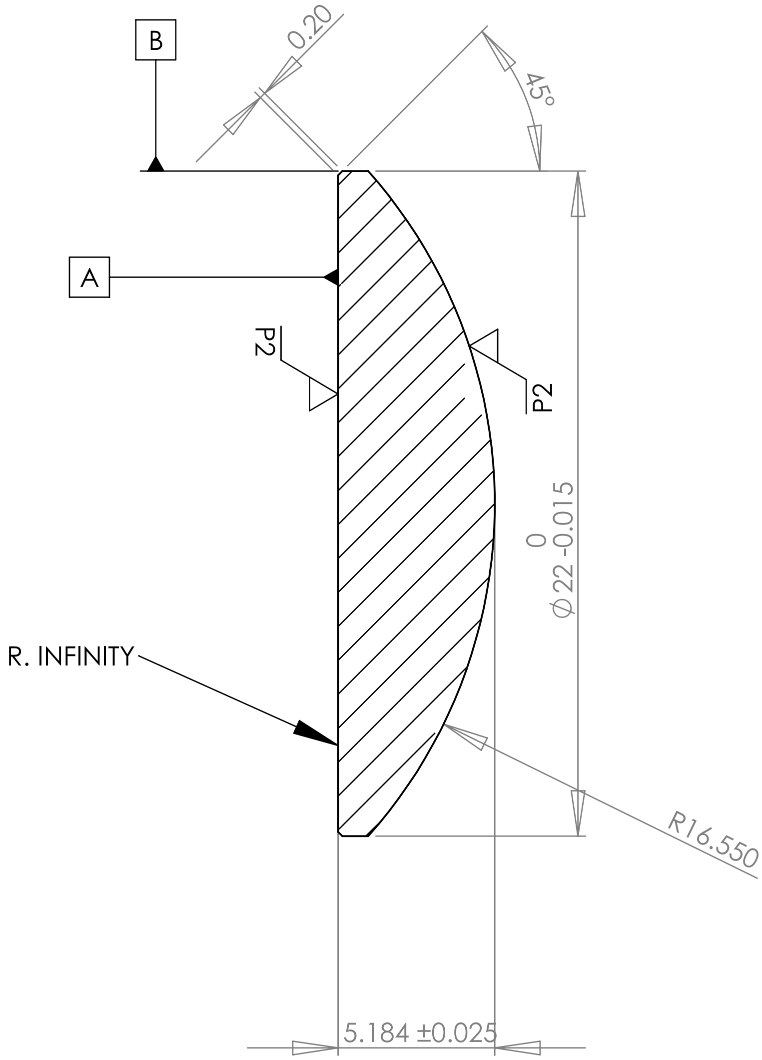
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SIZE	DWG. NO.	REV.
A	L2.v2	

SCALE:4:1 WEIGHT: SHEET 1 OF 1



AR COATED at 650nm <0.2%

LEFT SURFACE	MATERIAL	RIGHT SURFACE
∅ 19.8 CA	GLASS: N-SF11	∅ 19.8 CA
Prot. Chamfer: 0-0.2	Nd=1.78472;Vd=25.679998	Prot. Chamfer: 0-0.2
3/ 1(0.5)	0/ 5	3/ 3.8(0.5)
4/ 0.5'	1/ 3 x 0.16	4/ 0.5'
40-20 Scratch Dig	2/ 4;4	40-20 Scratch Dig

