1 Introduction:

The main objective of this project is to design a polarization state generator that will be mounted on a mini-table using 1/4-20 screws. The object of the design is to make the system with the proper tolerances as well as the right material so that the system will be able to generate the proper polarization state. The light coming out of the system must be diverging as well.

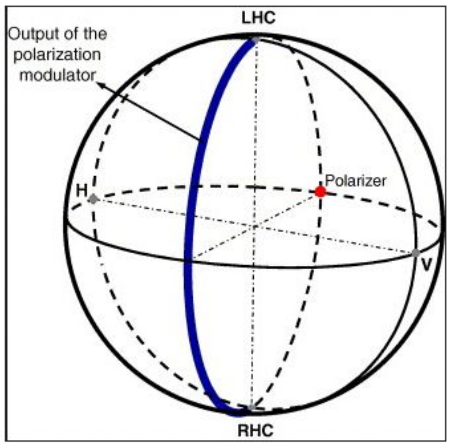

Figure 1: The Poincare Sphere

2 Requirements:

2.1 Top Level Requirements:

Requirement	**Value**	**Comment**
Laser FOV	$14°$	
stage resolution	$10 arcmin$	
stage range of travel	360°C	
stage 1 speed	N/A	Manual control
stage 2 speed	$> 60°/sec$	Motorized control
stage 3 speed	$> 60°/sec$	Motorized control
Load limit	100 N	
Stage Parallelism tolerance	$< 80\mu m$	
Stage Concentricity tolerance	$< 80\mu m$	
Stage Wobble tolerance	$< 50\mu m$	
Spacing tolerance	$< 20\mu m$	

2.2 Operational Requirements:

Requirement	**Value**	**Comment**
Temperature range	$-20°$ C - $50°$ C	

2.3 Survival Requirements:

Requirement	**Value**	**Comment**
Temperature range	$0°$ C - $60°$	
Life time	3.10^6 Full turns	

2.4 Limitations:

Requirement	Value	Comment
Box Size	8 x 18 x 7	Portable
Materials	Aluminum 6061 Alloy	Except for purchase part
Weight	30LBF	Portable

2.5 Materials:

Requirement	Value	Comment
Stages	Stainless Steel	OPTO-SIGMA and Newport Optics
Custom Patrs	Aluminum 6061 Alloy	

2.6 Interface requirements:

The system must be assembled on a mini-table using 1/4-20

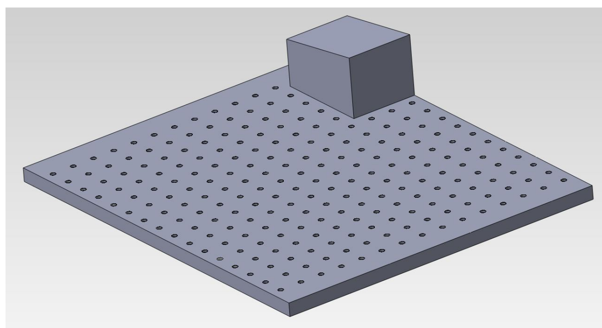

Figure 2: Interface

2.7 Determined parameters:

Requirement	Value	Comment
Polarization element diameters	1”-2”	
stage ID	4”	
Laser to Polarizer Spacing	50mm	
Stage 1 to Stage 3 Spacing	50mm	
Laser to Stage 3 Spacing	180mm	
Stage 2 position	between 1 and 3	

3 Design Concept:

The figures below show most of the detailed sketches of the system components. The system is going to consist of three stages, where the first one is a manual stage purchased from Opto-Sigma, and the last two are motorized stages from Newport Optics. The table where everthing is assembled on and the all other custom parts will be build here in our machine-shop. All custom parts are going to be made using Aluminum 6061 alloy.

