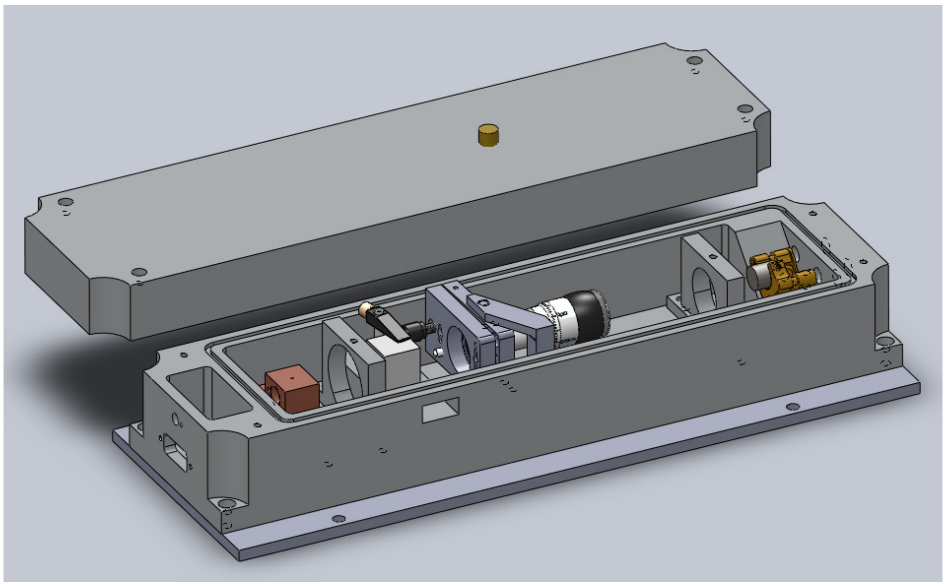
Design, Construction, and Characterization of an Interference-Filter Stabilized External-Cavity Diode Laser



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Executive Summary

As scientists understand more about the principles of atomic physics, they need tools which allow them to conduct precise measurements which reveal the fundamental properties of the building blocks of matter. One of the most important of these tools is the laser—a coherent light source with well defined frequency—that is capable of exciting and even cooling atoms. In this report we develop techniques for measuring the linewidth and stability of narrow bandwidth interference filter-stabilized external cavity diode lasers. Based on the characterization of two prototypes lasers, we identified key design parameters affecting laser linewidth and stability. Using these results, we designed a monolithic, hermetically sealable, diode laser using the same interference based feedback system.

Using characterization techniques found in literature, such as self-heterodyne and heterodyne interference linewidth measurements, we measured an upper limit for the prototype diode laser linewidth of 10 kHz. This is significantly less than the upper limit of 100 kHz defined in the project proposal. We ensured the output was stable and capable of continuous single mode operation using a Fabry–Pérot interferometer. Precise focal lengths of optical components within the cavity were measured using a conventional knife-edge technique. The effects of misalignment on laser performance were investigated to provide reasonable tolerances for machining and adjustment ranges of components. The optical transmission of a commercial and a custom manufactured interference filter were characterized using variable angle transmission tests. This data was used to determine the tuning range and precision of the optical filters within the cavity to achieve the desired frequency range and sensitivity of hundreds of GHz and 1 GHz respectively.

We have demonstrated that the desired performance characteristics can be achieved using interference filter-stabilized diode lasers. Therefore, we recommend a more robust laser should be fabricated whose design is outlined and justified in this report. This monolithic design will have improved stability and increased sensitivity to frequency tuning. This device must be characterized using the methods developed when testing the prototype lasers to ensure it meets its performance specifications. We outline issues with these testing methods and explain why we believe a conventional heterodyne measurement using two lasers would provide more accurate results than the self-heterodyne measurement. However, this will require the implementation of a control system to lock the lasers together to limit drifting of the beat frequency. This drifting is currently preventing accurate linewidth measurements. After completion of the above mentioned experiments and performance goals for the laser are met, multiple laser units can be manufactured for general use for atomic physics applications.

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Introduction

This report summarizes a list of recommendations for the UBC QDG Lab that are essential for the use of the external-cavity diode laser (ECDL) for its intended purpose. A final design for the ECDL has been submitted to the UBC Department of Physics and Astronomy Machine Shop, and the final product will need to be tested and characterized before it can be put into operation.

The ECDL project was started for the purposes of building a low-cost and functionally robust master laser with a very narrow linewidth. In recent years, atomic physicists have turned to diode lasers as a relatively cheap and effective alternative to conventional coherent light sources for their research. Being both small in size and not requiring elaborate cooling systems, diode lasers can be easily incorporated into most optical systems. Traditionally, diode lasers could not compare in wavelength coverage and output power to traditional dye lasers, but technological advancements have expanded their potential applications. Furthermore, due to the inherent semiconducting properties of diode lasers, the output amplitude is stable and can be tuned for sensitive absorption or fluorescence measurements [1].

The objectives for this project are to design, construct and characterize an interference-filter stabilized ECDL. The laser housing is to be mechanically robust, such that acoustic vibrations and temperature fluctuations and gradients do not significantly modulate the amplitude or frequency of the emitted laser. The housing will be portable and mountable to a standard optics table, and will have the ability to be hermetically sealed and evacuated. The housing will accommodate interchangeable components, namely diode lasers, lenses, interference filters and beam splitters that can easily be mounted without additional parts. A mirror mounted to a piezoelectric transducer with the ability to be PID controlled will maintain the length of the external cavity. The diode laser and housing will each be thermally stabilized with Peltier devices. This monolithic device will contain all the necessary control circuitry, as well as a protection circuit for the laser diode.

The output wavelength of the ECDL should be tunable over nanometers about the native wavelength of the diode laser, which will be in the visible to telecom emission spectrum. This output should be stable in both frequency and amplitude, with less than 1 part in 10^5 attributed to noise. The overall design of the ECDL should result in a laser that can be used for laser cooling applications. The desired atoms to be cooled and their required laser linewidths are 1 MHz for lithium and rubidium, and 100 kHz for ytterbium. The power of the laser is dependent on the diode and the application, but will typically range from tens to hundreds of milliwatts.

The fully assembled ECDL will be characterized by its wavelength tuneability, amplitude and frequency stability, and laser linewidth. The successful product is to be replicated, on the order of 5 to 10 units, for atomic and molecular optics experiments.

This report serves as a detailed description of the development and optimization of experimental techniques necessary for characterizing narrow linewidth diode lasers. These methods were used to characterize the performance of two prototype interference-filter stabilized lasers and investigate key design parameters important for stability and a narrow linewidth. The results of these experiments guided the design of a monolithic, hermetically sealable, diode laser using the same interference-filter feedback system. Once constructed, this laser's linewidth and stability must be characterized before being used to ensure it meets the performance requirements necessary for its intended application. The required experimental equipment and optical setups are available in the QDG labs, and the characterization must be completed before multiple units are to be constructed. Due to the limited time-frame of this project, this report does not address specific considerations such as thermal flow analysis and fabrication cost optimization. The thermal cooling design is based on research into similar external cavity laser designs and was not quantitatively assessed. The design of the laser was driven by optimizing performance and assumed a low reproduction quantity. Therefore industrial design considerations will not be addressed in this report.

This report begins by introducing the background theory of the ECDL, and gives a detailed outline of all the components comprising the laser setup. Specifically, the collimator lens, half-wave plate, beam splitter, and the piezo-controlled mirror. Then, an overview of the methods and testing protocols are presented, such as the alignment of the components, measuring the focal point of the cavity lens, and the use of the Fabry-Pérot interferometer. Results are then presented and discussed detailing data collected from all the experiments, along with sources of error. Conclusions are then drawn from the results of the experiments.

Following these discussions, project deliverables are listed as a follow-up of the project proposal, along with a financial summary of the costs associated with the project and ongoing commitments by team members.

Finally, the report is concluded with a discussion on project recommendations to outline directions to be taken after the submission of this report.

Discussion

Theory

A typical diode laser operates by sending a current though the active region of a diode sandwiched between two n and p doped layers. This injection current produces free electrons in the conducting band and holes in the valence band. For direct band gap semiconductors, electron-hole recombination leads to a photon being emitted. The wavelength of the light is determined by the energy gap between the bands. Figure 1 shows a schematic of a standard diode laser.

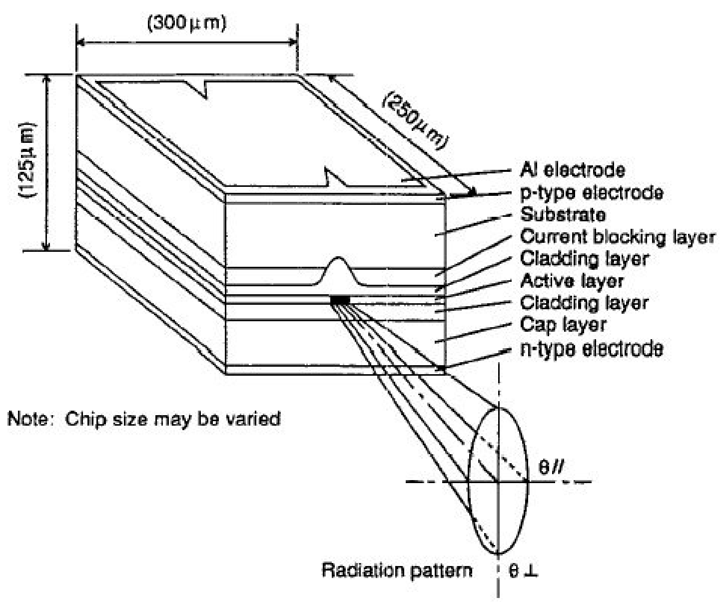


Figure 1. Schematic of basic diode laser [1].

For a device to operate properly, coherent light must be generated through stimulated emission - a process where excited electrons recombine when stimulated by photons with energy matching that of the band gap. This requires two conditions: first a population inversion must be achieved by electrical pumping and secondly, there must be a resonator that keeps photons contained within the device to stimulate further emission. When the losses of the system are overcome by the system's gain, which occurs when the current reaches the threshold level, the device will lase [2].

External Cavity Design

As mentioned above, a resonator keeps emitted photons confined to the device in order for stimulated emission to occur at a substantial rate. Typically, this is achieved by coupling the light to an external cavity with feedback mirrors. The cavity can also control certain spectral properties. Figure 2 shows a basic design for the external cavity.

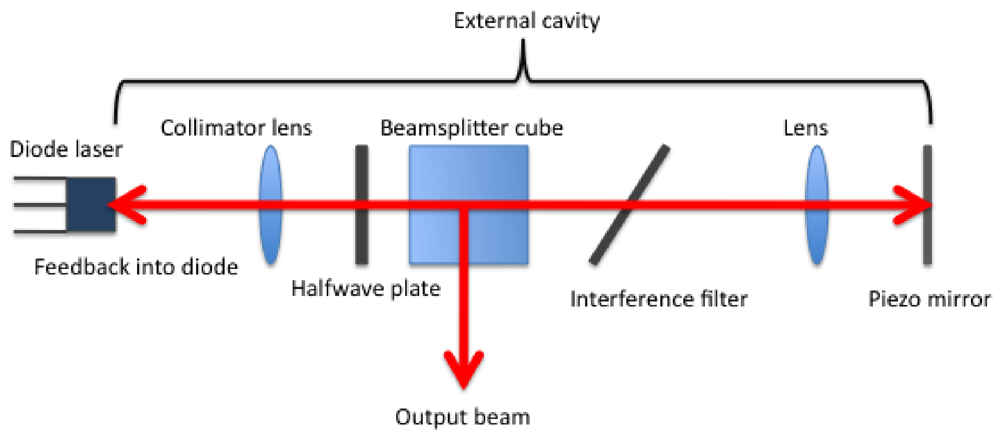


Figure 2. Schematic of an external cavity laser.

Collimator Lens

As a result of the scale of the active region, the emitted laser beam is highly divergent—in some cases up to 90^{o} [2]. Therefore, at the output of the laser a collimator with a high numerical aperture must be placed to collect the emissions. For best results, the collimator should be free of spherical aberration and have a maximum spot size on the order of the dimensions of the active region.

Half-wave Plate

The half-wave plate rotates the plane of polarization and thus decouples the polarization from the spatial mode orientation. [4] By controlling the polarization of the beam, the feedback to output ratio of the beam splitter can be set.

Beam Splitter

The beam splitter controls the ratio of output power to feedback power. This ratio must be optimized for each device to achieve the necessary feedback to sustain lasing. The output ratio is defined by the polarization vector of the light with respect to the surface of the cube; therefore the wave plate can set the fraction of the beam that is emitted. By opting for a beam splitter over partial reflective mirrors, this ratio can be easily adjusted without switching components. Figure 3 shows how a beam splitter cube transmits and reflects light of different polarizations.

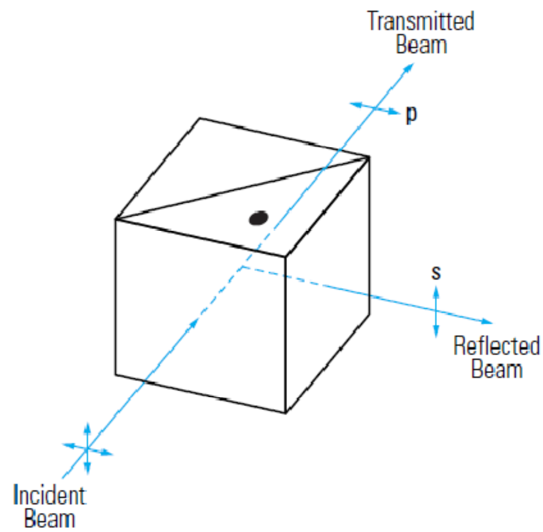


Figure 3. Polarization beam splitter.

Interference Filters

Two of the key properties of lasers for atomic physics are output frequency and linewidth. The laser's source must be tuned to particular atomic transitions of interest, with a narrow spectral output. A narrow linewidth is important since it maximizes the amount of energy at the desired frequency and thus increases the probability of absorption. Free running diode lasers do not provide the necessary linewidths needed for atomic cooling, and external filters are needed to increase the quality factor of the output. Two interference filters placed at set angles with respect to each other may be used instead of one custom filter due to budget constraints - custom filters can cost up to $10,000. Interference filters have been shown in the literature to work effectively to select the desired wavelengths with narrow linewidths [5]. Wavelength discrimination using an interference filter utilizes multiple reflections within its dielectric coatings and can be modeled as a thin Fabry-Pérot etalon. The transmitted wavelength is given by:

$$\lambda = \lambda_{max}\sqrt{1-\left(\frac{\sin\theta}{n_{eff}}\right)^2} \tag{1}$$

where λ is the output wavelength, λ_{max} is the wavelength at normal incidence, θ is the angle between the beam path and filter, and n_{eff} is the effective refractive index [5]. The interference filter is a Gaussian band pass filter. Changing the angle of both filters together sets the wavelength, while changing the angle between the two filters sets the linewidth. This can be seen in Figure 4.

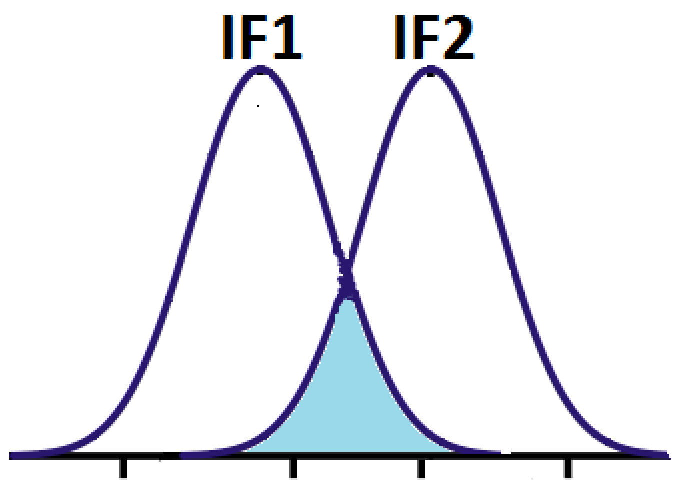


Figure 4: The two interference filers (IF) are multiplied together and the overlapping area is the transmitted region.

It is clear that the product of two Gaussians is also a Gaussian. Figure 4 illustrates a key point - increased linewidth comes at the cost of output power.

The filter also helps to suppress the other modes of the laser. This design was chosen over a diffraction based filter system, such as the Littrow arrangement, because wavelength discrimination and the optical feedback are performed by two independent elements. Also, diffraction arrangements are ultra-sensitive to misalignments due to increased beam width.

Piezo Controlled Cavity Mirror

The final optical component within the cavity is the piezo controlled mirror. The mirror reflects the emission back into the laser diode to sustain lasing. The cavity of the laser must be a multiple of the wavelength. Since the laser operates with wavelengths in the visible and infrared regime, the cavity length must be stable with a high degree of precision - hence the need for the piezo control.

Laser Housing

The optical components and laser diode must be securely housed in a sealed container. The laser's housing must be rigid to minimize vibrations, and be able to sustain a vacuum within the cavity so that water does not condense on the laser diode when it is cooled below the dew point. The laser's design should be modular and allow for the exchange of optical components for various experimental tasks. Fine optical adjustments should be possible during operation without breaking the vacuum seal. This will require external electrical controllers. The device will be mounted to an optical table where real estate is valuable; therefore the device should have a small footprint. Another design concern is temperature stability. Thermal expansion and contraction of the housing will cause wavelength instability. A temperature control system must be implemented. Finally, the total length of the laser cavity must be considered. The performance of the laser will be characterized by its Q factor. The Q factor is a ratio of the energy stored in the system to the energy lost per cycle. Naturally, as the length of the cavity increases the energy lost per cycle decreases since the number of cycles increase. This means that a longer cavity length leads to a better Q factor; however at some point the decreased mechanical rigidity of a longer cavity decreases the Q factor and becomes a hindrance to laser performance. Additionally, it has been found that when the relaxation oscillation frequency (typically a few GHz for diode lasers) is larger than the axial mode spacing, mode hopping becomes an issue [6][7].

Temperature Control System

The optical properties of diode lasers are highly dependent on their operational temperature. A closed-loop feedback control system using Peltier devices and thermistors will be implemented for this laser. The Peltier device is a two terminal semi-conductor device that makes use of the thermoelectric effect. Depending on the current's direction, the device will either absorb or release heat. The basic principle of the feedback system is to use a thermistor as one of the legs of a balancing bridge, then amplify the voltage across the bridge to power the Peltier device [8]. There will be separate Peltier devices for the laser diode mount and the outer housing. The laser diode mount will be set to a variety of temperatures that could range from -40 to +80 °C, with the housing acting as a heat sink for the Peltier device controlling the laser diode mount. The housing will also have a Peltier device regulating the temperature of the housing to roughly ambient temperature.

Applications of Diode Lasers

The laser diode system being proposed will be primarily used for laser cooling. An atom will absorb a photon if the photon's energy matches one of its electronic transitions. In the process the atom will absorb the photon's momentum. By red shifting the light with respect to the transition of interest, the frequency will be Doppler shifted to the correct transition energy as the atom moves towards the light source, making absorption possible and slowing the atom. By using 6 lasers, two pointing in opposite directions on three orthogonal axes, atoms can be cooled to ultra low temperatures. The final design will be used to cool rubidium, lithium, and ytterbium atoms. This requires the laser to produce a linewidth in the hundred to thousand kHz range, and be free of mode-hopping over a tunable range of hundreds of GHz.

Methods and Testing Protocol

Component Alignment

Preparing the laser to run experiments requires the alignment and setup of various components. It is necessary to align the mirrors, polarizing plates, filters, and beam-splitting cubes as well as the optical fiber-coupling mounts in order to minimize the attenuation of the signal along the tabletop setup. Having a misaligned beam will reduce the transmitted power such that the photodiodes and optical spectrum analyzers will either not able to detect a signal, or the signal to noise ratio will be too low to intelligibly determine the signal characteristics.

The process for alignment optimization is carried out in two steps: rough estimation by eye, followed by a precise optimization using a power meter or a photodiode connected to an oscilloscope. The laser beam is aligned in the cavity by adjusting the positioning of the collimator tube so that the beam is centered on the cat's eye lens. A piece of transparent plastic is then inserted into the cavity to provide a plane for viewing the incident and reflected beams. This arrangement can be seen in Figure 5.