ISO ELEMENT DRAWING INDICATIONS ACCODING TO ISO 10110

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

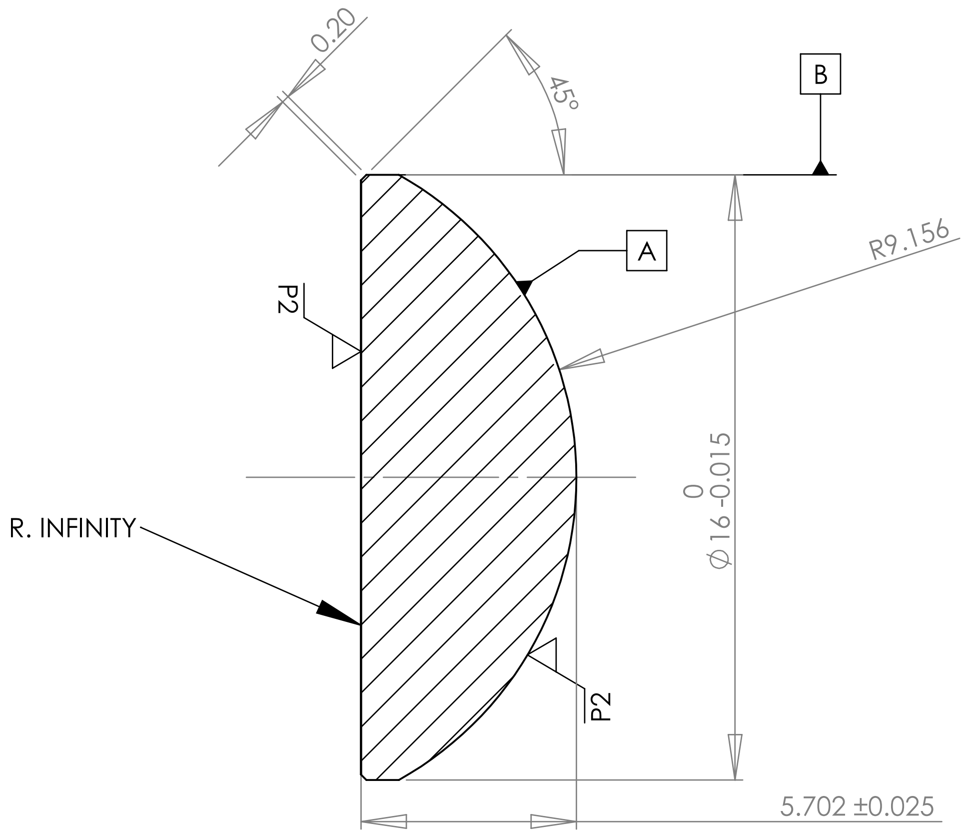
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SIZE	DWG. NO.	REV.
A	L3.v2	

SCALE:4:1 | WEIGHT: | SHEET 1 OF 1



AR COATED at 650nm <0.2%

LEFT SURFACE	MATERIAL	RIGHT SURFACE
Ø 7.2 CA Prot. Chamfer 3/ 1(0.5) 4/ 0.5' 40-20 Scratch Dig	GLASS: N-SF11 Nd=1.78472;Vd=25.679998 0/ 5 1/ 3 x 0.16 2/ 4;4	Ø 7.2 CA Prot. Chamfer 3/ 2.6(0.5) 4/ 0.5' 40-20 Scratch Dig