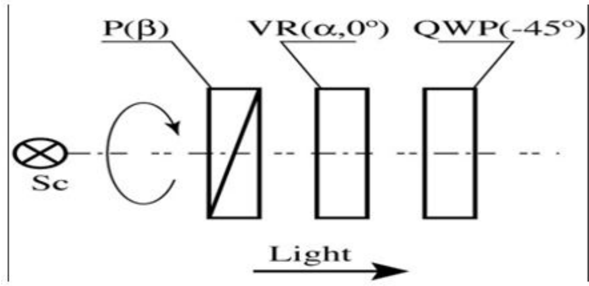

Figure 3: Set up of the PSG

The figure above show how the system is going to set up. The element Sc represents the laser source that will be used to illuminate a the scene, P is a linear polarizer, VR is going to be a linear half wave plate, and QWP is a linear quarter wave plate. The purpose of the linear polarizer is clean up the polarization of the light coming out of the laser. Then the linear half wave plate is going to rotate this polarization state around the equator of the Poincare sphere so that we will be able to get access to all of the linear polarization states. The quarter wave plate is going to move our polarization state along the poles of the Poincare sphere to get all elliptical polarization states.

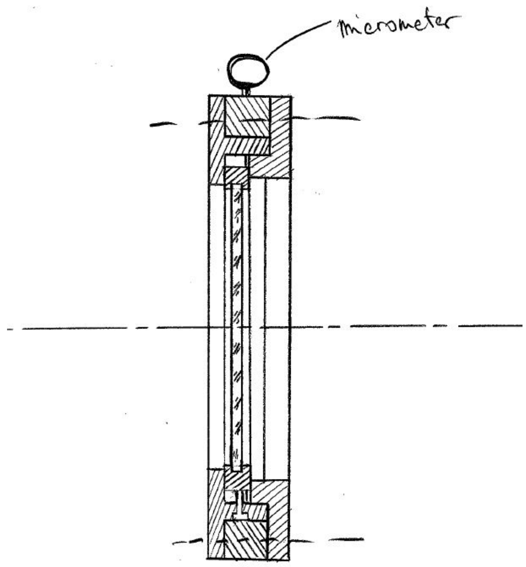

Figure 4: Stage sketch

Fig. 4 shows a hand sketch of how the polarizer is going to be mount on the manual rotation stage. This stage is going to be set only once since we won't need to move around. It's purpose is just to clean the laser's initial polarization.