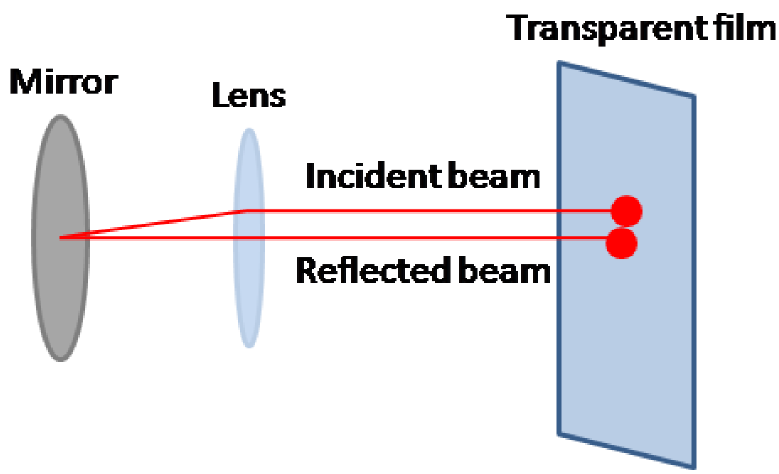


Figure 5. Method for aligning the laser beam in the cavity.

The kinematic mount that the mirror is attached to can then be tilted appropriately so that the two beams overlap on the transparent film. When the two beams overlap, the intensity of the beam spots on the film will dramatically increase since the laser is being provided with feedback. This is most easily seen when looking at the transparent film through an infrared scope. The fine adjustment for the internal cavity alignment is then performed by shining the laser beam onto a photodiode and looking at the signal on an oscilloscope. The current supplied to the diode is ramped about the threshold by modulating the output of the current driver with a triangle wave from a function generator. The mirror angle of the mirror is then fine adjusted so that the threshold current for stimulated emission is minimized. At this point, the laser beam is optimally aligned within the cavity. Figure 6 shows a graph of light output as a function of current.

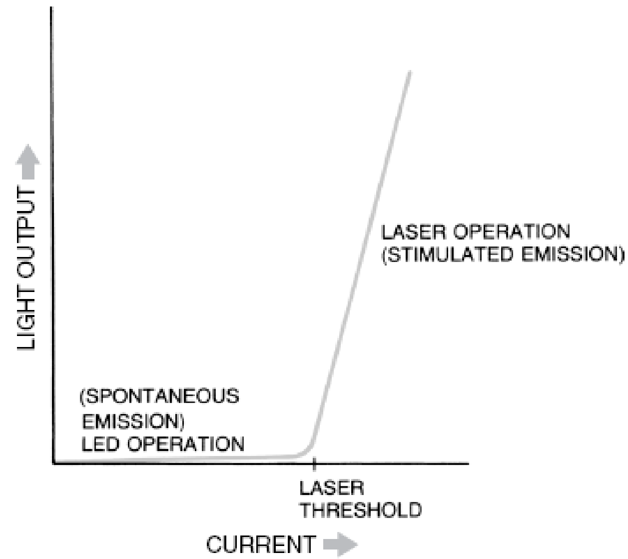


Figure 6. Light output of a laser diode as a function of supply current.

Most components on the table top are mounted to kinematic mounts, allowing precise control over the orientation and angle of mirrors and lenses. By using an infrared viewing card, coarse alignment can be performed. Fine adjustments can then be made by using a power meter where necessary.

Beam Focus / Profiling

A potential variable necessary in the design of the cavity is the focal length of the cat's eye lens/mirror configuration. Beam diffusion of all laser beams is a Gaussian function of the length of the beam. This means that the focal length of the cat's eye setup varies with cavity length. Since data relating cavity length to spectral linewidth is required for this project, it was first necessary to determine the focal length at various cavity lengths as well as the linewidth sensitivity to deviations from the optimal focal length. With this data, the effect of cavity length on linewidth can be independently investigated.

Data relating cavity length to focal length was obtained using knife-edge diffraction. To do this, a razor blade was attached to a micrometer-adjustable stage. The razor edge was placed perpendicular to the beam and cut partway into it. This setup can be seen in Figure 7.

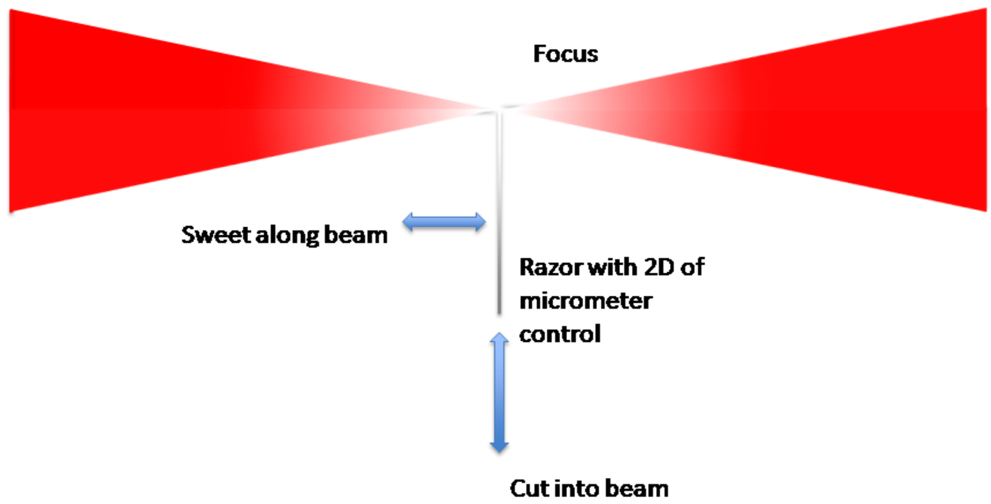


Figure 7. Knife-edge laser beam profiling.

The image of the beam on the other side of the razor was viewed on a piece of paper. When the razor is on the short side of the focus, the image of the beam on the paper is inverted. When the razor is on the far side of the focus, the image on the paper is non-inverted. By sliding the razor/stage with the micrometer along the axis of the beam and cutting in and out of the beam, location of the focus can be determined.

IF Filter Transmission Test

Using a master laser locked at 780 nm, the transmission of the interference filters can be tested by measuring the amount of power transmitted as a function of the filter angle. This is most easily done be determining the angle of the reflected beam and dividing by two.

Fabry-Pérot Interferometers for Single Mode Selection

The methods used for measuring linewidth require that the laser is operating in a single mode. To verify this a Fabry-Pérot Interferometer was used. This consists of two highly reflective planar mirrors with slight transparency whose separation cavity distance is swept over a range using a piezoelectric transducer. When a laser is injected into the cavity, it will experience strong constructive interference when the separation distance in a multiple of the half integer wavelength. By monitoring the output of the cavity with a photodiode, multiple modes of that laser that are in resonance with cavity at various piezo voltages can be seen. Figure 8 shows a spectrum of a single mode laser spectrum output from a Fabry-Pérot cavity. A multimode spectrum would consist of a forest of spikes that are periodic.

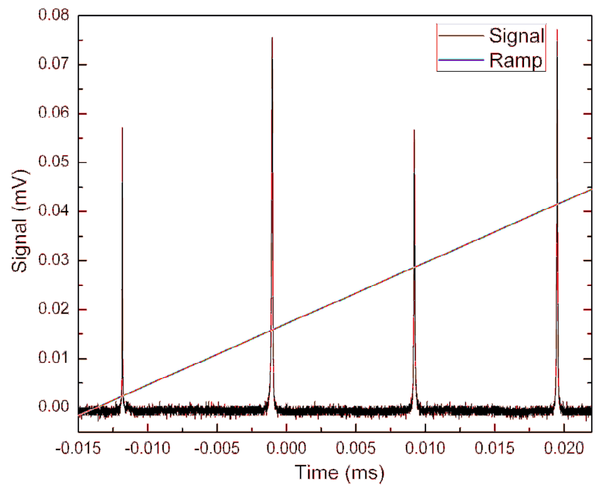


Figure 8. Output spectrum of a single mode laser in a Fabry-Pérot cavity.

Self-heterodyne Linewidth Measurement

A common way to obtain a measurement of spectral linewidth is to use a self-heterodyne mixing technique. The beam from the cavity is split in two, and one of the beams is sent through a fiber delay of approximately 5km, presumably longer than the coherence length of the laser. The other beam is sent to an acousto-optical modulator (AOM), which shifts the frequency by 80 MHz. The resulting beat note of the recombined beams is centered about the sum and difference of the frequencies. The photodiode is only fast enough to detect the difference signal at 80 MHz. Figure 9 shows a schematic of the self-heterodyne setup.

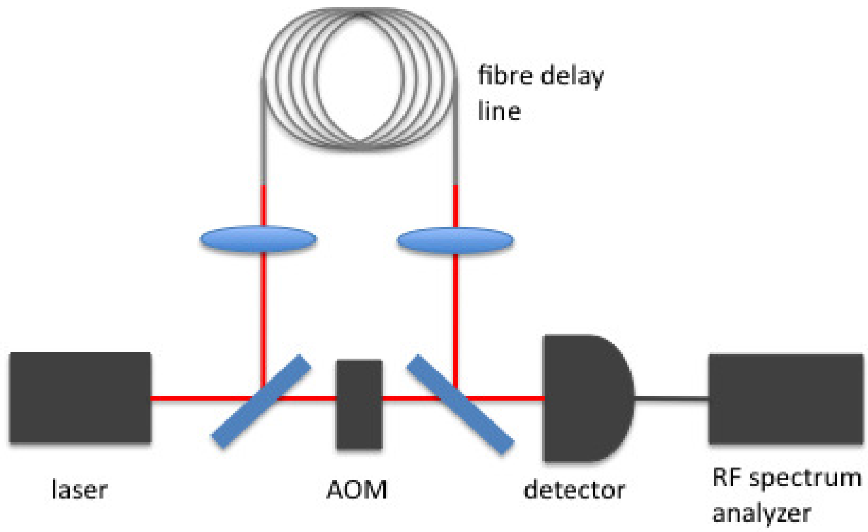


Figure 9. Self-heterodyne linewidth measurement.

Ideally, this frequency superposition would be Lorentzian, from which the spectral linewidth could easily be discerned.

Two Laser Heterodyne Interference Linewidth Measurement

Another technique similar to the self-heterodyne measurement is to use two lasers and mix the two output beams to produce a beat note spectrum centered at the frequency difference, with a linewidth which is the sum of the two individual laser linewidths.

To produce the beat note, the two beams must be co-linear and have the same polarization. The signal is coupled to an optical fiber which can be connected to the input of an optical spectrum analyzer or a receiver optical sub-assembly (ROSA) consisting of a high speed photo diode and filtering electronics. The ROSA is then inputted to a spectrum analyzer. The bandwidth of the ROSA is 10 GHz, therefore the two lasers' wavelengths must be within 0.02 nm of each other. This was achieved by finding stable modes for both lasers whose wavelengths overlap within the tuning range of the interference filter. Next, while monitoring the optical spectrum analyzer, the wavelengths were tuned to each other to produce a beat note within the bandwidth of the ROSA. Then, the signal is fed via the ROSA to the spectrum analyzer.

This method does not suffer from the beams being correlated, as is the case with the self heterodyne measurement, because they originate from two separate lasers. However, stability of the lasers is critical to ensure the beat note remains centered at a constant frequency. This was not an issue with the self heterodyne measurement since the frequency fluctuations are the same for both beams and the frequency difference is unaffected. Figure 10 shows the schematic for producing a two laser heterodyne linewidth measurement.

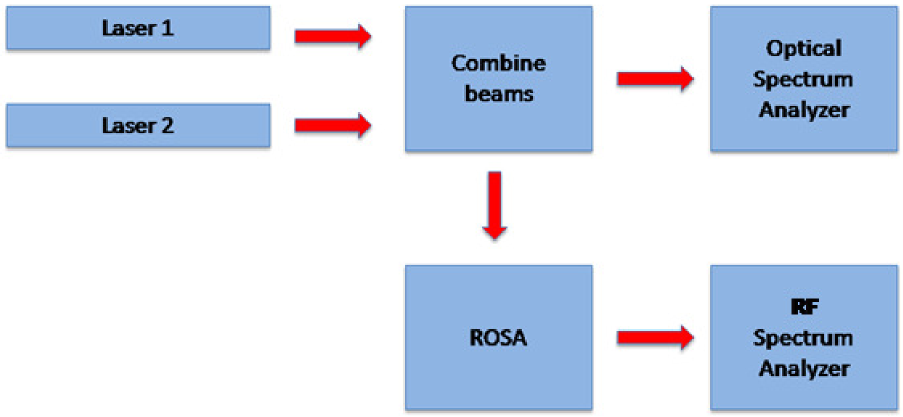


Figure 10. Experimental setup for the two laser heterodyne linewidth measurement.

Experimental Equipment

Figure 11. Thorlabs LDC 500 laser diode controller

Figure 12. Thorlabs TEC2000 temperature controller.

Figure 13. Thorlabs MDT694A single channel piezo controller.

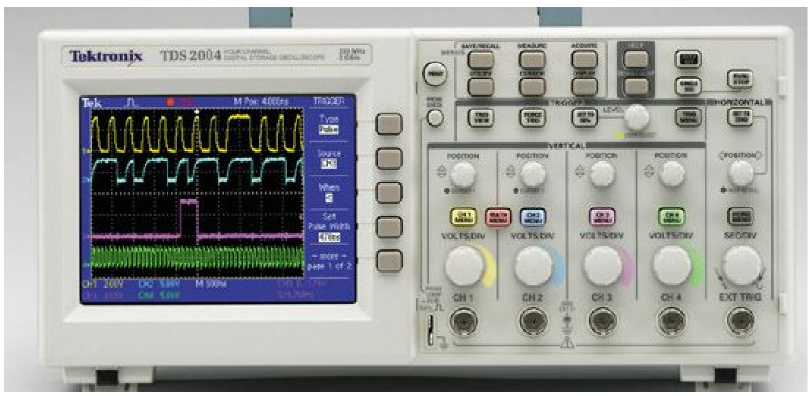


Figure 14. Tektronix TDS 2004 oscilloscope.

Figure 15. Agilent E4407B spectrum analyzer.

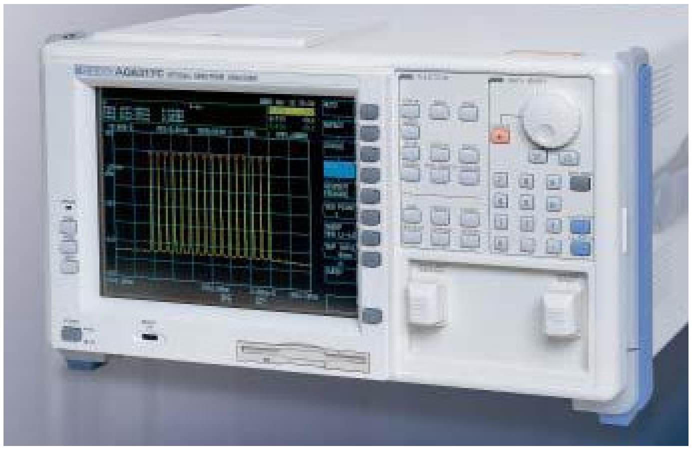


Figure 16. Ando AQ-6135A optical spectrum analyzer.

Figure 17. Coherent LabMax 10 power meter.

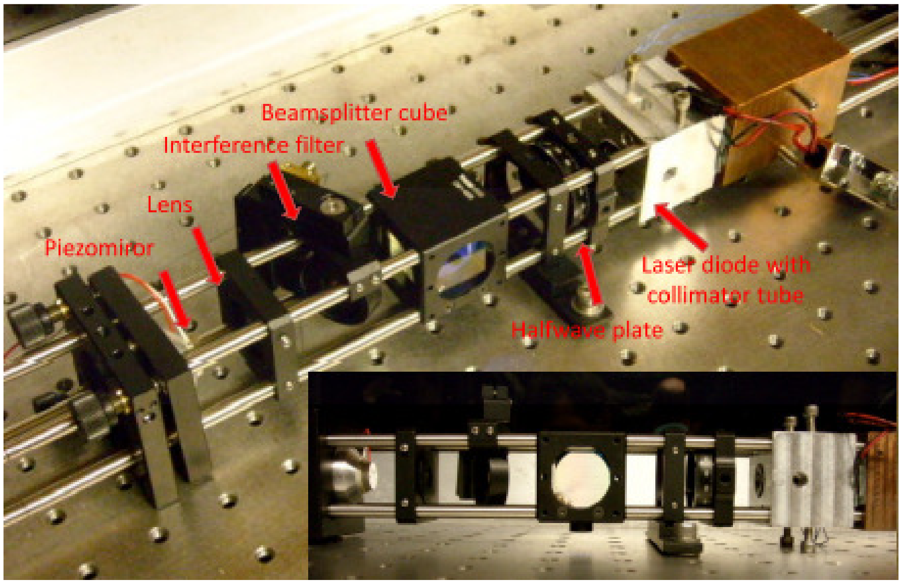


Figure 18. Protoype laser.

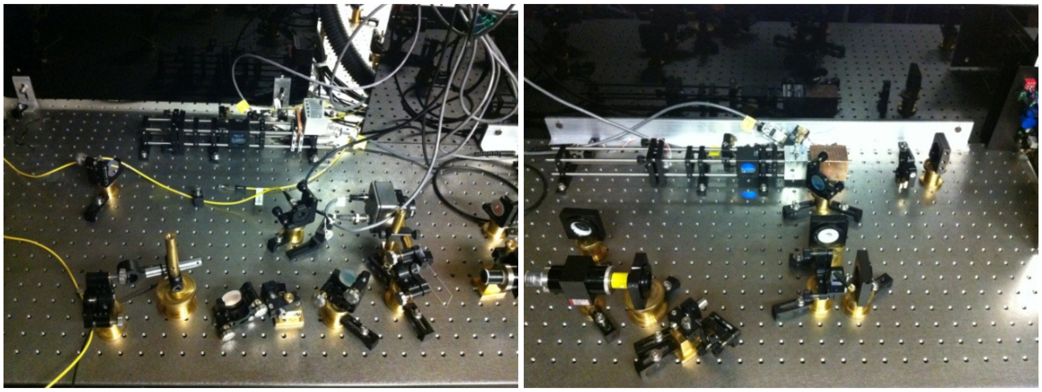


Figure 19. Table top setup of the prototype lasers and optics

Results

The results of the knife-edge diffraction beam profiling can be seen in Figure 20. This test determined the size of the beam waist at the focal point of the lens.

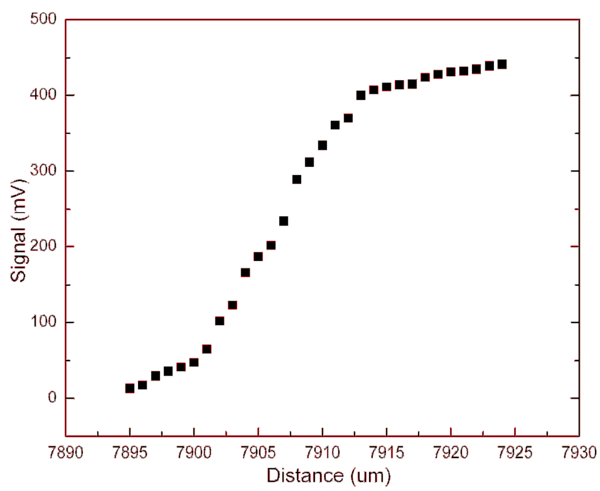


Figure 20. Gaussian beam waist profile.

There are many methods for interpreting the size of the beam waist from this data. The most accurate technique is to fit the power profile to the error function. A few short-hand techniques just look at the distance between the 90% and 10%, or 70% and 30% power data points and use a scaling factor. Since we were just interested in the order of the beam waist size, a rough estimate on the order of 10 µm from the data in Figure 20 is sufficient.

The results of the focal length tests are shown in Figure 21. From this graph it can be seen that the focal length decreases as the cavity length increases. This can be attributed to the divergence of the beam.