ISO ELEMENT DRAWING INDICATIONS ACCODING TO ISO 10110

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

MATERIAL

FINISH

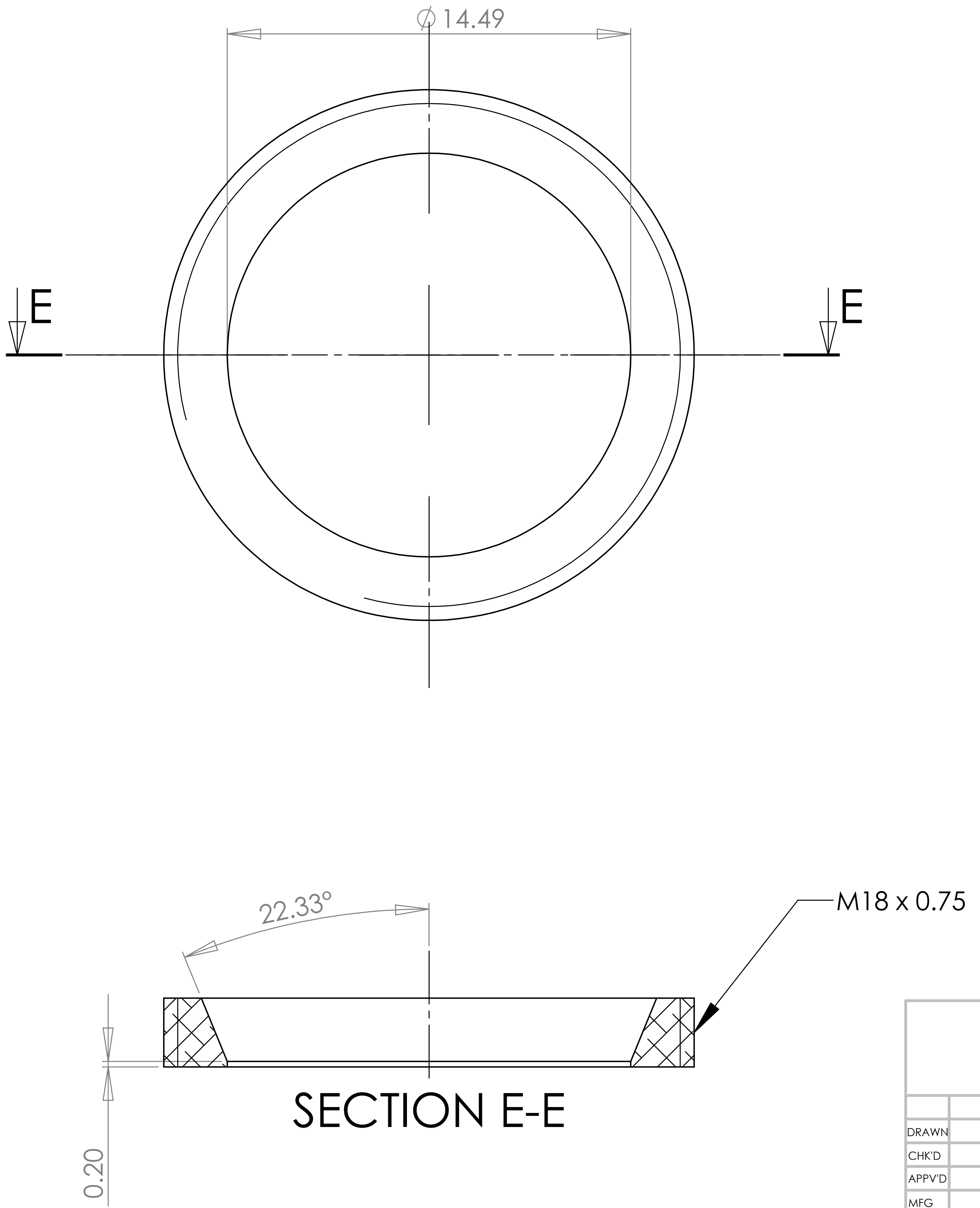
NEXT ASSY | USED ON

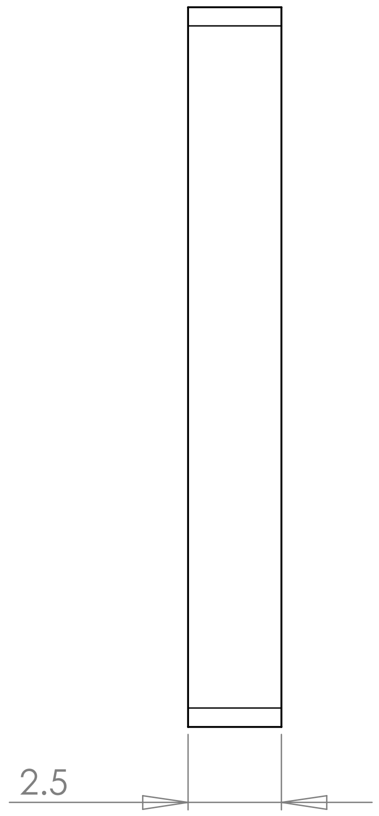
APPLICATION

DO NOT SCALE DRAWING

SIZE	DWG. NO.	REV.
A	L4.v2	

SCALE:5:1 | WEIGHT: | SHEET 1 OF 1





FINISH: Black Annodized Mil-A-8625, Type I, Class2 black		DO NOT SCALE DRAWING	REVISION	