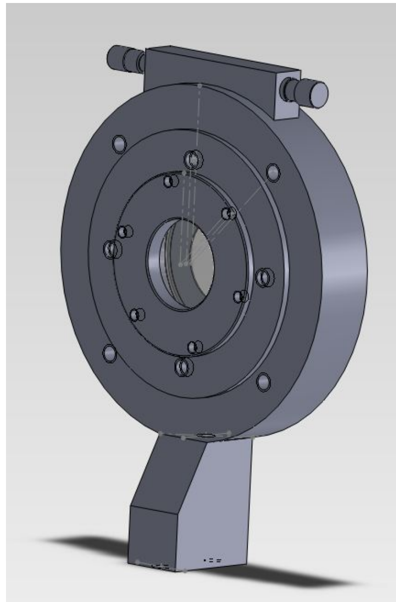

Figure 5: Rotation Stage

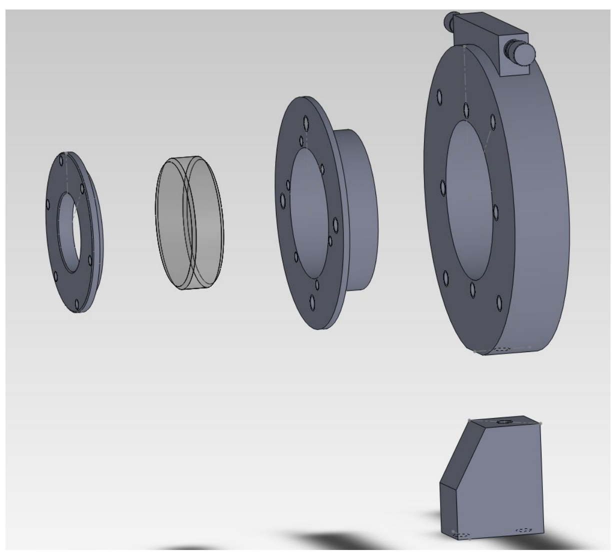

Figure 6: Manual Stage Assembly

4 Design Details:

The design is simple and only requires a $1/4 - 20$ screws to mount everything on the optical breadboard. Stages are not easy things to design, for that reason all stages will be purchased intead of custom making them. Besides making the stages will cost too much. The choice of the materials to be used for the custom parts is due to the fact the Aluminum is easy to work on and has a very low cost. However the choosing the stages has more to to do with the their performance as well the cost. The table below shows some of the parameters of the stage:

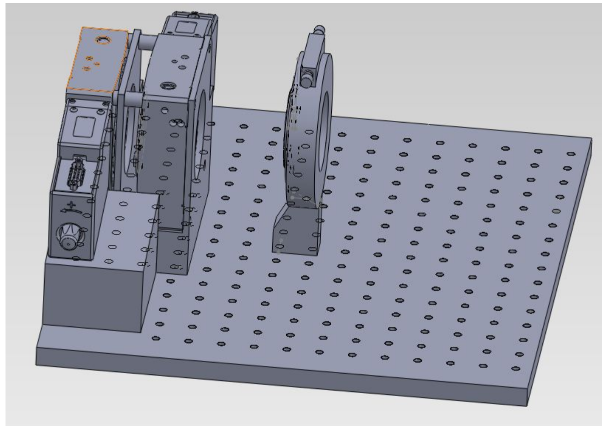

Figure 7: Manual Stage Assembly

Fig. 7 shows the system assembly, where the empty space on the breadboard is reserved for mounting the laser (illuminator) and all small electronic devices, such as microcontroller board. To better see all parts, Fig. 8 shows an exploded view with more details.

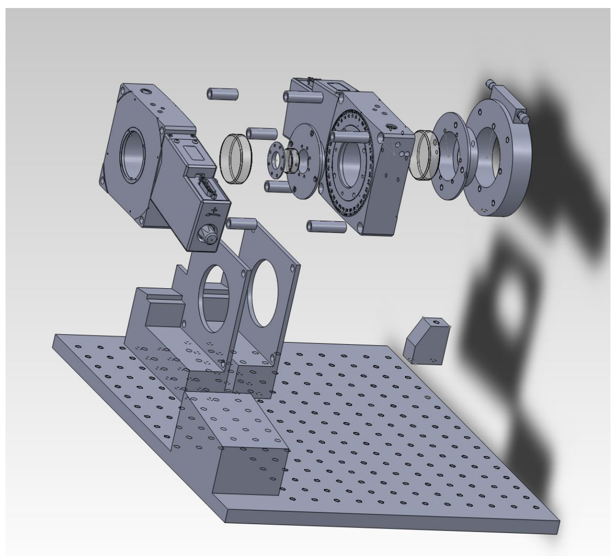

Figure 8: Manual Stage Assembly

4.1 Budget:

The detail price of all parts is tabulated below. Some of the parts are purchased from vendors such as Opto-Sigma, and Newport Optics. However other parts are custom made. so the price for the custom parts may vary depending on the machine-shop that is going to make the parts. In our case here, the price for the custom parts is determine based on a quote provided by a local machine-shop.

Part	Unit Cost	Quantity
Manual Stage	795	1
Motorized Stages	3800	2
Custom cover	350	2
Custom adapter	350	2
Brackets	500	2
Custom Stage Support	300	1
$1/4-20$ Screws	50	100
mini-table	1000	1
Polarizer	300	1
HWP	500	1
QWP	500	1

The total price comes to 8,445 dollars

5 Requirement Verification:

Requirement	**Value**	**Comment**
stage resolution	$5arcmin$	
stage range of travel	360°C	
stage speed	N/A	Manual control
Load limit	196.0 N	
Stage Parallelism tolerance	$< 60\mu m$	
Stage Concentricity tolerance	$30\mu m$	
Stage Wobble tolerance	$< 30\mu m$	

the table above show the specs of the manual stage. By comparison we could see that all requirements are met.