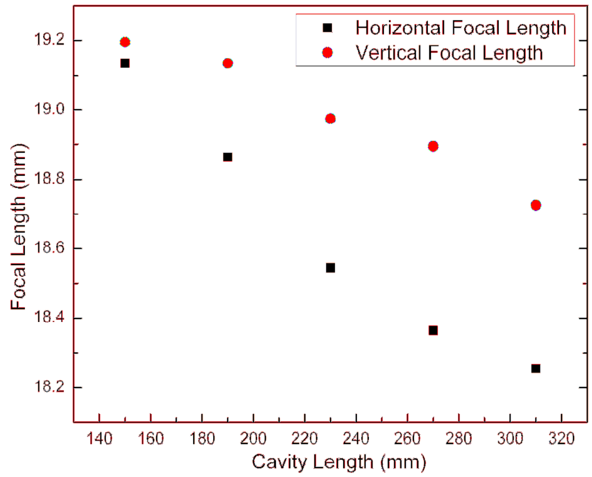


Figure 21. Focal length vs. cavity length.

Another interesting feature is the difference in focal length for the vertical and horizontal directions. This result represents the degree of astigmatism in the output of the laser beam.

The transmission test of the interference filters at various angles is shown in Figures 22 and 23. The data from these figures puts an upper limit on the range of angles for the interference filters to be set at.

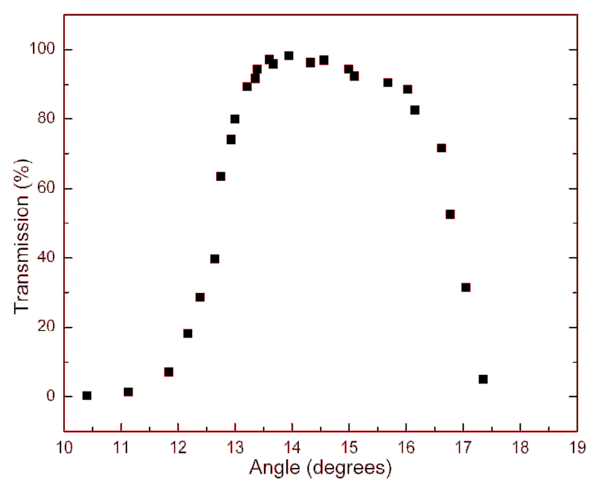


Figure 22. Transmission vs. incident angle for the 3nm interference filter.

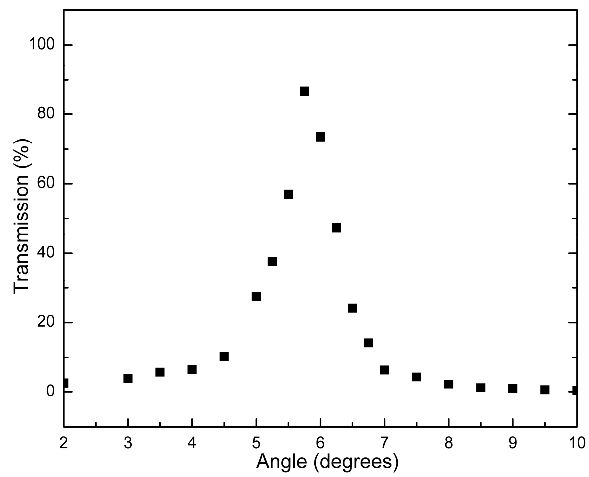


Figure 23. Transmission vs. incident angle for the 0.3 nm interference filter.

The results of the self-heterodyne linewidth measurement are shown in Figure 24. Spectra were taken for cavity lengths 150 mm and 310 mm at 30 mm increments. Additionally, spectra were taken for various distances between the mirror and the cat's eye lens.

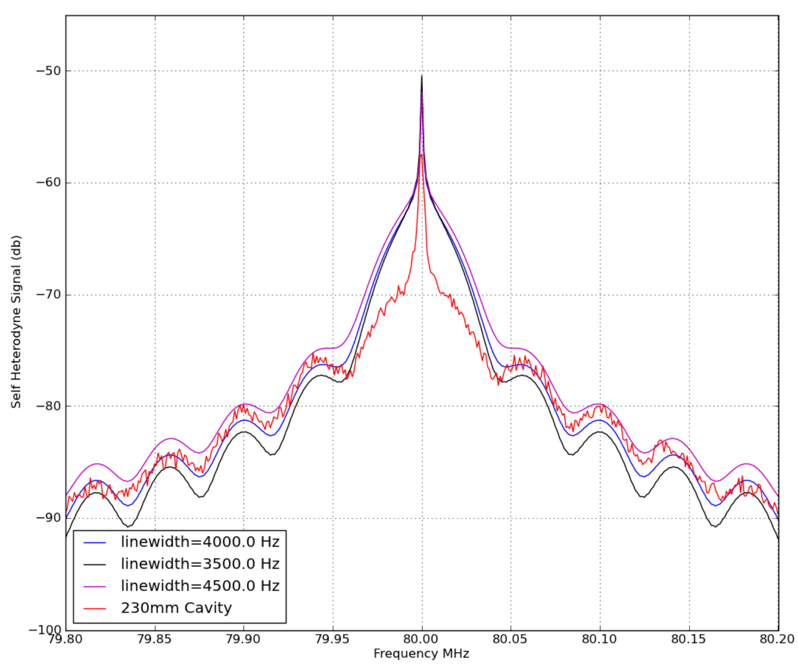


Figure 24. Self-heterodyne linewidth measurement for a 230 mm cavity with simulations.

Each spectrum was overlaid with a few simulated spectra to give upper and lower bounds on the linewidth. For a detailed analysis of the frequency noise spectrum, see Appendix A. The bounding simulations were determined from the depth of modulations in the wings of the spectra, which are indicative of the linewidth. Qualitatively, a trend towards more narrow linewidths can be observed as the cavity length increases, and very little difference can be observed as the distance between the mirror and the cat's eye lens is varied by approximately 1 - 2 mm about the nominal focal length. At variations larger than 1 – 2 mm, the laser becomes unstable.

Discussion of Results

Knife-Edge Diffraction Test

The results of the knife-edge diffraction test showed that the astigmatism of the beam resulted in a difference of up to 0.5mm in the horizontal and vertical focal lengths. Since the lens does not have a single focus, some averaging between the two is necessary. Further tests were done to determine the sensitivity of the linewidth to variations about this average focal length. The resulting spectra indicated that deviations from this average focal length by approximately 1-2 mm did not significantly affect the linewidth. At farther deviations, the laser became unstable and would not go into single mode operation. As a result of these tests, it was decided that using a caliper to set the distance between the lens and the mirror would be sufficient. It also indicated that since different diodes would have different degrees of astigmatism, that the lens mount and the kinematic mount for the mirror would need some range over which the distance can be adjusted. The kinematic mount selected for the final design has an adjustment range of 3.56mm. This range could be increased by introducing some variation in the set position of the lens mount. Additionally, the length of the metal slug that the mirror is mounted to could be custom cut for every build. It was decided that the simplest thing would be moving the lens mount because if the diode ever burns out and the new diode has a different degree of astigmatism, it would be undesirable to have another slug machined. Figure 25 shows the design of the lens mount with slotted holes, allowing the mount to be moved by up to 5mm along the beam path.

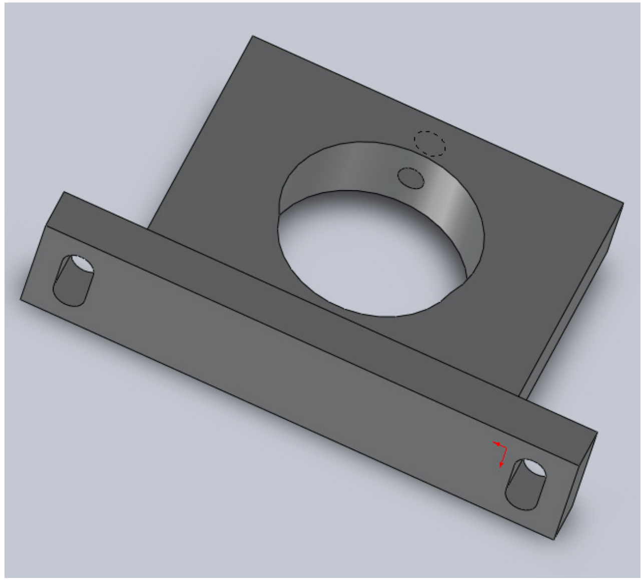


Figure 25. Final design for the cat's eye lens mount.

Interference Filter Transmission Test

From the transmission tests, it can be seen that the 3nm filter has a band pass that cuts off after 18 degrees. This puts an upper limit on the angle tuning range of the interference filters. The length of the actuator needs to be long enough to realize this angle range. Furthermore, the resolution of the actuator needs to be sufficient to select center frequencies at the desired resolution. From previous work done with the filters [20], we know that the angle sensitivity of 3 nm filter is 0.7 nm/deg and 0.5 nm/deg for the 0.3 nm filter. The frequency difference between two wavelengths is given by

$$\Delta f = \frac{c}{\lambda} - \frac{c}{\lambda + \Delta\lambda} \qquad (2)$$

Where λ is the lower wavelength, Δλ is the difference in wavelengths, and c is the speed of light. The change in angle due to a change in actuator length is given by

$$\Delta\theta = \tan^{-1}\frac{\Delta d}{\mathrm{w}} \qquad (3)$$

Where Δd is the change in actuator length and w is the length of the pivot arm at θ=0 degrees. Using the known angle sensitivity, the change in wavelength due to a change in angle is given by

$$\Delta\lambda = \Delta\theta \frac{d\lambda}{d\theta} \qquad (4)$$

Where $\frac{d\lambda}{d\theta}$ is the angle sensitivity. Putting together (2), (3), and (4), we can solve for the required actuator resolution

$$\Delta d = w \tan\left[\left(\frac{\lambda^2 \Delta f}{c - \lambda \Delta f}\right)\frac{d\theta}{d\lambda}\right] \qquad (5)$$

Using a desired frequency resolution of 1 GHz at a nominal wavelength of 780 nm and the known angle sensitivity, a value of 2 µm for actuator resolution is required for a pivot arm of 30 mm. The final design for the interference filter mount assembly is shown in Figure 26. The micrometer shown is a Thorlabs DRV505 which provides 2 µm actuator resolution over a distance of 16.2 mm. The first filter holder pivots about a ball and cone contact to keep a tight pivot point without over constraining the design. An extension spring counters the action of the micrometer.

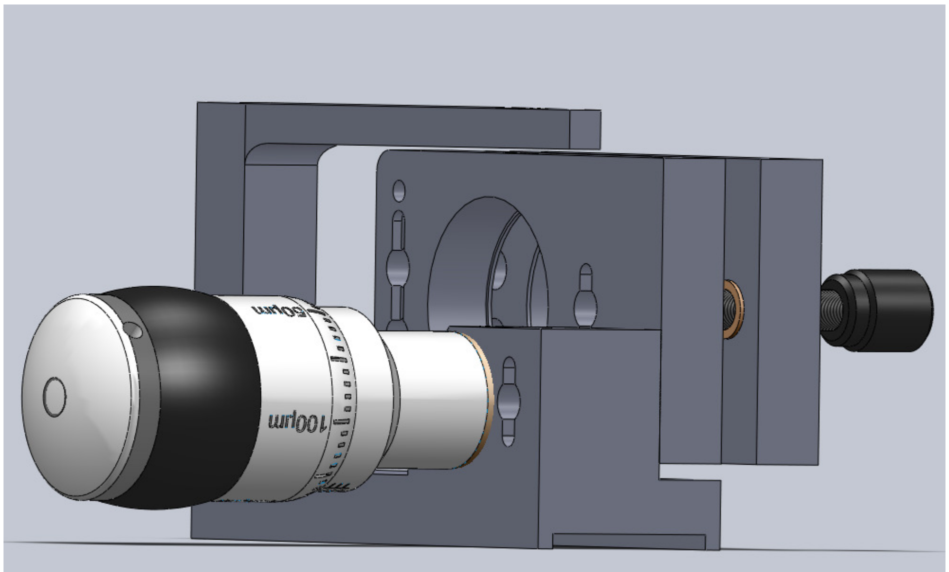


Figure 26. Final design for the interference filter mount assembly.

The second filter holder pivots on the first one on two balls, and is pulled together by extension springs. A 100 TPI fine adjustment screw is used to set the relative angle between the two plates with an extension spring countering the action of the set screw. The interference filters are held in place in the mounts with a standard 1” retaining ring. This method allows the filters to be held in place parallel to the mounting face much better than by using a set screw.

Detailed schematics of the laser assembly design are in Appendices B and C.

Self-Heterodyne Linewidth Measurement

The purpose of the self-heterodyne experiment is to produce two decoupled beams by passing one through an optical fiber and then combine them to produce a beat note. However, due to the long coherent length of the laser, complete decoherence is not possible with the available equipment and therefore the analysis of the measurement is made more difficult.

The results of the self-heterodyne measurement failed to match the theoretical model and we could not precisely fit our data. The experimental results have much wider coherence peaks at 80 MHz and the central lobe is not as high as predicted by the theoretical model. Therefore, we could not use this method to get definitive values for the 1/f noise and white noise. However, the depth of the lobe modulations in the sidebands are positivity correlated to the laser's linewidth. Fortunately, for this region of the frequency spectrum the model and data were in agreement and we were able to fit an upper and lower bound to the linewidth. This can be seen in Figure 15. Using this technique we can confidently determine that our linewidth is less than 10 kHz and in the range of 5 kHz, although more definitive measurements must be made. Although we can qualitatively say that there is a trend towards more narrow linewidths for longer cavity lengths, the resolution of this measurement process limits a quantitative determination of this trend. Additionally, the decrease in linewidth from a 150 mm cavity to a 310 mm cavity can be estimated to be on the order of a few kHz. Taking this into account, we designed our laser cavity to be as small as practically possible.

Sources of Error in the Self Heterodyne measurement

The most obvious error with this method is the premise that laser noise can be accurately modeled by a random white noise parameter and a 1/f noise factor. It assumes that the contribution of systematic noise sources can be neglected when compared to the effect of the previously mentioned terms. This may not be valid for lasers with narrow linewidths [19]. We also believe that temperature stability of the optical fiber could be an issue. Small temperature changes result in the expansion and contraction of material which are magnified when working with a 5 km long fiber. These changes in length can introduce phase artifacts between the beams which can distort the interference signal. Finally, from discussion with Daniel Steck, a researcher at the University of Oregon who is also working on similar laser designs, it may possible that our laser is in a multiple mode state with frequencies outside the bandwidth of the Fabry-Pérot. All of these factors could contribute to the accuracy of this measurement technique.

Two Laser Heterodyne Linewidth Measurement

We investigated the cause of low frequency oscillations of the beat frequency. We hypothesized these fluctuations arose from mechanical instability of our design which caused the cavity length to change because of thermal fluctuation, vibrations, and air flow around the device. We tested the lasers at cavity lengths of 310 mm and 150 mm. We observed an oscillation range of 150 MHz and 20 MHz for the 310 mm and 150 mm cavity lengths, respectively. We also used custom made enclosures to protect our laser from air currents but observed no significant change in oscillation range. This indicates that cavity length is an important mechanical factor in the final laser design. However, precise quantitative measurements of prototype stability as a function cavity length and design are irrelevant for our design because the final product will be milled out of aluminum rather than mounted on optics rails.

Conclusions

The focal length of the lens depends on cavity length and the degree of astigmatism in the diode, but measurements on the linewidth as the distance between the mirror and the lens was changed showed that the linewidth is not very sensitive to the exact positioning of the lens. As a result, the cat's eye configuration was designed to allow for adjustment of the mirror to lens distance, with the expectation that a caliper would be sufficient to gauge this length.

Testing the sensitivity of the transmission of the interference filter with respect to the angle of the filter was important in designing the filter mount. Given that the desired resolution of the filter was 1 GHz at 780 nm, for a 30 mm pivot arm, 2 µm of resolution was necessary. Thus, the final design of the filter mount includes a Thorlabs DRV505 micrometer, which is capable of providing a resolution of 2 µm over a distance of 16.2 mm.

Experiments were conducted relating cavity length to the spectral linewidth of the beam using a self-heterodyne mixing technique. However, since the linewidth of the beam is too small for the length of the fiber delay in the self-heterodyne setup, we were unable to accurately fit our data. However, from a qualitative analysis we can conclude that our spectral linewidth was below 10 kHz, well below our objective. As expected, we were able to see that longer cavity lengths were more susceptible to mechanical vibrations. Since the linewidth gains for longer cavity lengths were not enough to justify building a longer laser, the laser housing was designed to be a more practical size.

Project Deliverables

List of Deliverables

The initial deliverable was a completely characterized interference filter stabilized diode laser. However, when beginning the design it was clear that many important design parameters which could affect laser performance were yet to be investigated. This issue was predicted as a possible set back in our project proposal. Therefore our first task was to first characterize the performance of the prototype laser to gain insight on our laser design. Unfortunately, the techniques which we intended to use to characterize the device were found to be not accurate enough to provide necessary resolution for sensitive linewidth measurements. As a result, after consulting with our project sponsor, the scope of our project changed. It now focused on developing experimental methods for investigating narrow linewidth diode lasers and using the results to design a monolithic interference filter stabilized laser to be characterized in the future.

The following table outlines the current state of all deliverables and what the project sponsor can expect to receive from our group now and in the future.

Item	Status	Comment
One working prototype interference filter stabilized laser.	Completed	
Characterization of the linewidth, stability and beam profile of prototype lasers.	Completed	
Optical setup for heterodyne interference linewidth measurements.	Completed	Successfully produce beat signal of the two prototype lasers.
Design and Solidworks drawings of an interference filter stabilized external cavity diode laser with thermal control and electrical systems.	Completed	Submitted to machine shop for manufacturing on March 30, 2011.
Lock in control system for stabilizing heterodyne interference linewidth measurement.	Not Completed	To be completed by April 22
Characterization of interference stabilized external cavity diode laser.	Not Completed	To be completed by June/July 2011

Financial Summary

Part	Quantity	Material / Vendor	Cost ($)	Extended Cost ($)
Machined Components				
Base	1	6061-T6 Aluminum	-	
Laser Housing	1	6061-T6 Aluminum	-	
Laser Top	1	6061-T6 Aluminum	-	
Diode Holder	1	Copper	-	
Generic Holder	1	6061-T6 Aluminum	-	
IF Holder Base	1	6061-T6 Aluminum	-	
IF Holder Front	1	6061-T6 Aluminum	-	
IF Holder Back	1	6061-T6 Aluminum	-	
Lens Holder	1	6061-T6 Aluminum	-	
Slug	1	Copper	-	
Total material cost			60 est	60.00
Total labour cost			800 est	800.00
Other Components				
U50-AL1 kinematic mount	1	Newport	114	114.00
DRV505 micrometer	1	Thorlabs	275	275.00
10mm beam splitter cube	1	Thorlabs	161	161.00
PM1 clamping arm	1	Thorlabs	10	10.00
MLD 780-100S5P 5.6 mm diode with 9 mm adapter	1	Meshtel	200	200.00
A230TM-B aspheric collimating lens f=4.51mm	1	Thorlabs	80	80.00
SM9RR 9mm retaining ring	1	Thorlabs	10	10.00
N100B2 1/16 threaded bushing	1	Thorlabs	6	6.00
UFS075 1/16 x 3/4 set screw	1	Thorlabs	13	13.00
AD1T 1” internal threaded optic holder	1	Thorlabs	18	18.00
LM1-A 1” optic holder, inner ring with angle markings	1	Thorlabs	20	20.00
SM1RR 1” retaining ring	3	Thorlabs	5	15.00
V1025-1 or V1021-1 vacuum valve	1	Cryocomp	400 est	400.00
CP1.0-63-08L TEC	1	Melcor	13	13.00
RL0503-5820-97-MS thermistor	1	GE	3	3.00
A34066-ND female DE-15 connector	1	Digi-Key	5	5.00
450-1522-ND toggle switch	1	Digi-Key	3	3.00
Microscope slide	1	-	-	0.00
Torr seal	4.2 oz	Thorlabs	85	85.00
Halfwave plate	1	Thorlabs	400	400.00
Lens	1	Thorlabs	70	70.00
Mirror	1	Thorlabs	15	15.00
Piezo stack	1	Thorlabs	100	100.00
Fasteners				

3/8-24 x 1/2 socket cap screw	3	McMaster Carr	10.56/10	3.17
1/4-20 x 1/2 socket cap screw	4	McMaster Carr	6.76/50	0.54
1/4-20 x ½ swivel ball bearing set screw	1	McMaster Carr	3.22/1	3.22
10-32 x 1/2 socket cap screw	4	McMaster Carr	6.63/100	0.27
8-32 x 1 1/2 socket cap screw	4	McMaster Carr	7.33/50	0.59
8-32 x 3/4 nylon socket cap screw	4	McMaster Carr	5.85/100	0.23
8-32 x 1/2 vented socket cap screw	7	McMaster Carr	6.93/5	9.70
8-32 x 1/4 soft tipped set screw	4	McMaster Carr	6.13/10	2.45
4-40 x 1/4 socket cap screw	2	McMaster Carr	2.74/100	0.05
1/4 washer	4	McMaster Carr	1.09/100	0.04
#10 washer	4	McMaster Carr	4.64/435	0.04
#8 washer	13	McMaster Carr	4.64/435	0.14
3/32 x 1 1/4 dowel pin	1	McMaster Carr	2.46/5	0.49
3/32 x 3/4 dowel pin	2	McMaster Carr	8.78/100	0.18
3/32 x 5/16 dowel pin	3	McMaster Carr	8.63/100	0.26
0.180 dia. X 0.544 ultra precision extension spring	4	McMaster Carr	8.18/3	10.91
5/16 steel ball	3	McMaster Carr	5.42/250	0.07
5/32 steel ball	6	McMaster Carr	3.14/500	0.04
3/32 thick 10” inner dia.Viton o-ring	1	McMaster Carr	6.29/1	6.29
1/16 thick 3/8 inner dia. Viton o-ring	3	McMaster Carr	6.82/100	0.20
0.072 thick 0.495 outer dia. silicon o-ring	1	McMaster Carr	3.28/50	0.07
Total Unit Cost				**2914.94**

Ongoing Commitments

We have not received an exact completion time for the laser from the UBC machine shop, however we estimate that it will take approximately four to six weeks. During this time, all three group members will implement the control system needed to lock the two prototype lasers together to stabilize the beat note. William Bowden will contact the UBC electronics workshop to fabricate the required surface mount circuits for the diode control and electrical protection.