	NAME	SIGNATURE	DATE	
DRAWN				UNLESS OTHERWISE SPECIFIED:
CHK'D				DIMENSIONS ARE IN MILLIMETERS
APPV'D				DEFAULT TOLERANCES:
MFG				.X ±.1 .XX ±.05 .XXX ±.025
Q.A				

TITLE:

MATERIAL: Aluminum Alloy 6061

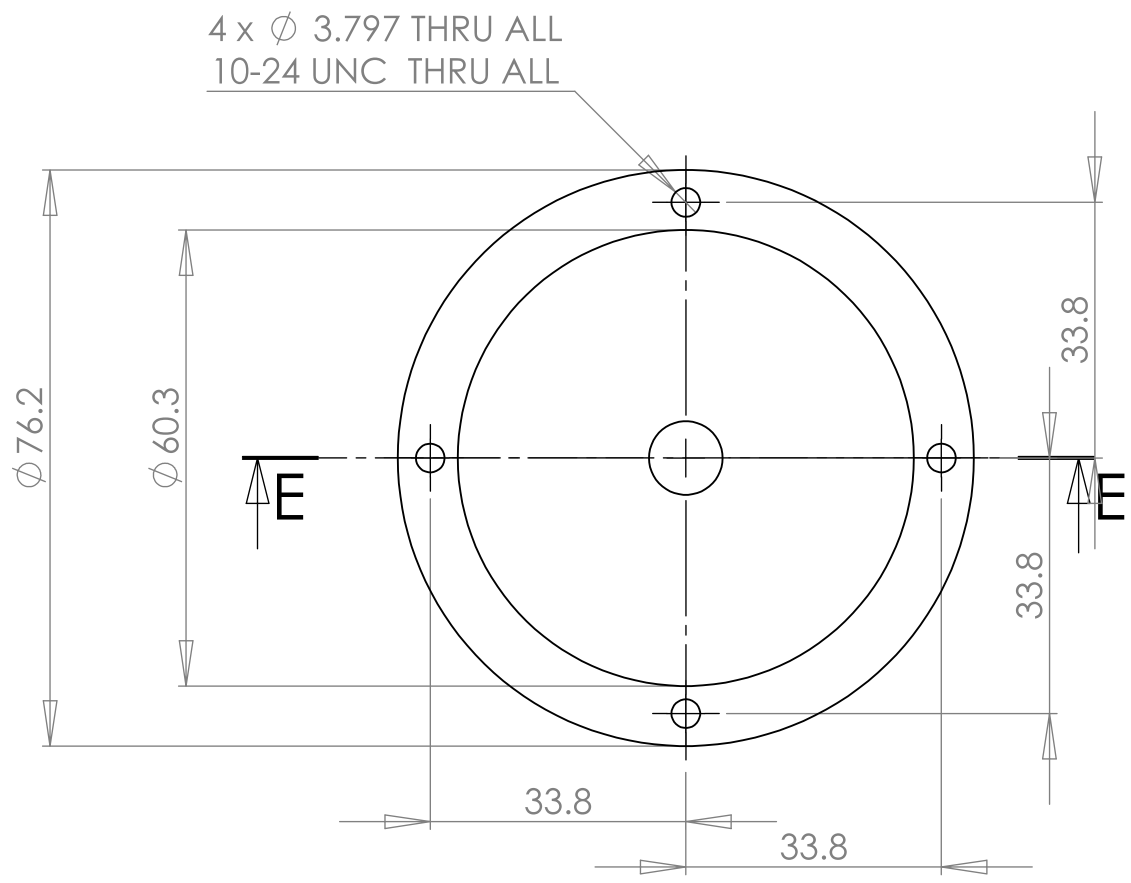
DWG NO. RR4

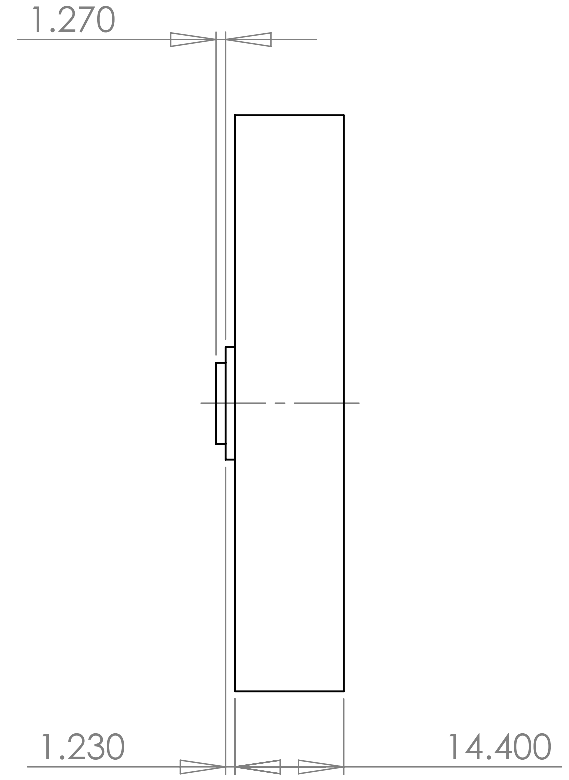
A3

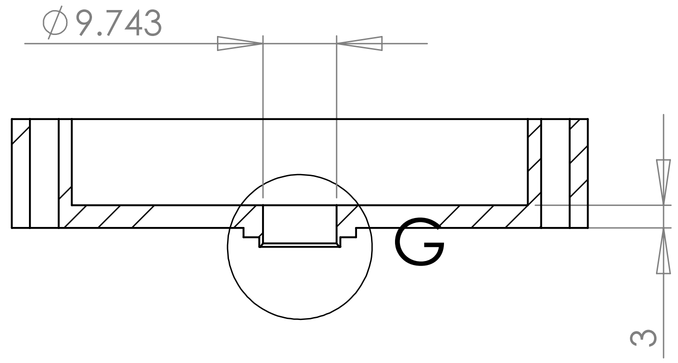
WEIGHT:

SCALE:5:1