Model	**URS100BCC**
Travel Range	360 °
Minimum Incremental Motion	0.002 °
Uni-directional Repeatability, Guaranteed	0.002 °
Absolute Accuracy, Guaranteed	0.023 ° or ± 0.0115 °
Maximum Speed	80 °/s
Wobble, Guaranteed	50 or ± 25 µrad
Eccentricity, Guaranteed	3 or ± 1.5 µm
MTBF	20000 h @ 25% load and 30% duty cycle h
Uni-directional Repeatability	0.002 °
Maximum Torque (Mz)	1 Nm
Transversal Stiffness (kα)	10 µrad/Nm
Normal Load Capacity (Cz)	300 N

Figure 9: Motorized stage specs

The specs of the motorized stage is also great and meet all of our customer requirements. Here the stage resolution is given in degrees. After conversion we get 0.7 arcmin, which great compared to 5 arcmin.

5.1 Parallelism:

Parallelism means the parallel error in the whole surface of the table of a linear or a rotation stage. Fix a linear stage on a precision granite table. Put a dial gauge on the granite table. Put the probe (point) of the gauge on the surface of a stage. Move the dial gauge as the probe (point) runs the whole surface of the table of the stage. The maximum difference of the gauge is the Parallelism of the stage.

5.2 Concentricity:

Concentricity means the centration error of the table of a rotation stage. Fix a rotation stage on a precision granite table. Fix a dial gauge on the granite table as the probe (point) of it contacts with the side surface of the rotation table. The half of the maximum difference of the gauge is the Concentricity of the rotation stage when it moves in 360 degrees.

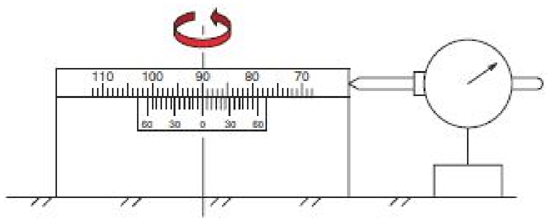

Figure 10: Concentricity Testing Procedure

5.3 Wobble:

Wobble means the parallel error of the table of a rotation stage. Fix a rotation stage on a precision granite table. Fix a dial gauge on the granite table as the probe (point) of it contacts with the edge of the top surface of the rotation table. The maximum difference of the gauge is the wobble of the rotation stage when it moves in 360 degrees.

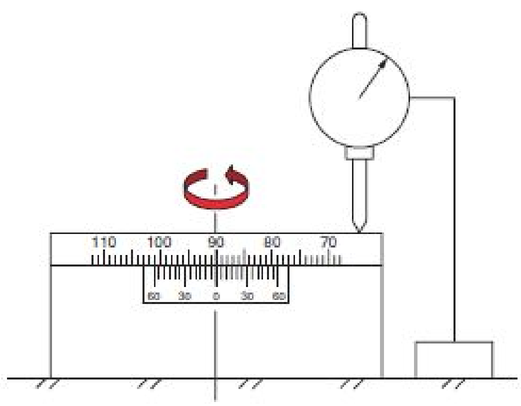

Figure 11: Wobble Testing Procedure

5.4 Repeatability:

Repeatability is the precision in which the stage displacement yields the same result.To check for the stages' (Motorized stages) repaetability, we move the stage and stop it at regular intervals throughout the full movement of the stage. At each point, measure the horizontal inclination angle using a laser interferometer. The maximum difference of inclination is the repeatability error of the stage.

5.5 Life time:

based on the calculations that we have done, we determined that stages 2 and 3 are going to have a life time of $n = 1.4.10^8$ rotations and the manual stage (stage 1) is going to have $n = 5.2.10^6$ full rotations. Both life times exceed our requirement of 3 millions full turns.