It is likely the final laser will arrive after the beginning of summer semester. Jon-Paul Sun will be unable to work on the project directly because he is leaving Vancouver for Co-op. William Bowden and Damien Quentin will be available to work on assembling and characterizing the laser this summer. These tasks are outlined in the following table and scheduled with respect to when the machine shop finishes the laser.

Group Remember(s)	Task	Duration
All	Set up laser locking system for heterodyne beat note	April 4 to April 8
William Bowden	Submit surface mount PCB designs for fabrication	April 4 to April 8
William Bowden	Test laser protection circuit	Upon Completion of PCB (1 day)

William Bowden/ Damien Quentin	Assemble Laser including wiring for TEC, Peizo and diode	1 week after laser manufactured
William Bowden/ Damien Quentin	Characterize linewidth and stability	1-2 week after laser manufactured
William Bowden/ Damien Quentin	Characterize frequency tuning range and resolution of filters	2-3 week after laser manufactured
William Bowden/ Damien Quentin	Compare single custom .3 nm bandpass filter to two angle 3 nm bandpass filters	3 week after laser manufactured
William Bowden	Conduct hydrogen leak test to examine vacuum seal integrity	1 day (when measurement system is available)

Recommendations

Based on our results from characterizing the prototype laser we recommend that the design for a monolithic interference stabilized diode laser proposed should be manufactured along with the necessary electronics for the diode protection circuit. While the device is being manufactured, a control system to lock the laser to stabilize the beat note must be implemented. This is required to characterize the final laser design. Once finished, the linewidth of the final design can be known precisely by producing a beat signal with the two prototype lasers individually and then beating the two prototypes to produce a final beat spectrum. This will produce 3 Lorentz spectrums which can used to simultaneously solve for the three linewidths. The device must also be characterized for stability—both when it is vacuumed sealed and kept at room temperature. This can be done by analyzing the output on a Fabry–Pérot Interferometer. Furthermore, the robustness of the vacuum should be tested using a helium leak test. If the laser meets the required specifications for its experimental applications of a stable output with a linewidth less than a 100 KHz, we recommended more units should be manufactured for general purpose lab use.

Appendices

Appendix A: Frequency Noise Model

Frequency Noise Model

The optical field of a single mode diode laser can be modeled as a monochromatic field with random phase fluctuations

$$E(t) = E_0 \exp j\left[\omega_0 + \phi(t)\right]. \tag{1}$$

The mean square phase fluctuations are related to the noise spectrum by

$$\left\langle \Delta\phi^2(t) \right\rangle = \frac{2}{\pi}\int_{-\infty}^{\infty} \sin^2\left(\frac{\omega\tau}{2}\right) S_\phi(\omega)\frac{d\omega}{\omega^2} \tag{2}$$

where the noise spectrum is modeled by a power-dependent white noise and power-independent 1/f noise

$$S_\phi(\omega) = S_0 + \frac{k}{|\omega|}. \tag{3}$$

The detected field for a delayed self-heterodyne linewidth measurement is the sum of the laser field and the a time delayed and frequency shifted version of itself

$$E_\tau = E(t) + \alpha E(t+\tau_0)\exp j\Omega t \tag{4}$$

where α is the amplitude ratio between the fields, τ_0 is the time delay, and Ω is the mean frequency difference. The optical intensity correlation function at the detector is

$$G_{E_\tau}^{(2)}(\tau) = \left\langle E_\tau(t)E_\tau^*(t)E_\tau(t+\tau)E_\tau^*(t+\tau) \right\rangle. \tag{5}$$

Substituting (4) into (5) and using (2) and (3) it can be shown that the autocorrelation function is

$$G_{E_\tau}^{(2)}(\tau) = E_0^4\left[(1+\alpha^2)^2 + 2\alpha^2\cos\Omega\tau\cdot\exp\left[-\frac{4}{\pi}\int_{-\infty}^{\infty}\sin^2\left(\frac{\omega\tau}{2}\right)\cdot\sin^2\left(\frac{\omega\tau_0}{2}\right)\frac{S_\phi(\omega)}{\omega^2}d\omega\right]\right]. \tag{6}$$

Evaluating the integrals results in

$$G_{E_\tau}^{(2)}(\tau) = E_0^4\left\{(1+\alpha^2)^2 + 2\alpha^2\cos\Omega\tau\cdot LG\right\} \tag{7}$$

where

$$L = \begin{Bmatrix} -S_0|\tau| & for & |\tau| \le \tau_0 \\ -S_0\tau_0 & for & |\tau| \ge \tau_0 \end{Bmatrix} \tag{8}$$

and

$$G = \left(\tau+\tau_0\right)^{-k(\tau+\tau_0)^2/2\pi}\left(\left|\tau-\tau_0\right|\right)^{-k(\tau-\tau_0)^2/2\pi}\cdot\tau^{k\tau^2/\pi}\tau_0^{k\tau_0^2/\pi}. \tag{9}$$

The spectrum observed on the RF spectrum analyzer is the Fourier transform of the autocorrelation function.

Appendix B: Laser Design

External Cavity Diode Laser

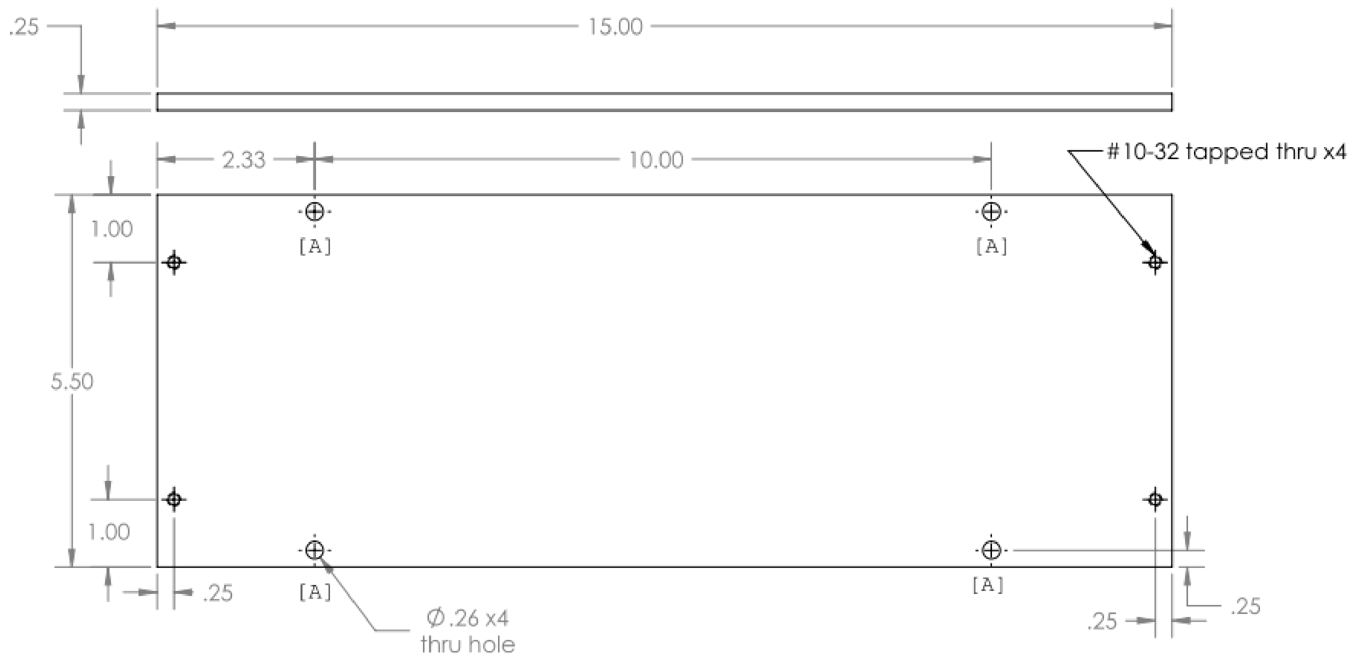
Jon-Paul Sun, William Bowden, Damien Quentin
Sponsored by Kirk Madison, Bruce Kapplauf
March 26, 2011

***Note: All units of machined components are in inches unless otherwise specified.**

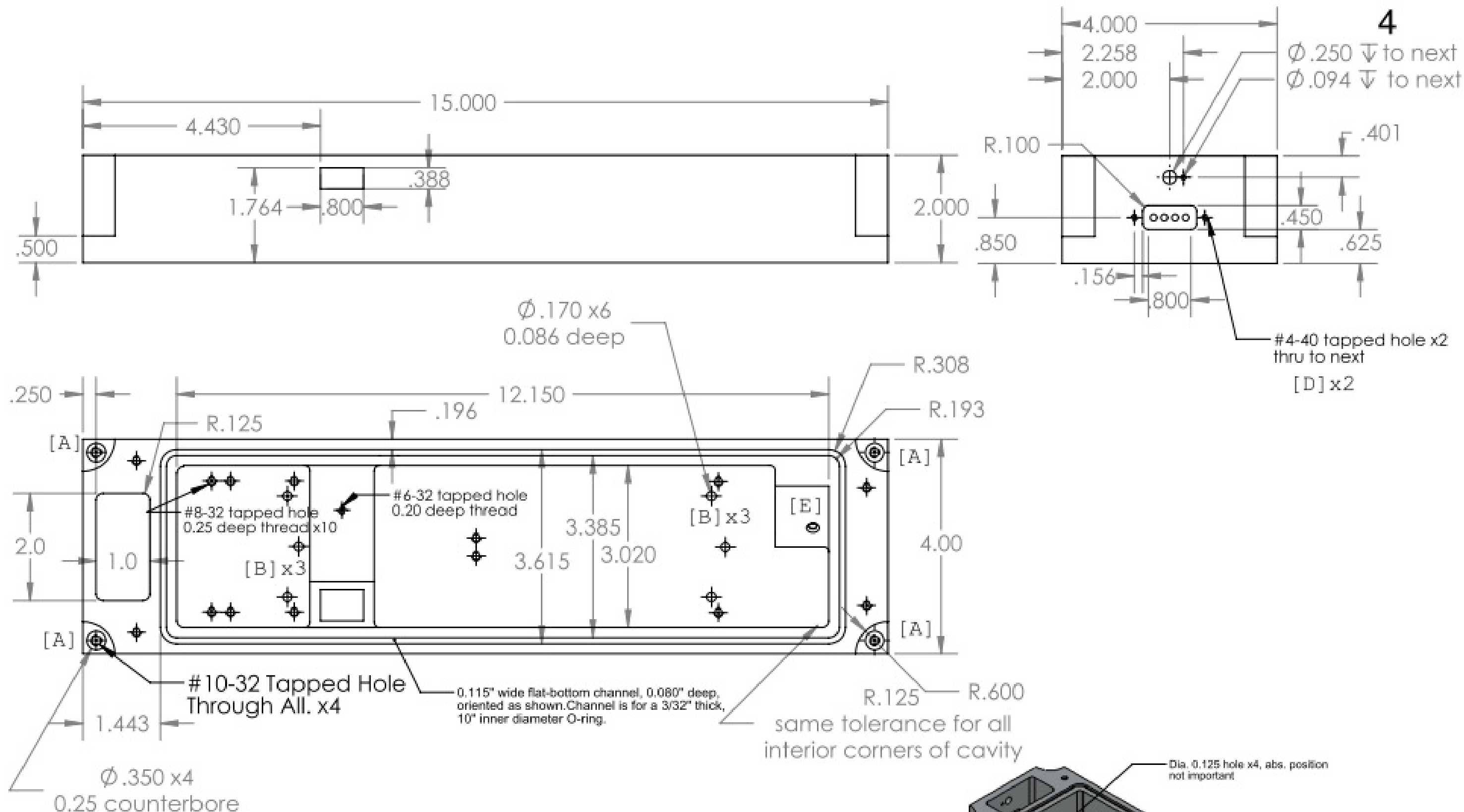
Part	Quantity	Material / Vendor	Page
Machined Components			
Base	1	6061-T6 Aluminum	3
Laser Housing	1	6061-T6 Aluminum	4-6
Laser Top	1	6061-T6 Aluminum	7
Diode Holder	1	Copper	8
Generic Holder	1	6061-T6 Aluminum	9
IF Holder Base	1	6061-T6 Aluminum	10
IF Holder Front	1	6061-T6 Aluminum	11
IF Holder Back	1	6061-T6 Aluminum	12
Lens Holder	1	6061-T6 Aluminum	13
Slug	1	Copper	14
Laser Assembly no lid	-		15
Laser Assembly with lid	-		16
IF Holder Assemly	-		17
Other Components			
U50-AL1 kinematic mount	1	Newport	18
DRV505 micrometer	1	Thorlabs	19
10mm beamsplitter cube	1	-	20
PM1 clamping arm	1	Thorlabs	21
9mm diode	1	-	22
A230TM-B aspheric collimating lens f=4.51mm	1	Thorlabs	23
SM9RR 9mm retaining ring	1	Thorlabs	24
LT230P-B 3/4 collimating tube (for reference)	-	Thorlabs	25
N100B2 1/16 threaded bushing	1	Thorlabs	26
UFS075 1/16 x 3/4 set screw	1	Thorlabs	27
AD1T 1" internal threaded optic holder	1	Thorlabs	28
LM1-A 1" optic holder, inner ring with angle markings	1	Thorlabs	29
SM1RR 1" retaining ring	3	Thorlabs	30
V1025-1 or V1021-1 vacuum valve	1	Cryocomp	31
CP1.0-63-08L TEC	1	Melcor	32-33
RL0503-5820-97-MS thermistor	1	GE	34
A34066-ND female DE-15 connector	1	Digi-Key	35
450-1522-ND toggle switch	1	Digi-Key	36-38
Microscope slide	1		-

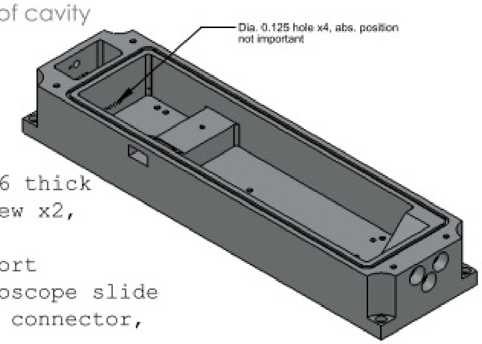
Torr seal			-
Fasteners			
3/8-24 x 1/2 socket cap screw	3	McMaster Carr	
1/4-20 socket cap screw	4	McMaster Carr	
1/4-20 x ½ swivel ball bearing set screw	1	McMaster Carr	
10-32 x 1/2 socket cap screw	4	McMaster Carr	
8-32 x 1 1/2 socket cap screw	4	McMaster Carr	
8-32 x 3/4 nylon socket cap screw	4	McMaster Carr	
8-32 x 1/2 vented socket cap screw	7	McMaster Carr	
8-32 x 1/4 soft tipped set screw	4	McMaster Carr	
4-40 x 1/4 socket cap screw	2	McMaster Carr	
1/4 washer	4	McMaster Carr	
#10 washer	4	McMaster Carr	
#8 washer	13	McMaster Carr	
3/32 x 1 1/4 dowel pin	1	McMaster Carr	
3/32 x 3/4 dowel pin	2	McMaster Carr	
3/32 x 5/16 dowel pin	3	McMaster Carr	
0.180 dia. X 0.544 ultra precision extension spring	4	McMaster Carr	
5/16 steel ball	3	McMaster Carr	
5/32 steel ball	6	McMaster Carr	
3/32 thick 10" inner dia. Viton o-ring	1	McMaster Carr	
1/16 thick 3/8 inner dia. Viton o-ring	3	McMaster Carr	
0.072 thick 0.495 outer dia. silicon o-ring	1	McMaster Carr	

3



Laser Base
Material: 6061-T6 Aluminum
Fasteners: [A] 1/4-20 socket cap screw with washers x 4