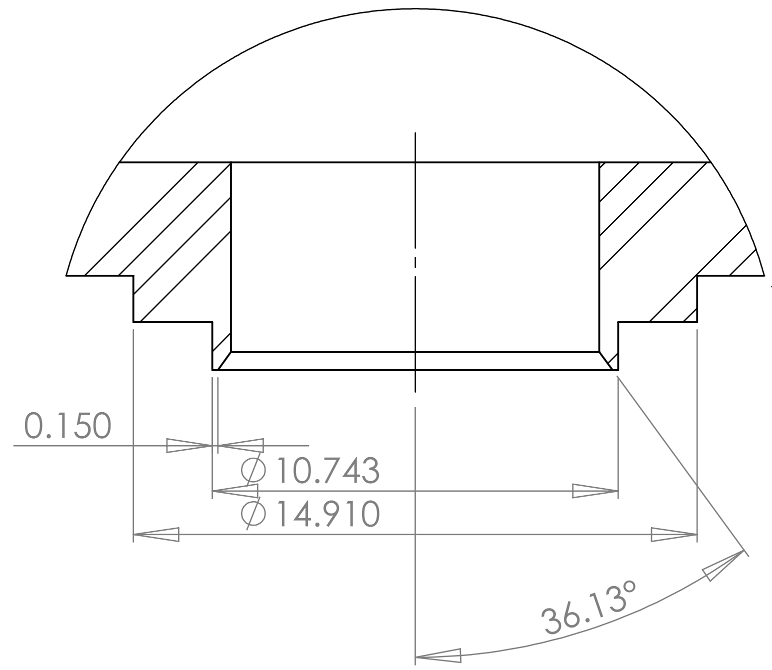
SHEET 1 OF 1







SECTION E-E



DETAIL G
SCALE 5 : 1

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

FINISH:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
DEFAULT TOLERANCES:
.X ±.1
.XX ±.05
.XXX ±.025

MATERIAL:
Polyjet VeroWhite

WEIGHT:

DO NOT SCALE DRAWING

REVISION

TITLE:

DWG NO.

TANK

A3

SCALE:1:1

SHEET 1 OF 1