6 Fabrication Plan:

6.1 Fabrication/Procurement:

The fabrication process for the system is broken into two parts. The first part is the easier one where parts such as the motorized stages, the screws, and polarization elements are to be designed and fabricated by a merchant. The second parts is where our own design, fabrication and testing proceedure comes to play. All custom parts are made from aluminum 6061 alloy, and are fabricated in our machine shop according to the drawings.

6.2 System Assembly and Alignment:

6.2.1 Assembly:

The Assembly process is decribed below:

- Try to not touch any optical element's active faces, if not dirty
- If dirty, clean it up using acetone
- Drop polarization elements into inserts/adapters
- Place adapter/insert into their respective rotation stages
- Put screw to mate the adapter and it rotation stage
- Then insert the cover to hold the polarization element in place
- Insert screws to bond the cover
- Mount the OptoSigma stage holder onto the optical breadboard using $1/4 - 20$ screws
- Mount the manual stage on top of the stage holder
- Mount the motorized stage's bracket on the optical breadboard using $1/4 - 20$ screws
- Mount motorized stage (stage 2) on the bracket using $1/4 - 20$ screws
- Insert the longer spacers on stage 2
- Insert the shorter spacers after stage 2
- Mount the motorized stage's bracket on the optical breadboard using $1/4 - 20$ screws
- Mount motorized stage (stage 3) on the bracket using $1/4 - 20$ screws
- Insert spacers on stage 3

6.2.2 Alignment:

The system alignment is mostly dictated by the tolerancing on of the design, as well as using back reflections from a HeNe laser. After the optical breadbord is design with tight tolerances, we placed it in front of a well align HeNe laser, then mounted each element on it by adjusting the height and tilt of element until we got a back reflection that goes straight back into the laser cavity.

7 Preliminary System Test Plan:

8 Appendices:

8.1 Preliminary Calculations:

Since we want to the exiting beam to be diverging, we need to determine the maximum distance between the laser and the entrance surface of the last polarization element FFOV = 14° D = 2in = 50.8mm

$$L_{max} = \frac{D}{2}\frac{1}{tan(7^\circ)} \tag{1}$$

$$L_{max} = 206mm$$

To determine the life time of the stages, we need to know the total of the custom parts and the polarization elements. Since the QWP weighs the most, we will used it to detemine the minimum life time of the stages.

$$M_{total} = M_{QWP} + M_{CP} \tag{2}$$

$$M_{total} = 2kg$$

The equation to determine the life time of the stage is defined as follow:

$$L = 50\frac{C^3}{8P^3} \tag{3}$$

L: Running life time (km)
C: Static allowable load 100N
P: Imposed load

$$P = M_{total} * 9.81m/s^2 = 19.62N$$
$$L = 827.53km$$

$$L = 2\pi\frac{D}{2}n \tag{4}$$

n: Is the number of rotations Solving for n, we get:

$$n = 5.2.10^6 \text{ For the manual stage } n = 1.4.10^8 \text{ For the manual stage}$$