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Laser Housing (view 1 of 3)
Material: 6061-T6 Aluminum
Fasteners: [A] 10-32 x 1/2 socket cap screw with washer x 4,
[B] 5/32 steel ball x 6, [C] 3/8-24 x 1/2 socket cap screw with 1/16 thick
3/8 inner diameter Viton o-ring x 3, [D] 4-40 x 0.25 socket cap screw x2,
[E] 8-32 x 1/2 vented socket cap screw
Components: Thorlabs PM1 clamping arm, 10mm beamsplitter cube, Newport
U50-AL1 kinematic mount, 3/32 thick 10" diameter Viton o-ring, microscope slide
with torr seal for Brewster window, Digi-Key A34066-ND female DE-15 connector,
Digi-Key 450-1522-ND toggle switch with lock-ring
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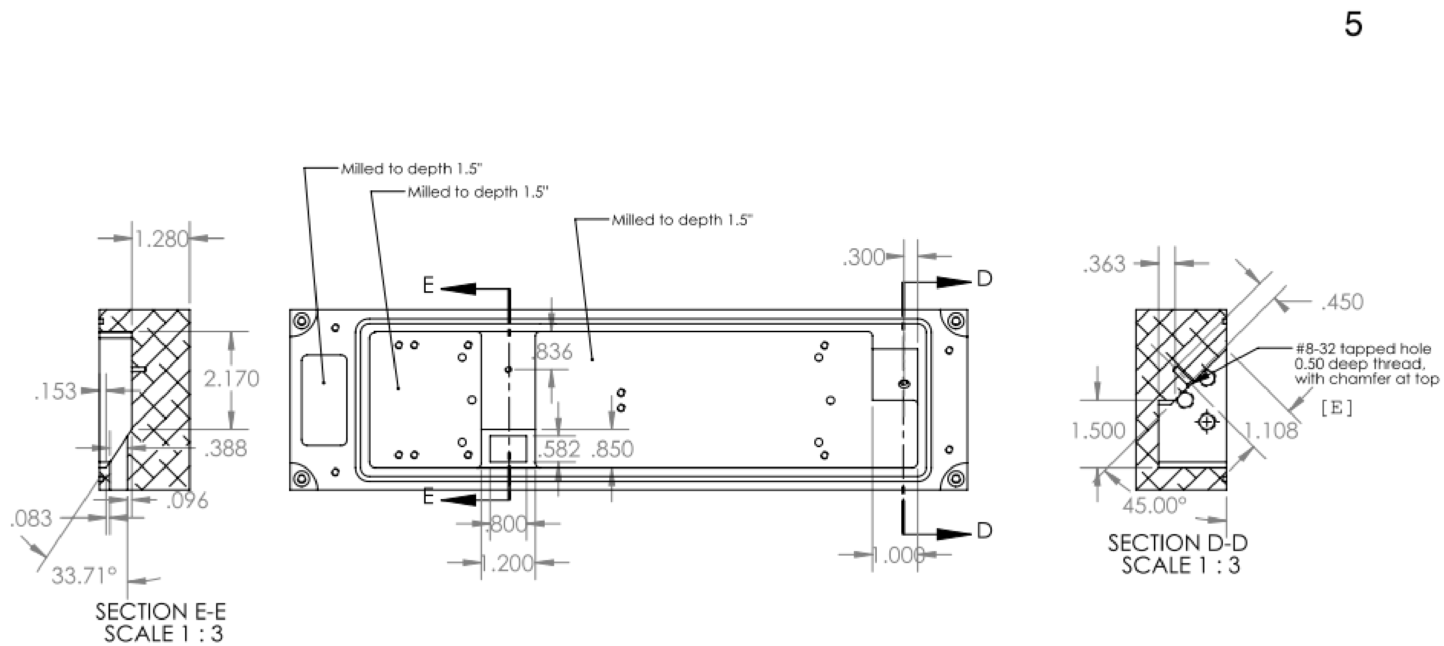
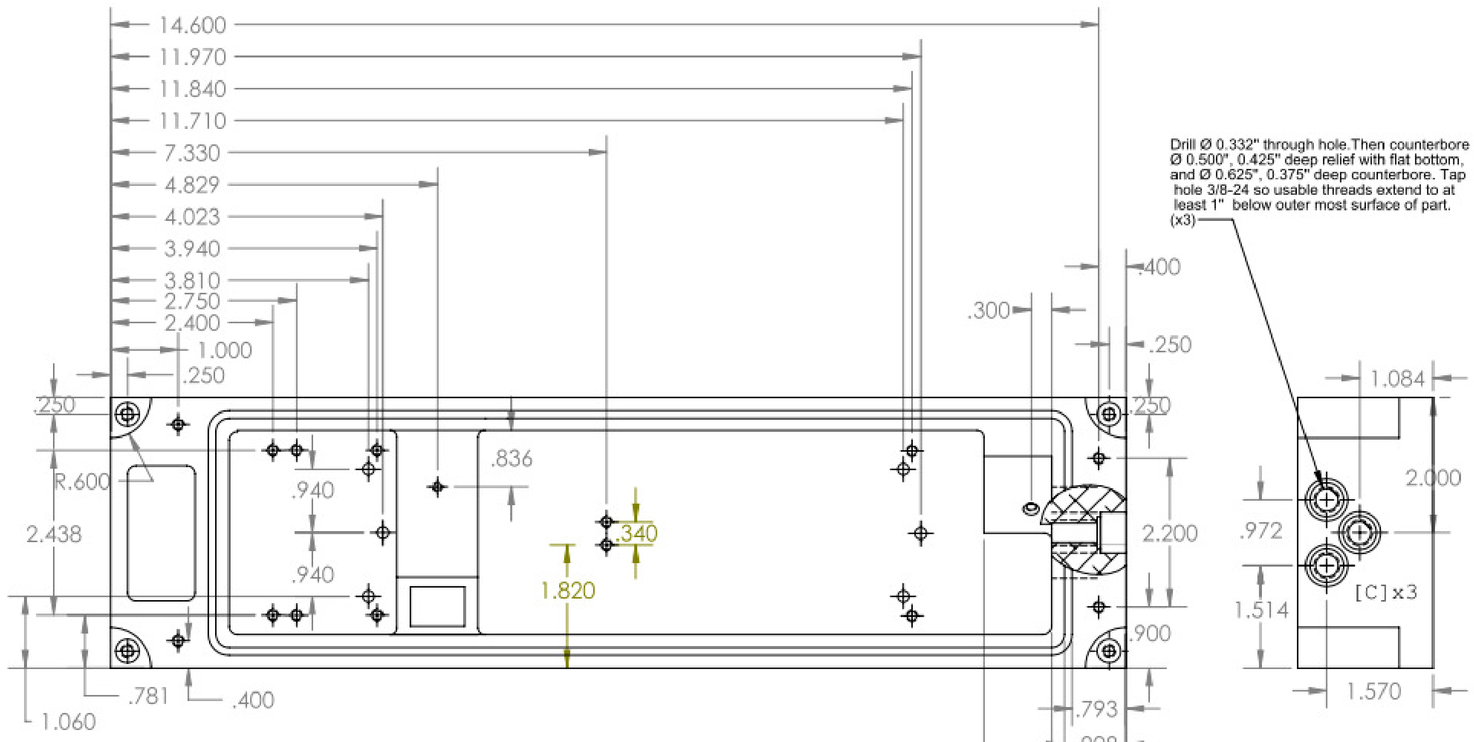
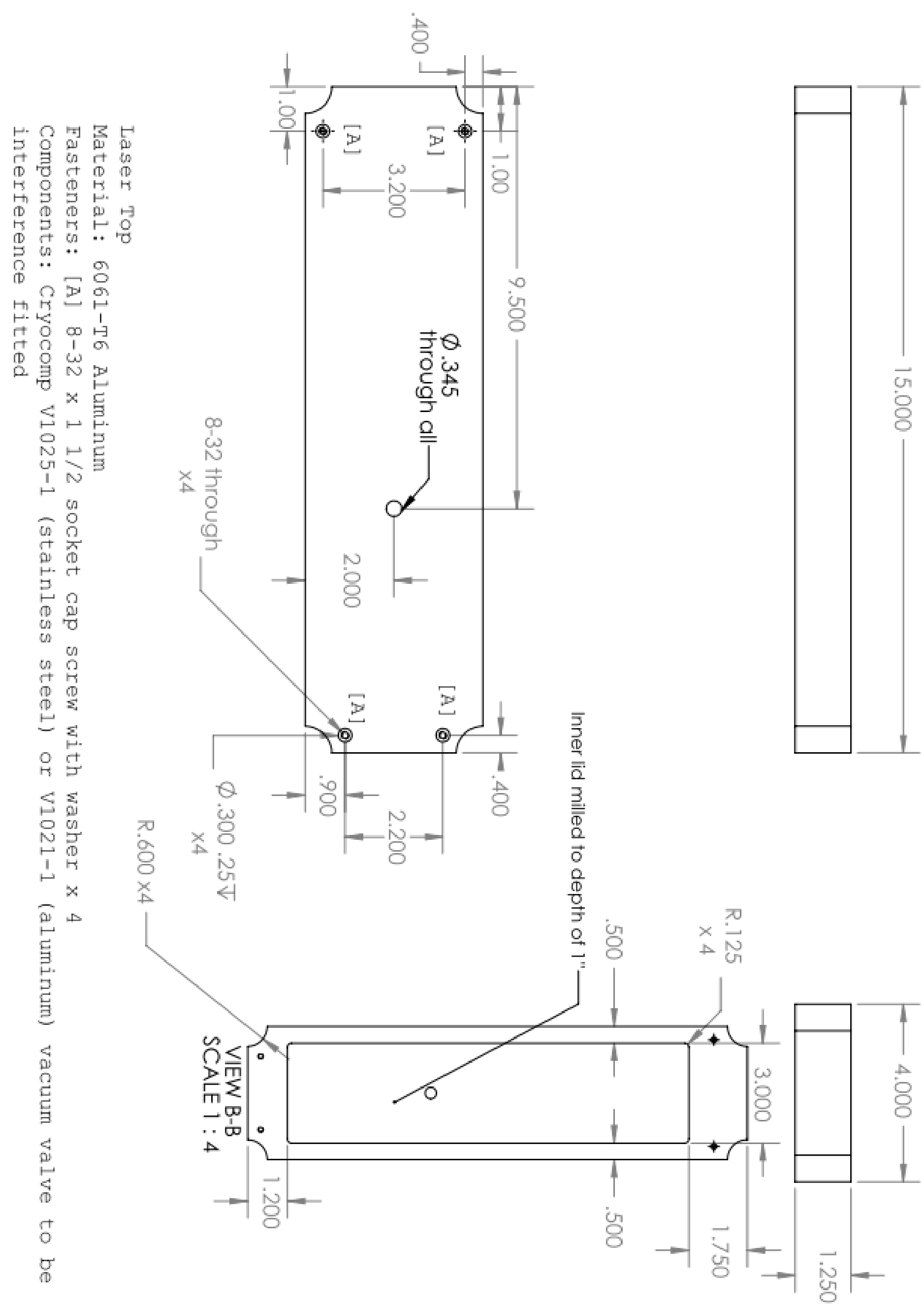


Laser Housing (view 2 of 3)
Material: 6061-T6 Aluminum
Fasteners: [A] 10-32 x 1/2 socket cap screw with washer x 4,
[B] 5/32 steel ball x 6, [C] 3/8-24 x 1/2 socket cap screw with 1/16 thick
3/8 inner diameter Viton o-ring x 3, [D] 4-40 x 0.25 socket cap screw x2, [E] 8-32 x 1/2
vented socket cap screw
Components: Thorlabs PM1 clamping arm, 10mm beamsplitter cube, Newport
U50-AL1 kinematic mount, 3/32 thick 10" diameter Viton o-ring, microscope slide
with torr seal for Brewster window, Digi-Key A34066-ND female DE-15 connector,
Digi-Key 450-1522-ND toggle switch with lock-ring

6



Laser Housing (view 3 of 3)
Material: 6061-T6 Aluminum
Fasteners: [A] 10-32 x 1/2 socket cap screw with washer x 4, [B] 5/32 steel ball x 6,
[C] 3/8-24 x 1/2 socket cap screw with 1/16 thick 3/8 inner diameter Viton o-ring x 3,
[D] 4-40 x 0.25 socket cap screw x2, [E] 8-32 x 1/2 vented socket cap screw
Components: Thorlabs PM1 clamping arm, 10mm beamsplitter cube, Newport U50-AL1 kinematic mount,
3/32 thick 10" diameter Viton o-ring, microscope slide with torr seal for Brewster window,
Digi-Key A34066-ND female DE-15 connector, Digi-Key 450-1522-ND toggle switch with lock-ring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x 4
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Inner lid milled to depth of 1"
VIEW B-B
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through all
8-32 through
x4
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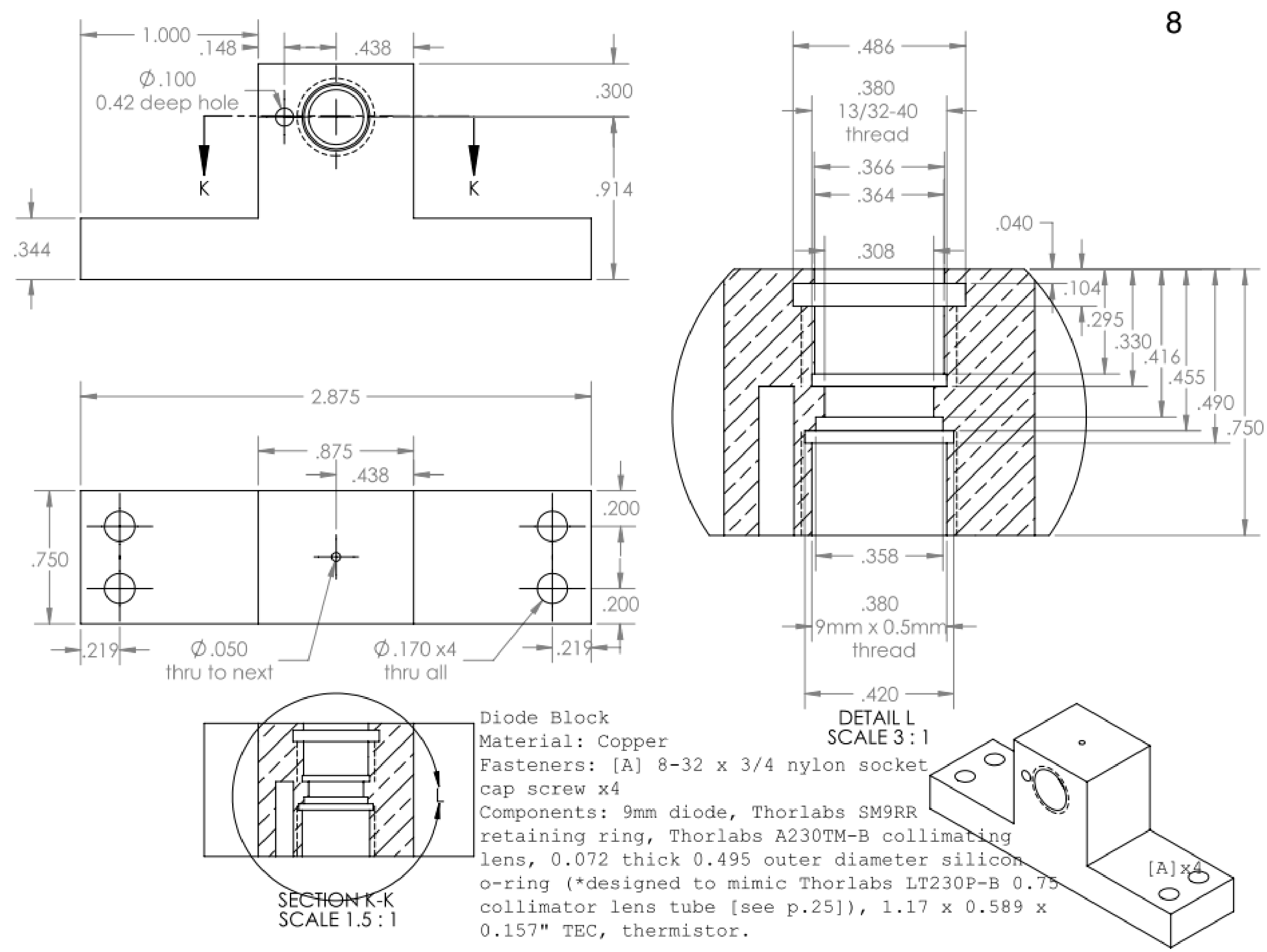
.400
.900
2.200
Ø.300 .25
x4
Laser Top
Material: 6061-T6 Aluminum
Fasteners: [A] 8-32 x 1 1/2 socket cap screw with washer x 4
Components: Cryocomp V1025-1 (stainless steel) or V1021-1 (aluminum) vacuum valve to be interference fitted

7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.344
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.875
.438
.750
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.219
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thru to next
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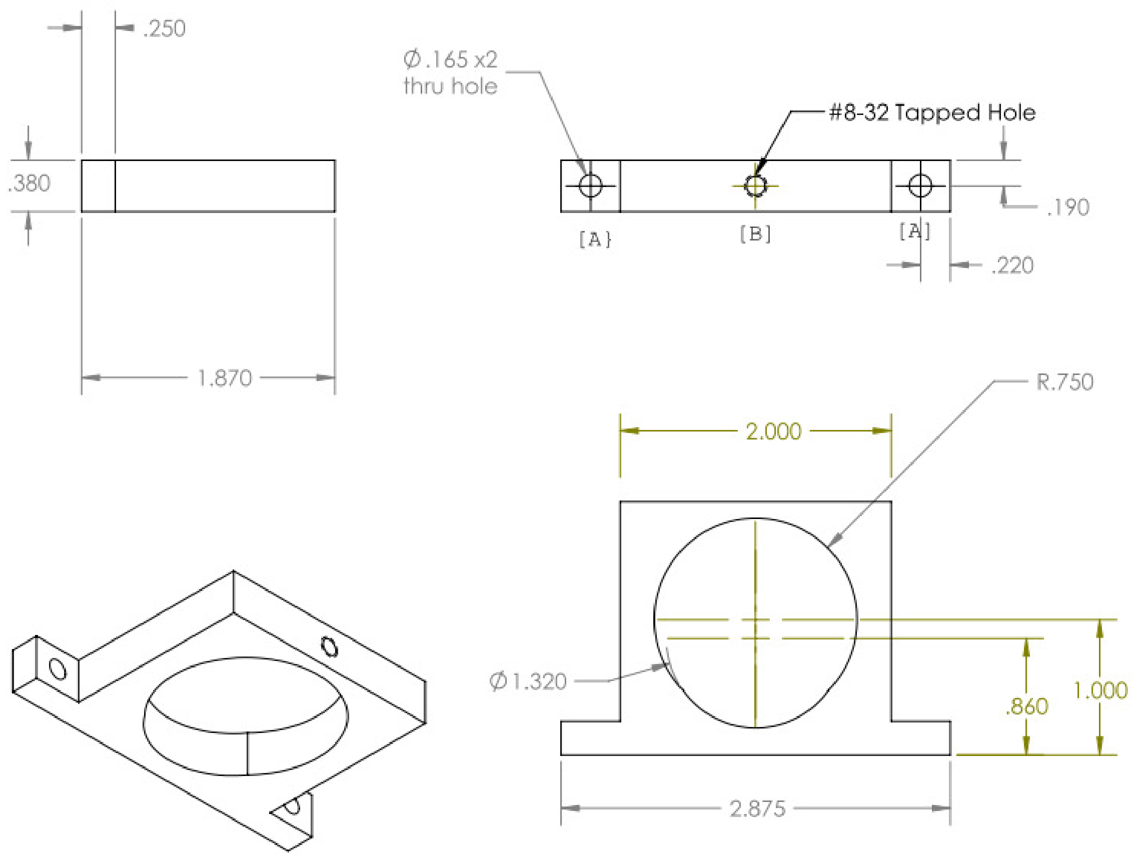
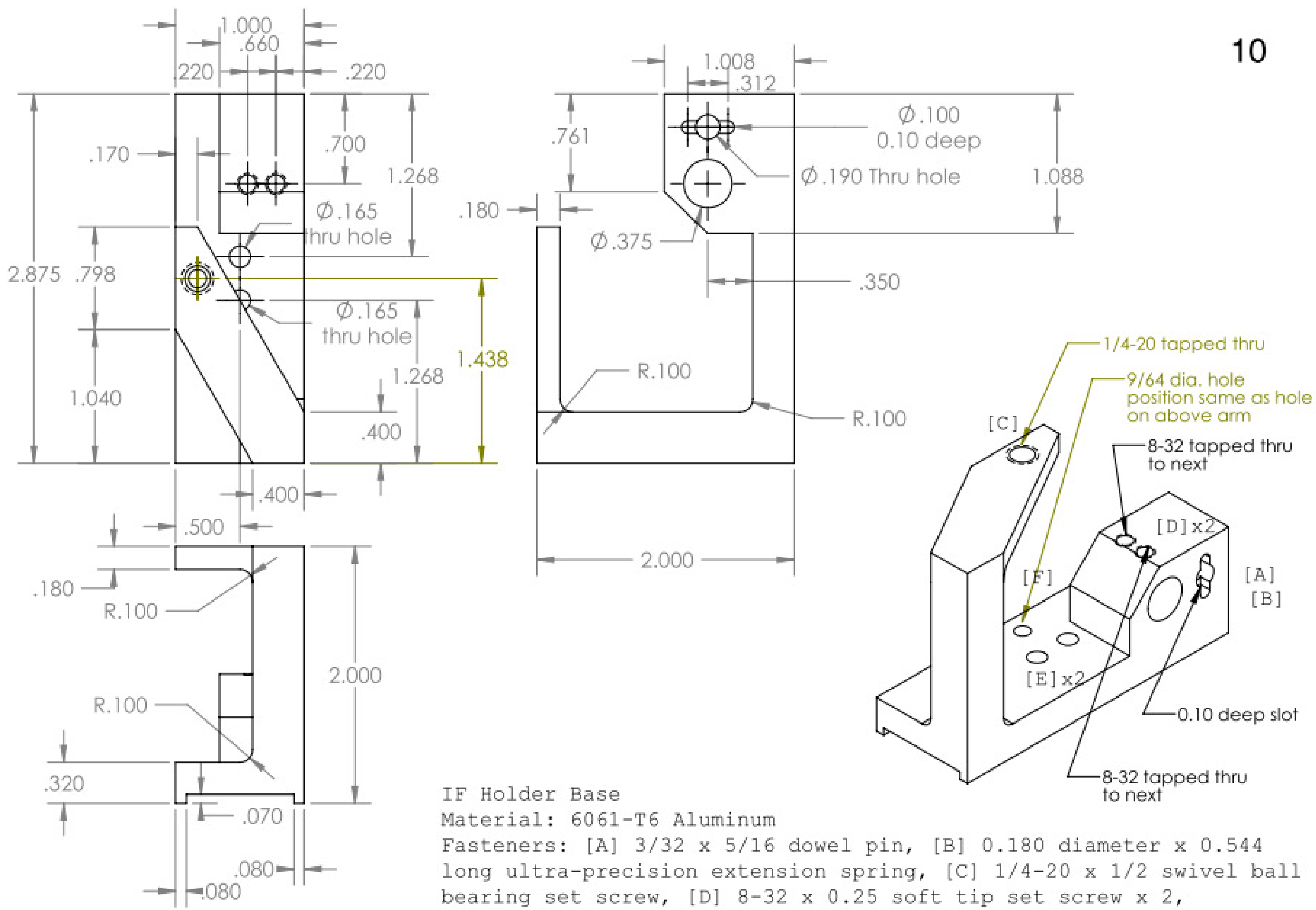
thru all
.219
.486
.380
13/32-40
thread
.366
.364
.040
.308
.104
.295
.330
.416
.455
.490
.750
.358
.380
9mm x 0.5mm
thread
.420
DETAIL L
SCALE 3 : 1
L
SECTION K-K
SCALE 1.5 : 1
Diode Block
Material: Copper
Fasteners: [A] 8-32 x 3/4 nylon socket cap screw x4
Components: 9mm diode, Thorlabs SM9RR retaining ring, Thorlabs A230TM-B collimating lens, 0.072 thick 0.495 outer diameter silicon o-ring (*designed to mimic Thorlabs LT230P-B 0.75 collimator lens tube [see p.25]), 1.17 x 0.589 x 0.157" TEC, thermistor.
[A]x4

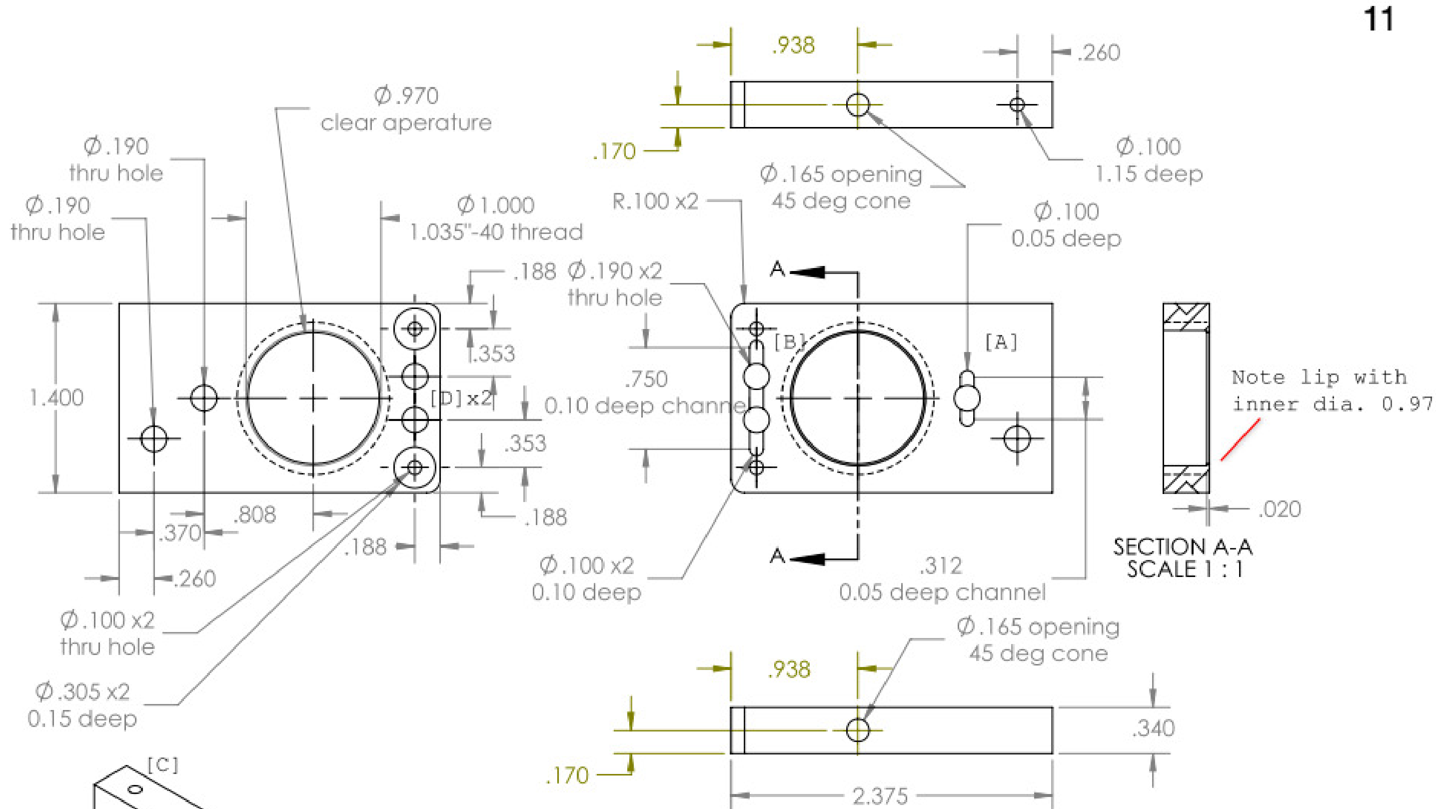
9

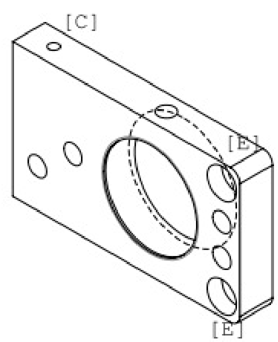


Generic Holder
Material: 6061-T6 Aluminum
Fasteners: [A] 8-32 x 1/2 vented socket cap screw with washer x2, [B] 8-32 x 1/4 soft tipped set screw
Components: 0.5 dia. half wave plate in Thorlabs AD1T internally threaded adapter, mounted in Thorlabs LM1-A nested inner lens carriage with angle markings.

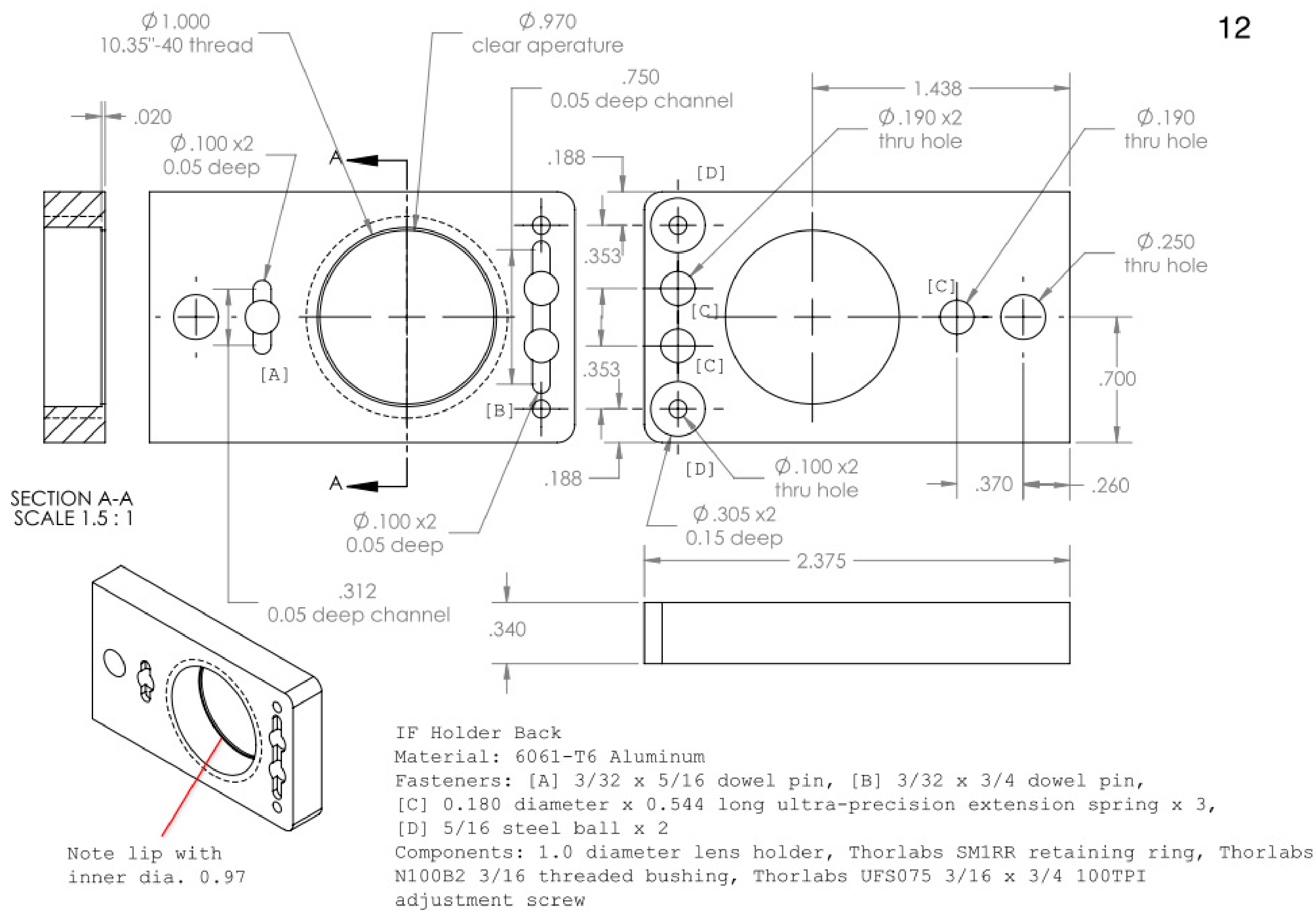


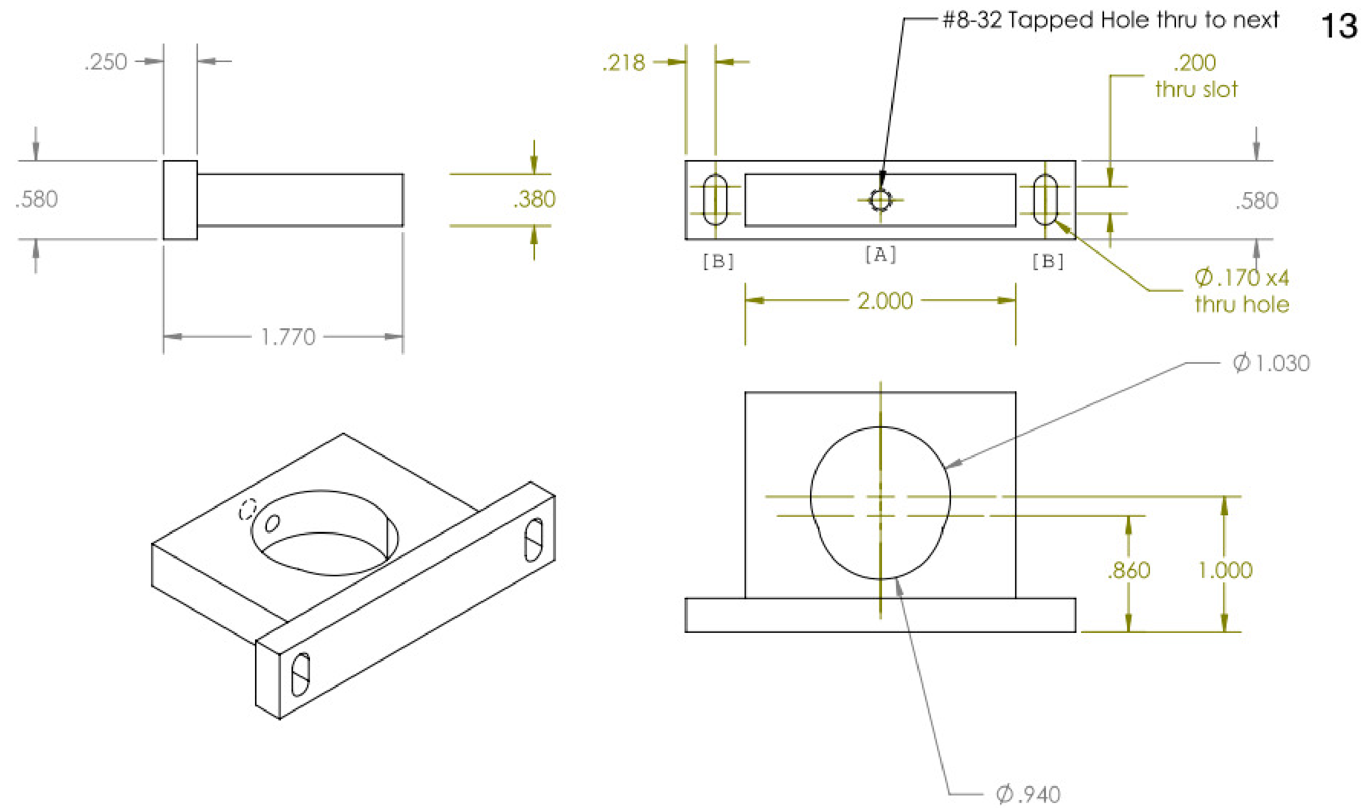
IF Holder Base
Material: 6061-T6 Aluminum
Fasteners: [A] 3/32 x 5/16 dowel pin, [B] 0.180 diameter x 0.544 long ultra-precision extension spring, [C] 1/4-20 x 1/2 swivel ball bearing set screw, [D] 8-32 x 0.25 soft tip set screw x 2, [E] 8-32 x 1/2 vented socket cap screw with washer x 2, [F] 5/32 steel ball
Components: Thorlabs DRV505 micrometer



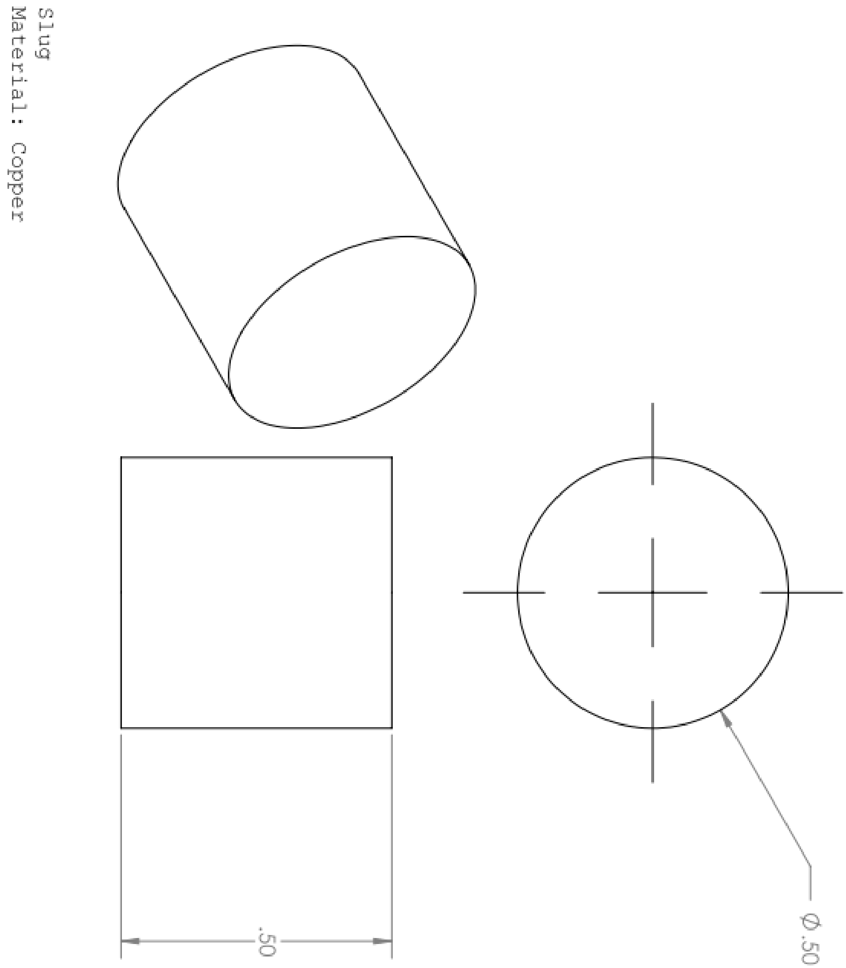


IF Holder Front
Material: 6061-T6 Aluminum
Fasteners: [A] 3/32 x 5/16 dowel pin, [B] 3/32 x 3/4 dowel pin, [C] 3/32 x 1 1/4 dowel pin, [D] 0.180 diameter x 0.544 long ultra-precision extension spring x 4, [E] 5/16 steel ball x 2
Components: 1.0 diameter lens holder, Thorlabs SM1RR retaining ring

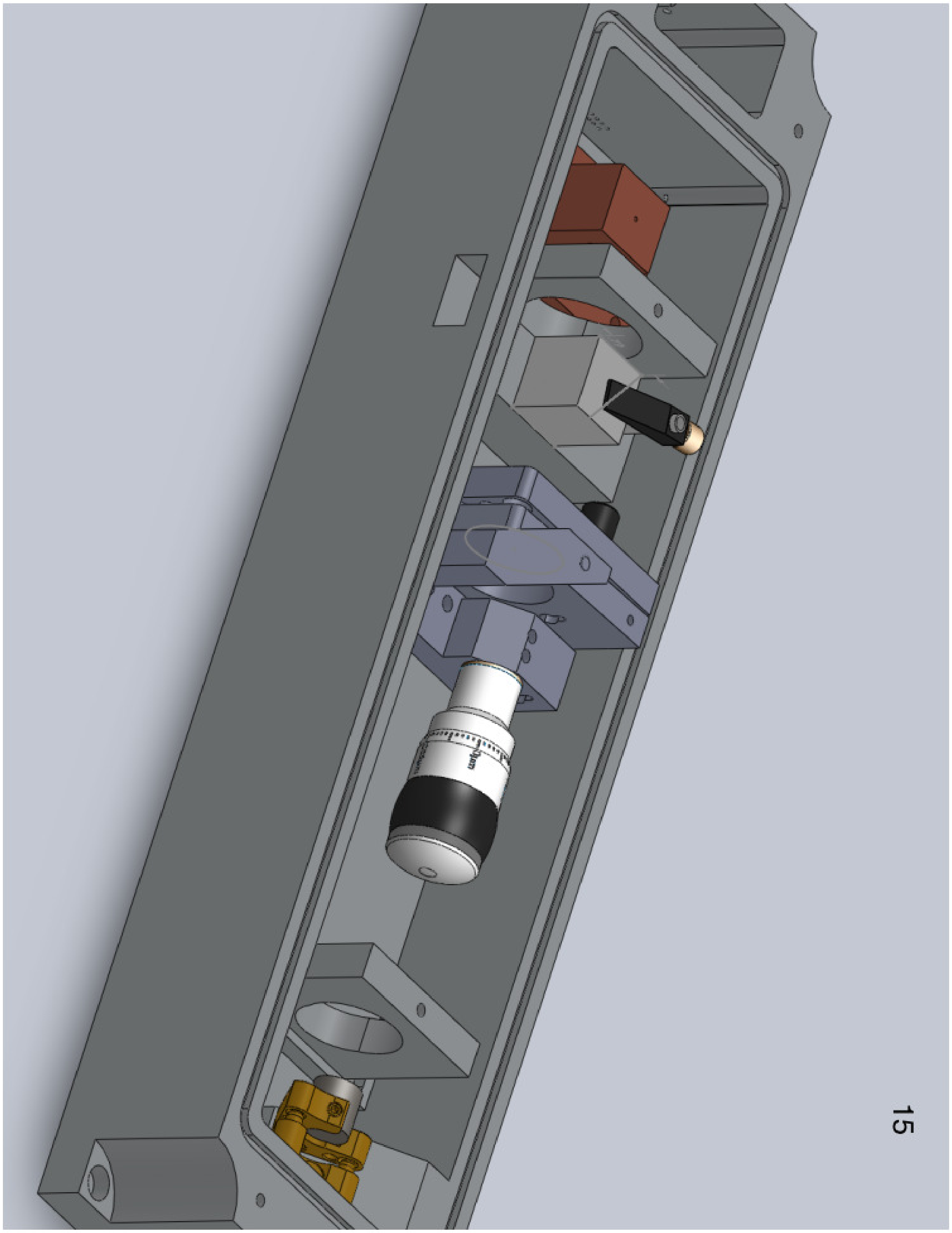

12
Ø 1.000
10.35"-40 thread
Ø .970
clear aperature
.750
0.05 deep channel
.020
Ø .100 x2
0.05 deep
.188
1.438
Ø .190 x2
thru hole
Ø .190
thru hole
Ø .250
thru hole
A
A
[A]
[B]
[C]
[C]
[C]
[D]
[D]
.353
.353
.700
.188
Ø .100 x2
thru hole
.370
.260
SECTION A-A
SCALE 1.5 : 1
Ø .100 x2
0.05 deep
Ø .305 x2
0.15 deep
2.375
.312
0.05 deep channel
.340
Note lip with
inner dia. 0.97
IF Holder Back
Material: 6061-T6 Aluminum
Fasteners: [A] 3/32 x 5/16 dowel pin, [B] 3/32 x 3/4 dowel pin,
[C] 0.180 diameter x 0.544 long ultra-precision extension spring x 3,
[D] 5/16 steel ball x 2
Components: 1.0 diameter lens holder, Thorlabs SM1RR retaining ring, Thorlabs
N100B2 3/16 threaded bushing, Thorlabs UFS075 3/16 x 3/4 100TPI
adjustment screw