8.2 Drawings:

files/Final Project/Adapter1.jpg

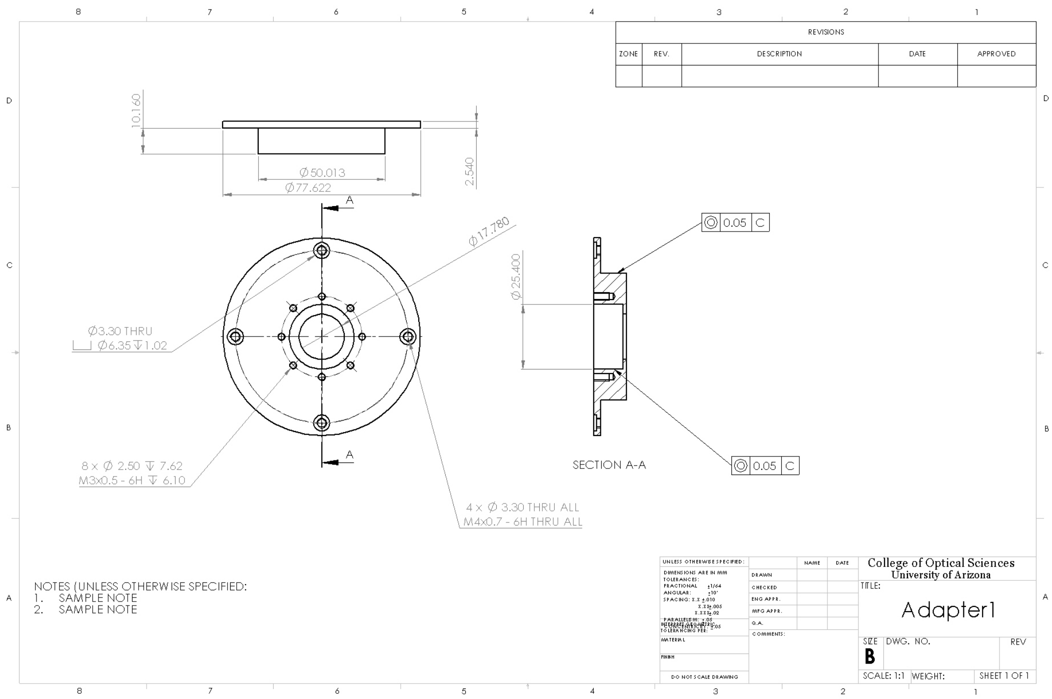

Figure 12: Adapter

files/Final Project/Insert.jpg

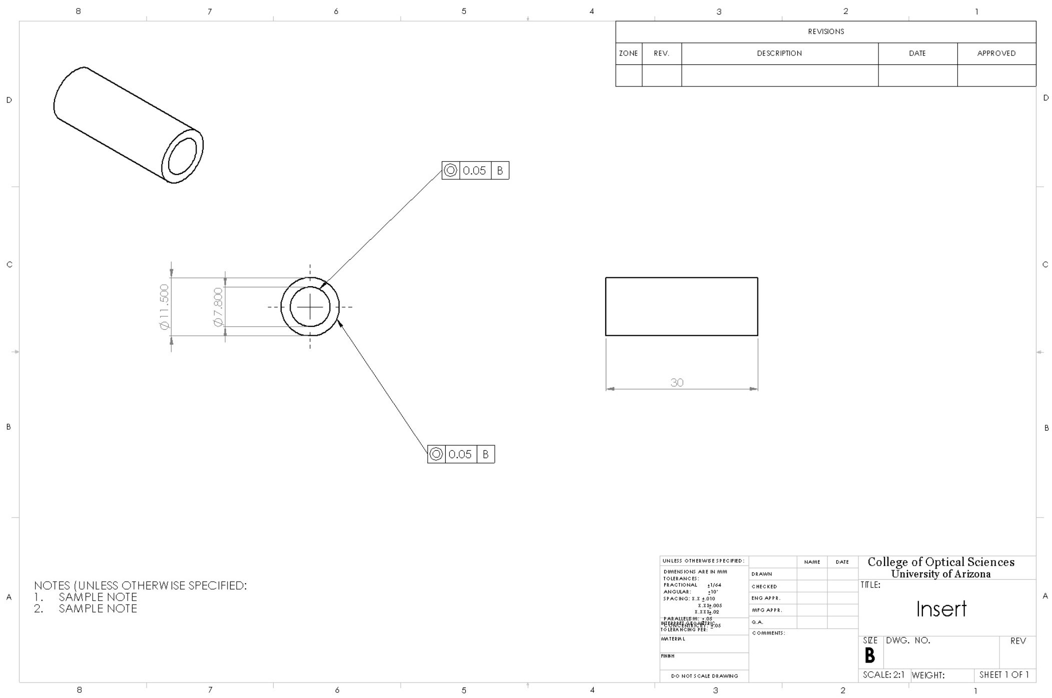