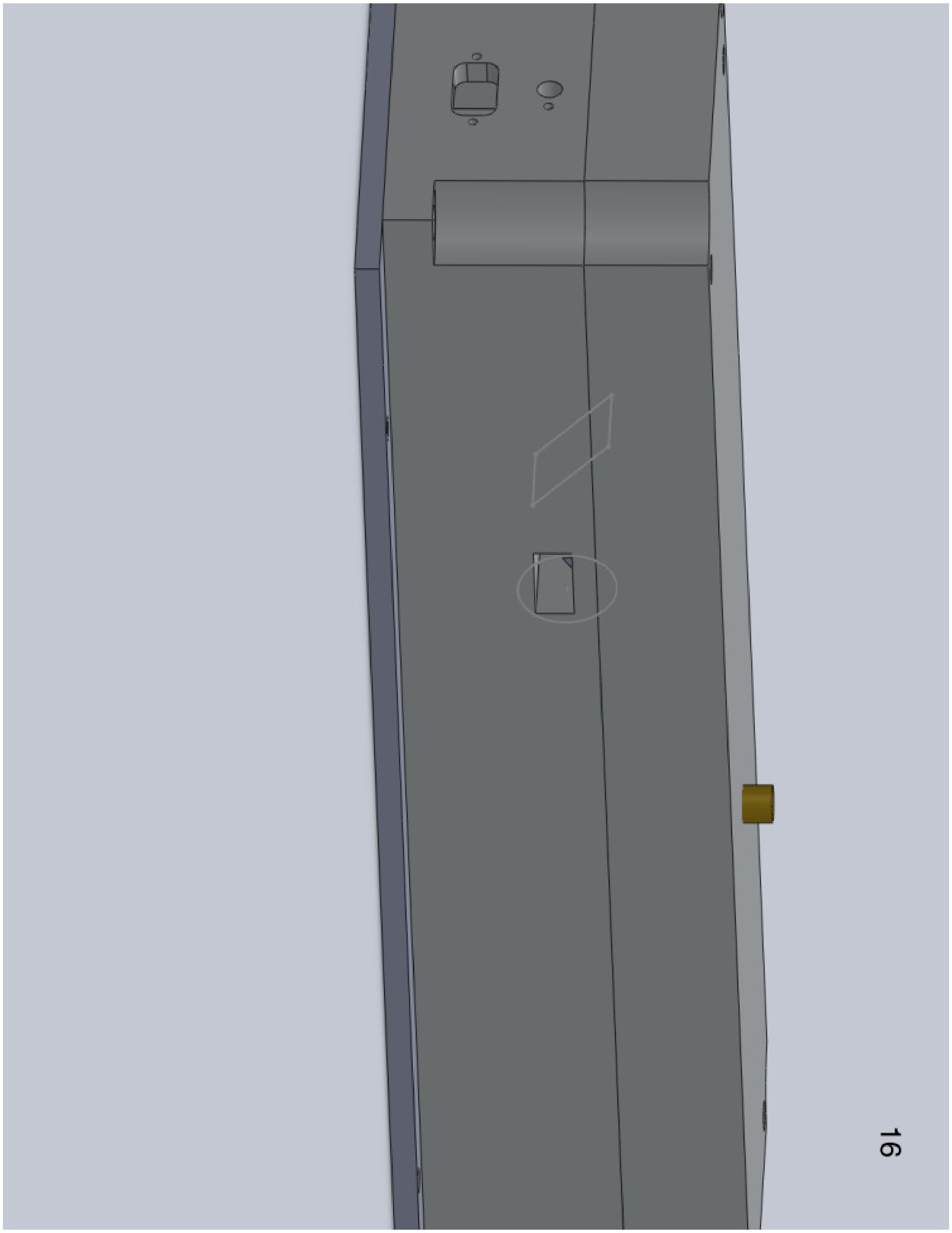


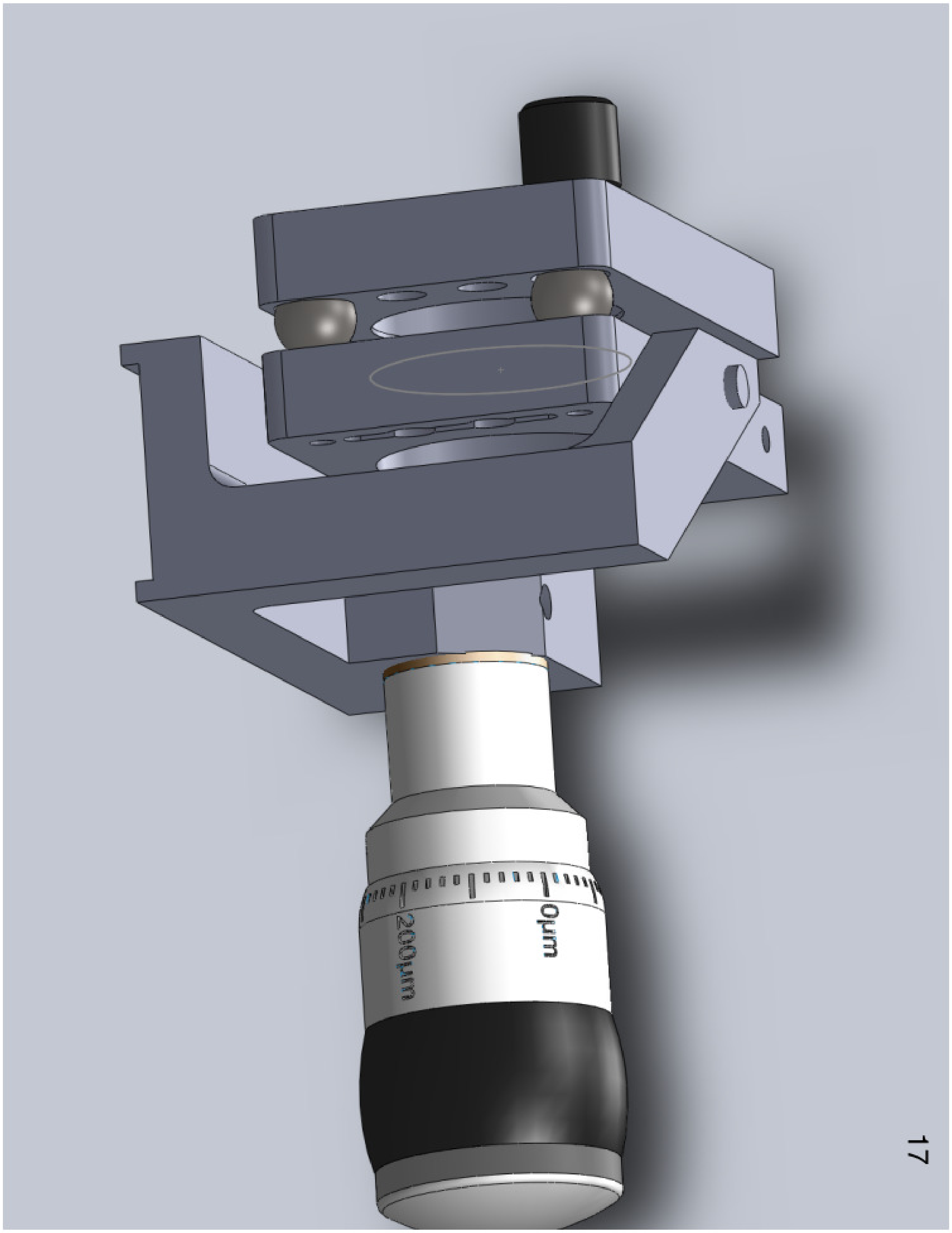
Lens Holder
Material: 6061-T6 Aluminum
Fasteners: [A] 8-32 x 0.25 soft tip set screw x 2,
[B] 8-32 x 1/2 vented socket cap screw with washer x 2
Components: 1.03 diameter lens holder

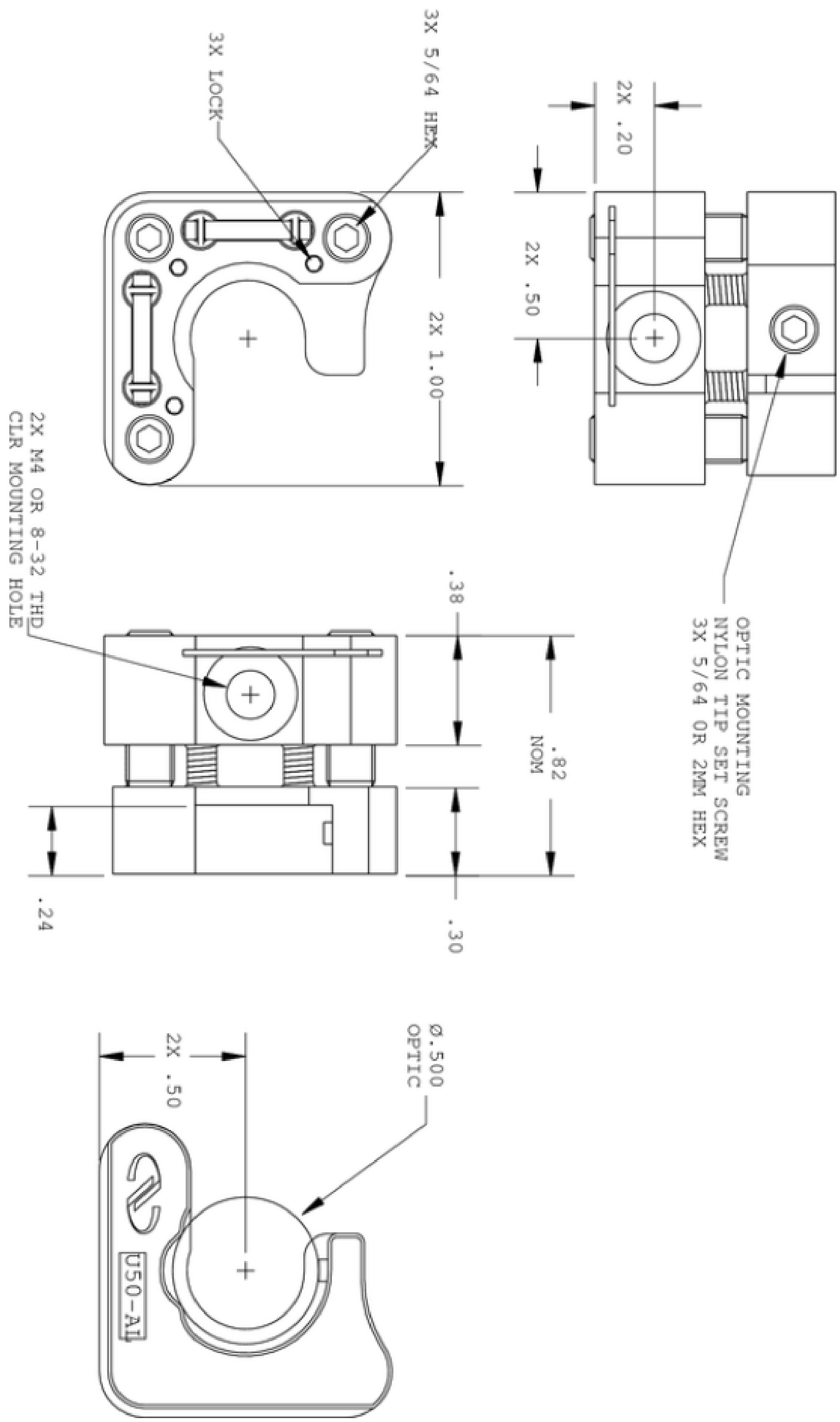


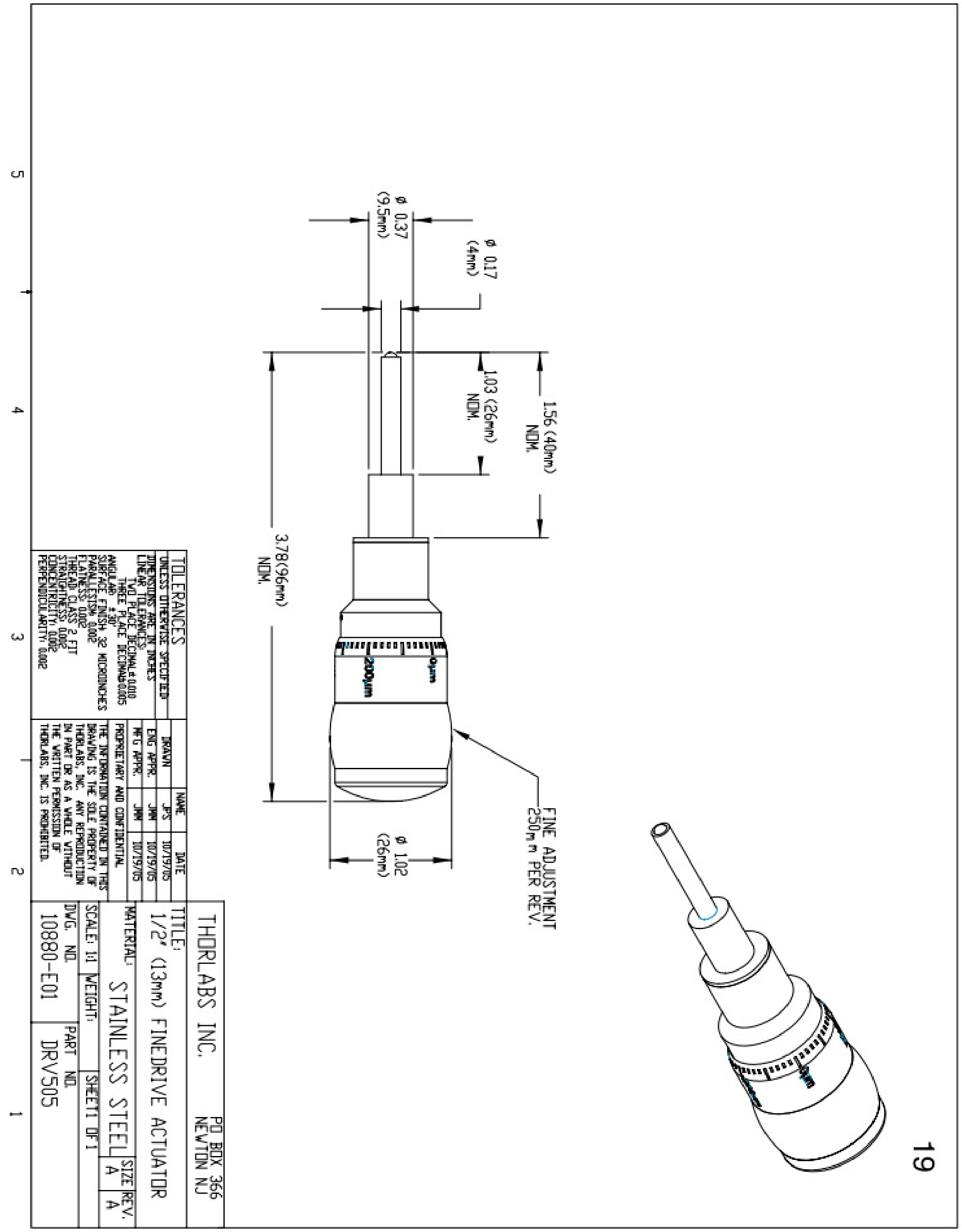
14


15


16


0μm
200μm
17


3X 5/64 HEX
3X LOCK
2X .20
2X .50
2X 1.00
2X M4 OR 8-32 THD
CLR MOUNTING HOLE
OPTIC MOUNTING
NYLON TIP SET SCREW
3X 5/64 OR 2MM HEX
.38
.82
NOM
.30
.24
Ø.500
OPTIC
2X .50
U50-A1