Figure 13: Insert

files/Final Project/Mini Table.jpg

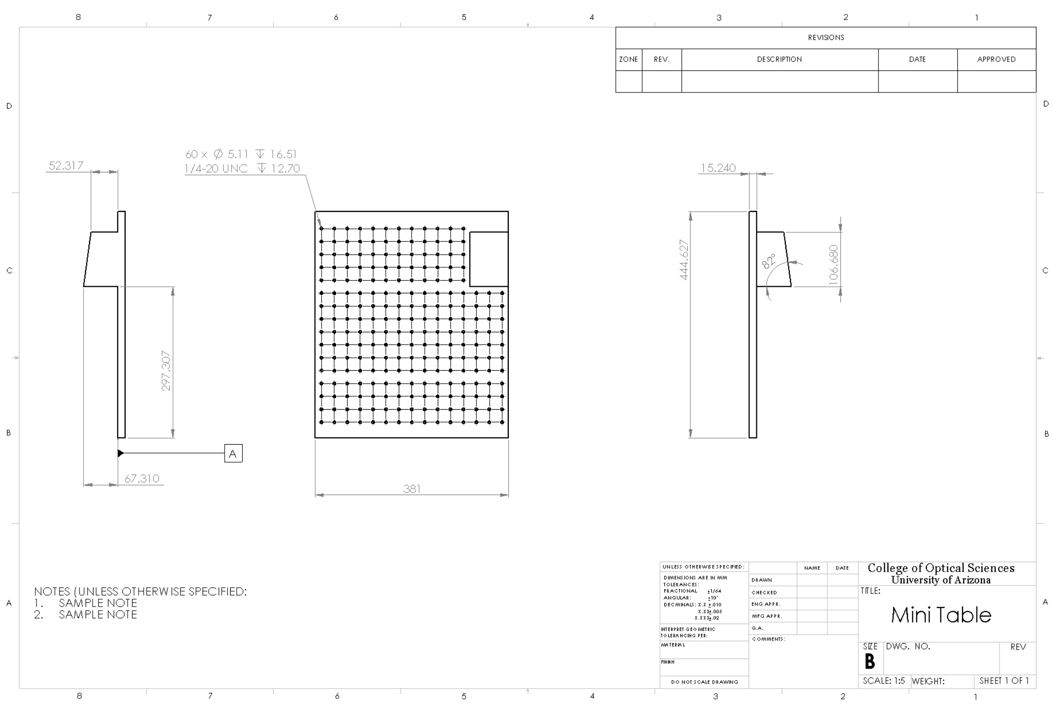

Figure 14: Optical breadboard

files/Final Project/OptoSigmaStage.jpg

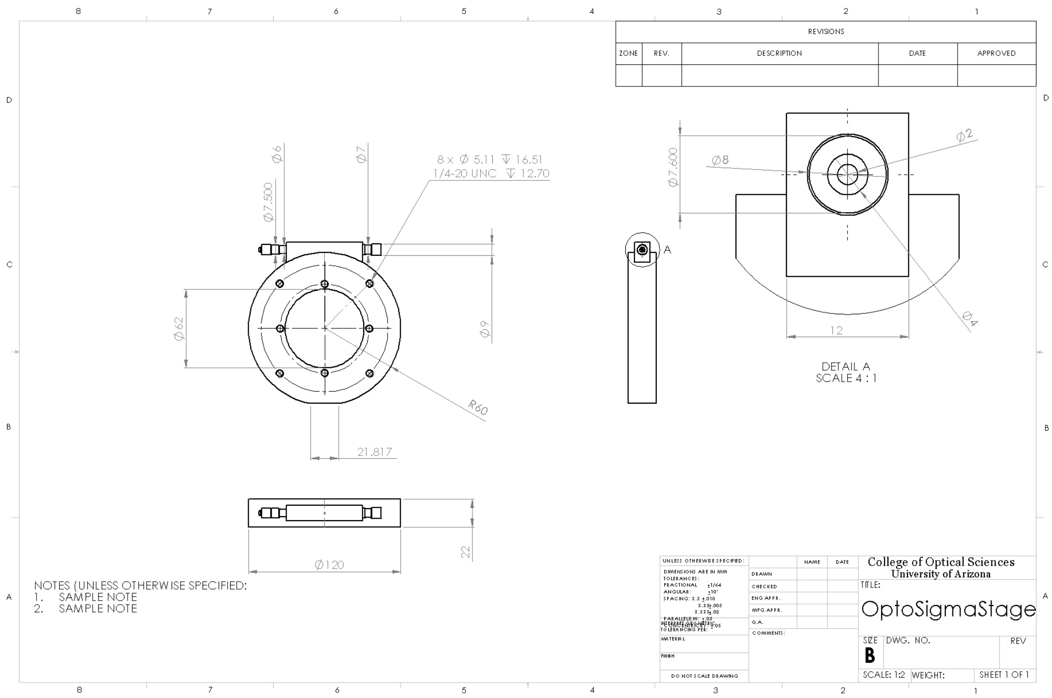

Figure 15: Manual Stage

files/Final Project/Support.jpg

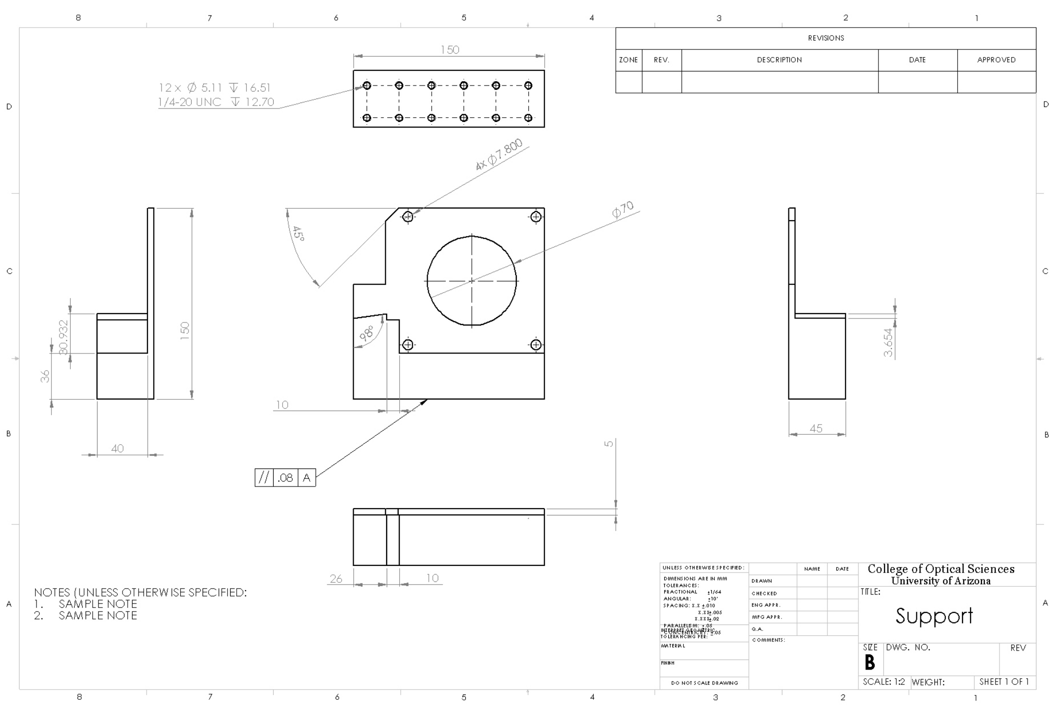

Figure 16: Support