ø 0.37
(9.5mm)
ø 0.17
(4mm)
1.03 (26mm)
NOM.
1.56 (40mm)
NOM.
3.78(96mm)
NOM.
ø 1.02
(26mm)
FINE ADJUSTMENT
250μm PER REV.
0μm
200μm
19
TOLERANCES
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
LINEAR TOLERANCES
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL±0.005
ANGULAR ±.30'
SURFACE FINISH 32 MICROINCHES
PARALLELISM 0.002
FLATNESS 0.002
THREAD CLASS 2 FIT
STRAIGHTNESS 0.002
CONCENTRICITY 0.002
PERPENDICULARITY 0.002
NAME DATE
DRAWN JPS 10/19/05
ENG APPR. JMM 10/19/05
MFG APPR. JMM 10/19/05
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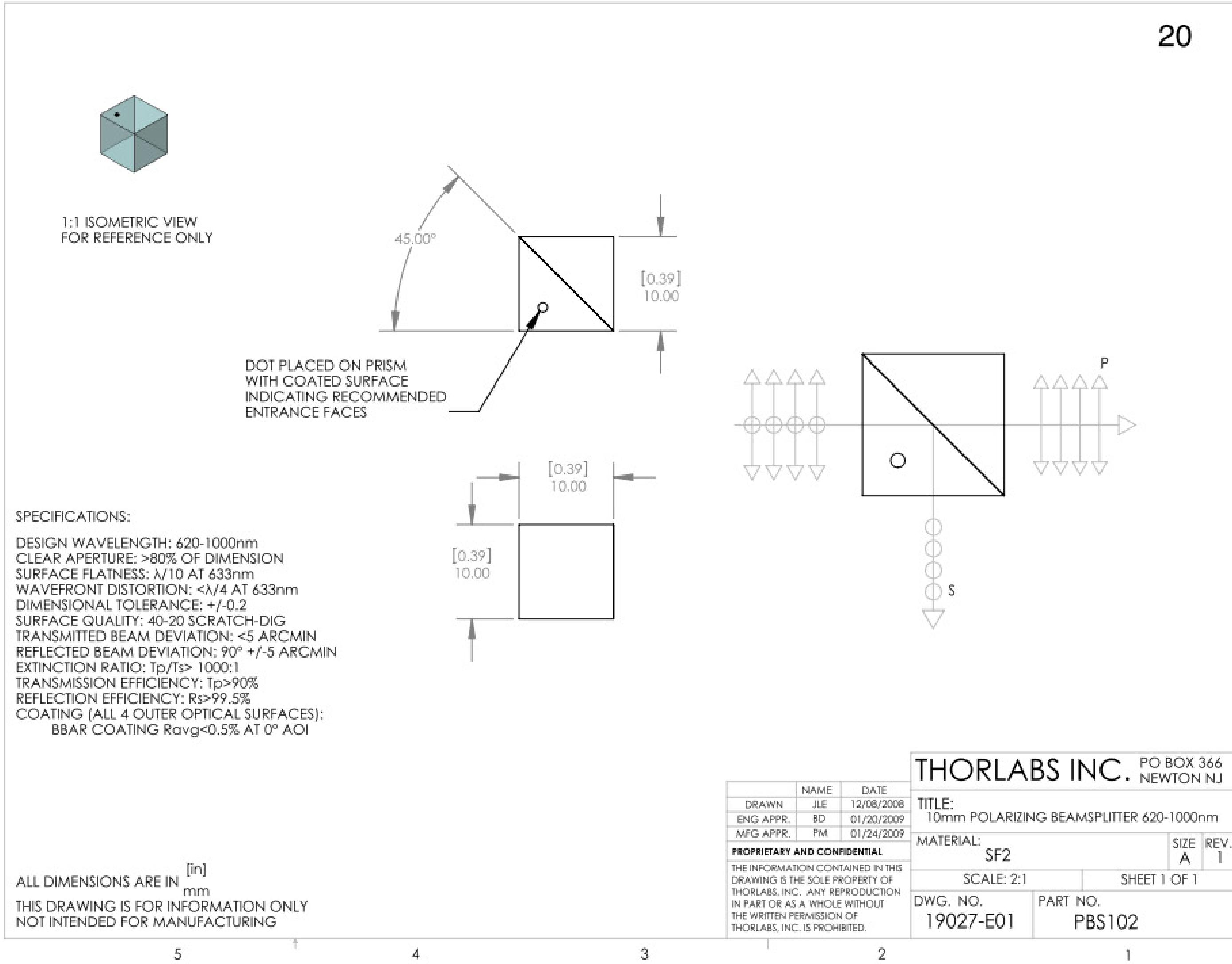
THORLABS INC.
PO BOX 366
NEWTON NJ
TITLE:
1/2" (13mm) FINEDRIVE ACTUATOR
MATERIAL:
STAINLESS STEEL
SIZE A
REV. A
SCALE: 1:1
WEIGHT:
SHEET1 OF 1
DWG. NO.
10880-E01
PART NO.
DRV505
5
4
3
2
1


20
1:1 ISOMETRIC VIEW
FOR REFERENCE ONLY
45.00°
[0.39]
10.00
DOT PLACED ON PRISM
WITH COATED SURFACE
INDICATING RECOMMENDED
ENTRANCE FACES
[0.39]
10.00
[0.39]
10.00
P
S
SPECIFICATIONS:
DESIGN WAVELENGTH: 620-1000nm
CLEAR APERTURE: >80% OF DIMENSION
SURFACE FLATNESS: λ/10 AT 633nm
WAVEFRONT DISTORTION: <λ/4 AT 633nm
DIMENSIONAL TOLERANCE: +/-0.2
SURFACE QUALITY: 40-20 SCRATCH-DIG
TRANSMITTED BEAM DEVIATION: <5 ARCMIN
REFLECTED BEAM DEVIATION: 90° +/-5 ARCMIN
EXTINCTION RATIO: Tp/Ts> 1000:1
TRANSMISSION EFFICIENCY: Tp>90%
REFLECTION EFFICIENCY: Rs>99.5%
COATING (ALL 4 OUTER OPTICAL SURFACES):
BBAR COATING Ravg<0.5% AT 0° AOI
ALL DIMENSIONS ARE IN [in] mm
THIS DRAWING IS FOR INFORMATION ONLY
NOT INTENDED FOR MANUFACTURING
NAME DATE
DRAWN JLE 12/08/2008
ENG APPR. BD 01/20/2009
MFG APPR. PM 01/24/2009
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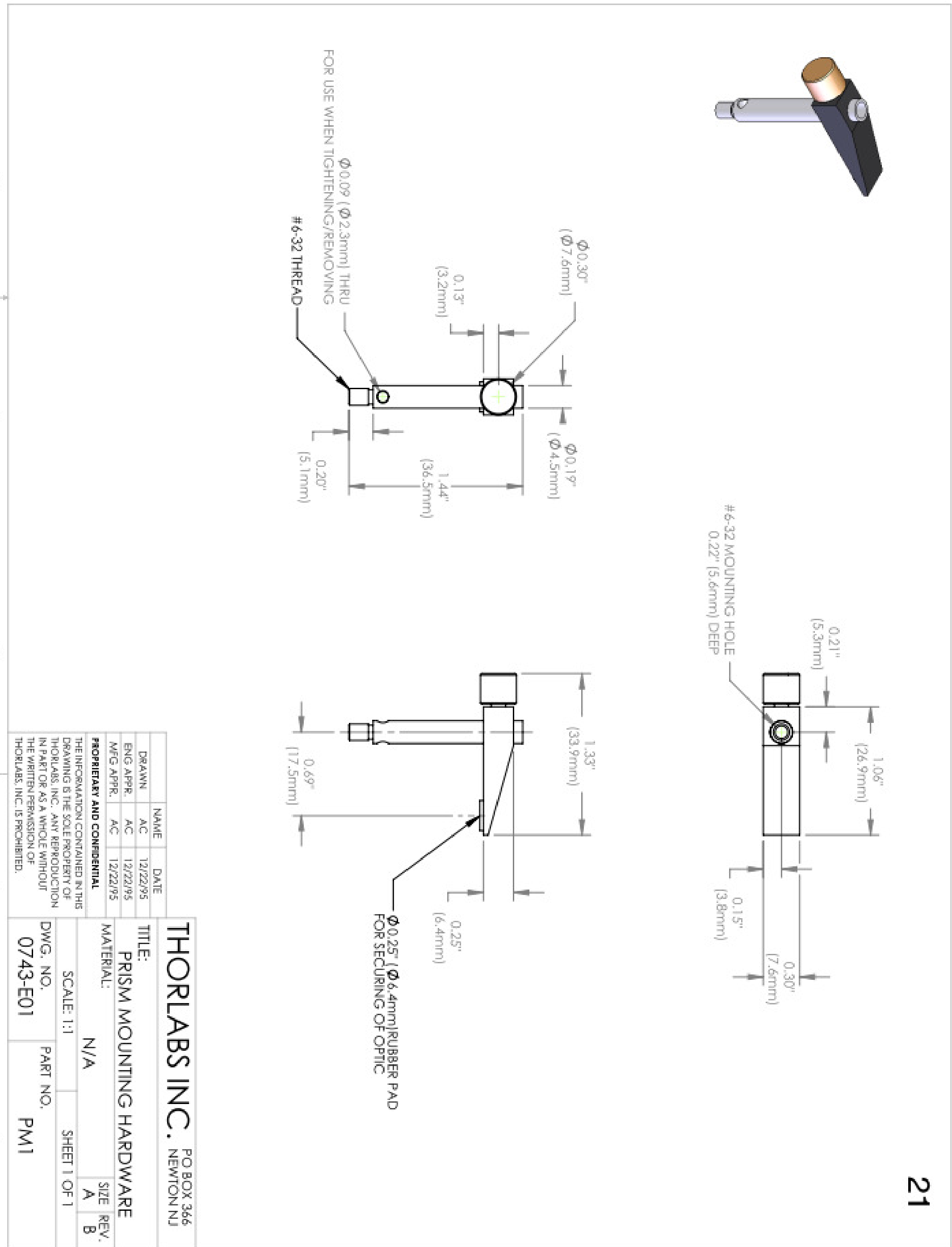
THORLABS INC. PO BOX 366 NEWTON NJ
TITLE:
10mm POLARIZING BEAMSPLITTER 620-1000nm
MATERIAL:
SF2
SIZE A
REV. 1
SCALE: 2:1
SHEET 1 OF 1
DWG. NO.
19027-E01
PART NO.
PBS102
5
4
3
2
1



21
Ø0.30" (Ø7.6mm)
0.13" (3.2mm)
Ø0.09 (Ø2.3mm) THRU
FOR USE WHEN TIGHTENING/REMOVING
#6-32 THREAD
Ø0.19" (Ø4.5mm)
1.44" (36.5mm)
0.20" (5.1mm)
#6-32 MOUNTING HOLE
0.22" (5.6mm) DEEP
0.21" (5.3mm)
1.06" (26.9mm)
0.15" (3.8mm)
0.30" (7.6mm)
1.33" (33.9mm)
0.69" (17.5mm)
0.25" (6.4mm)
Ø0.25" (Ø6.4mm)RUBBER PAD
FOR SECURING OF OPTIC
THORLABS INC.
PO BOX 366
NEWTON NJ
TITLE:
PRISM MOUNTING HARDWARE
MATERIAL:
N/A
SIZE A
REV. B
SCALE: 1:1
SHEET 1 OF 1
DWG. NO.
0743-E01
PART NO.
PM1
NAME DATE
DRAWN AC 12/22/95
ENG APPR. AC 12/22/95
MFG APPR. AC 12/22/95
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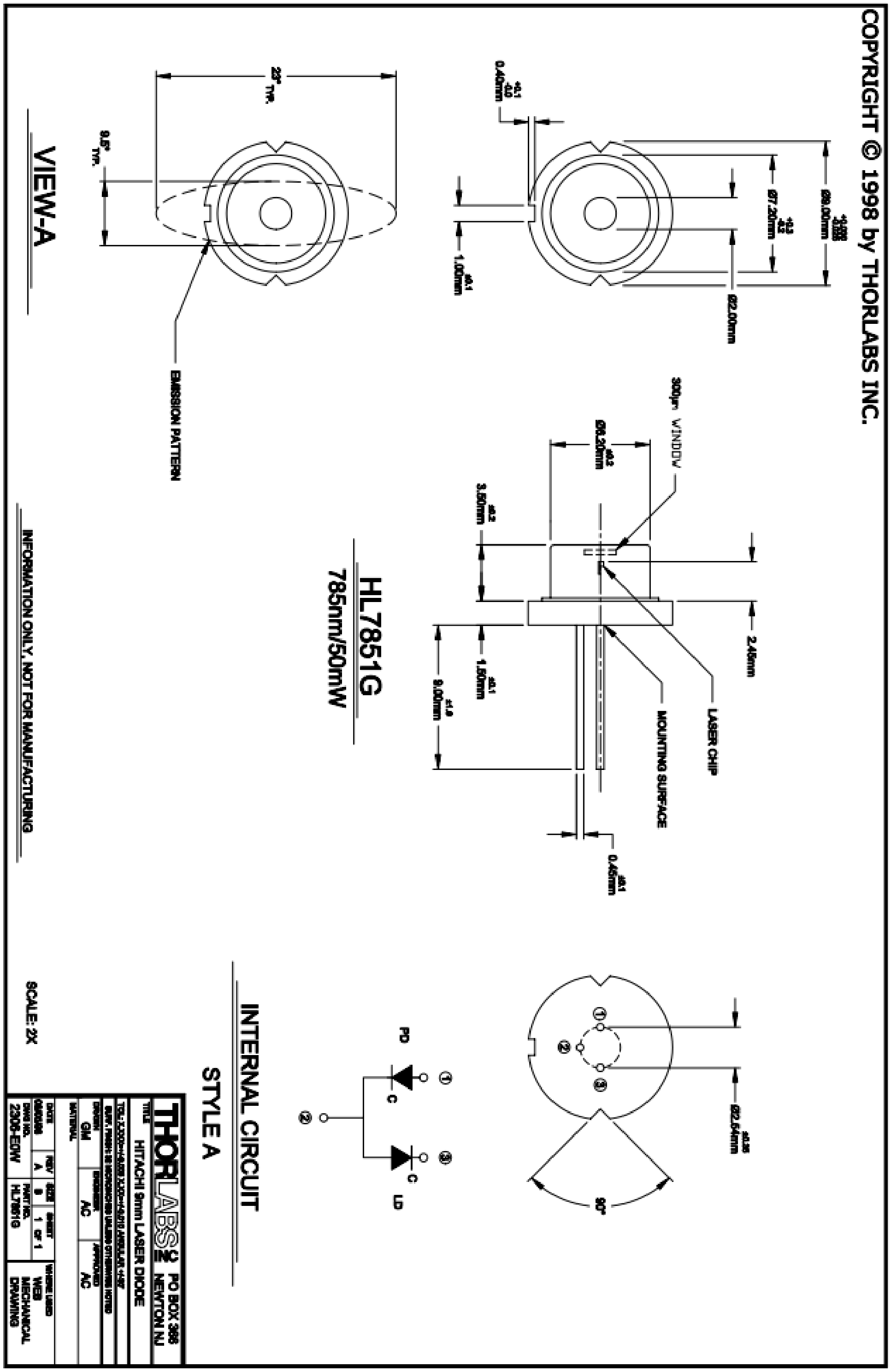

COPYRIGHT © 1998 by THORLABS INC.
VIEW-A
EMISSION PATTERN
300µm WINDOW
LASER CHIP
MOUNTING SURFACE
HL7851G
785nm/50mW
INFORMATION ONLY, NOT FOR MANUFACTURING
INTERNAL CIRCUIT
STYLE A
PD
LD
SCALE: 2X
PO BOX 366
NEWTON NJ
HITACHI 9mm LASER DIODE

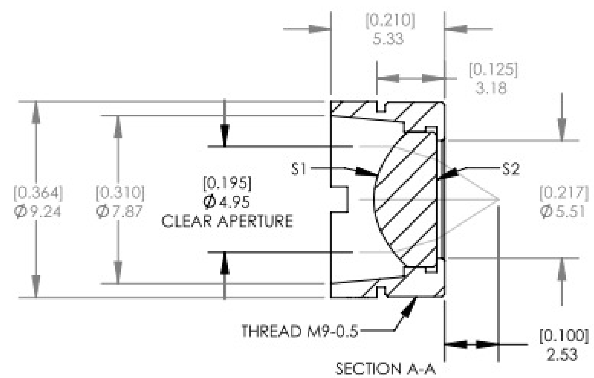
23

ASPHERIC COEFFICIENTS

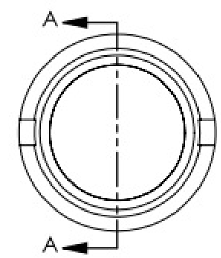
	R	k	A_2	A_4	A_6	A_8	A_{10}
S1	3.48	-0.126	-	-1.261E-03	-1.090E-04	3.226E-07	-7.834E-07
S2	-	-	-	-	-	-	-

$$z = \frac{Y^2}{R(1+\sqrt{1-(1+k)Y^2/R^2})} + A_2Y^2 + A_4Y^4 + A_6Y^6 + A_8Y^8 + A_{10}Y^{10}$$

ASPHERIC LENS EQUATION



SECTION A-A
SCALE 4 : 1



ISOMETRIC VIEW

SPECIFICATIONS:

DESIGN WAVELENGTH: 780nm
EFFECTIVE FOCAL LENGTH: 4.51mm
EFL TOLERANCE: ±1%
NUMERICAL APERTURE: 0.54
WORKING DISTANCE: 2.53mm
DIAMETER TOLERANCE: ±0.015mm
CENTER THICKNESS TOLERANCE: ±0.015mm
SURFACE QUALITY: 40-20 SCRATCH-DIG (INCLUDES ENTIRE BULK MATERIAL)
RMS WFE: 0.050 WAVES
MAGNIFICATION: INFINITE
REFRACTIVE INDEX (AT DESIGN WAVELENGTH): 1.776
COATING(S1&S2): BBAR Ravg<0.5% FROM 650-1050nm

ALL DIMENSIONS ARE IN mm [in]
THIS DRAWING IS FOR INFORMATION ONLY
NOT INTENDED FOR MANUFACTURING

	NAME	DATE
DRAWN	SFG	11/23/2009
ENG APPR.	DJ	12/05/2009
MFG APPR.	DD	12/17/2009

PROPRIETARY AND CONFIDENTIAL

THORLABS INC. PO BOX 366 NEWTON NJ

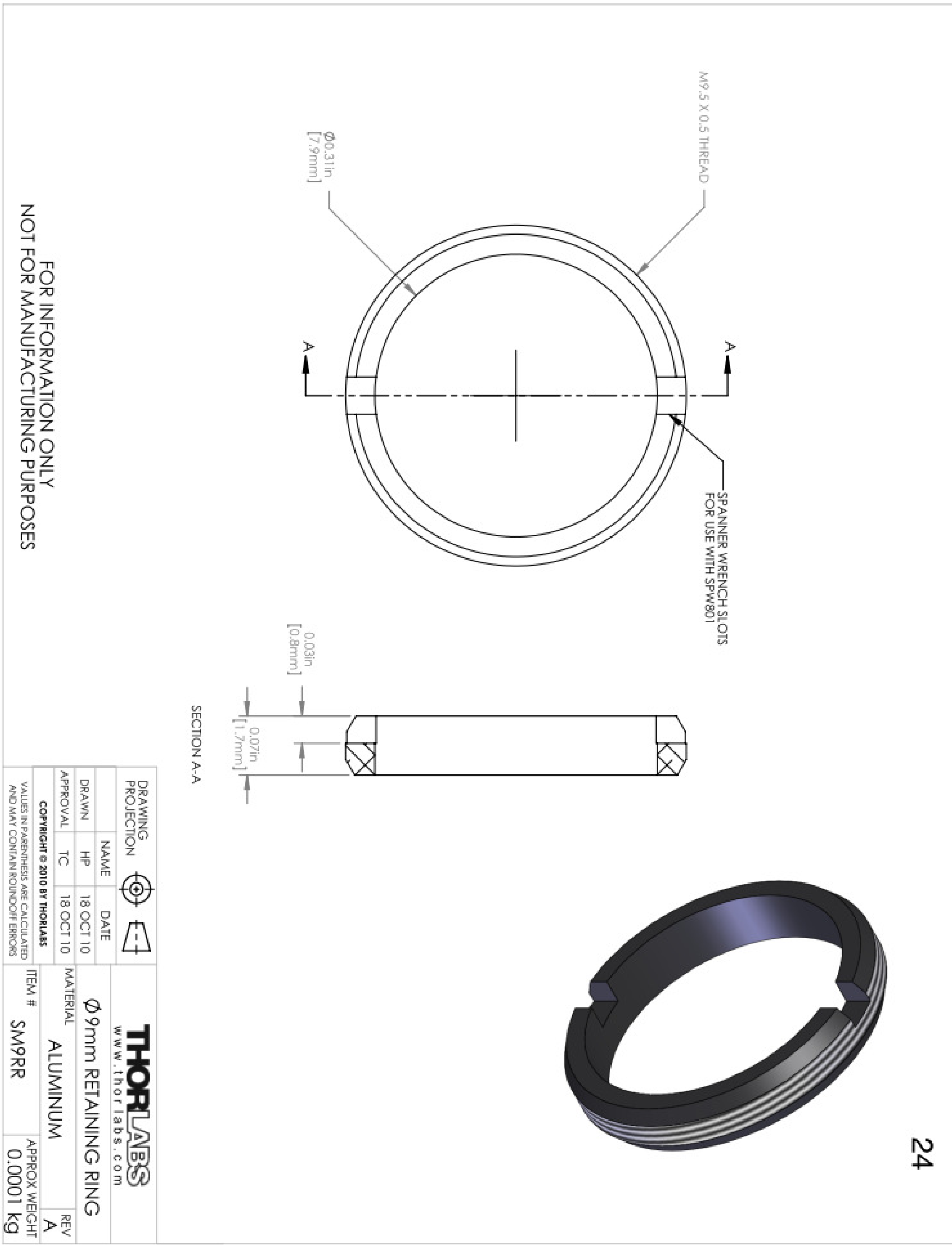
TITLE: MOUNTED -B COATED ASPHERIC COLLIMATING LENS EFL=4.51mm

MATERIAL: S-NPH1 | SIZE A | REV. D

SCALE: 4:1 | SHEET 1 OF 1

DWG. NO. 15980-E01 | PART NO. A230TM-B

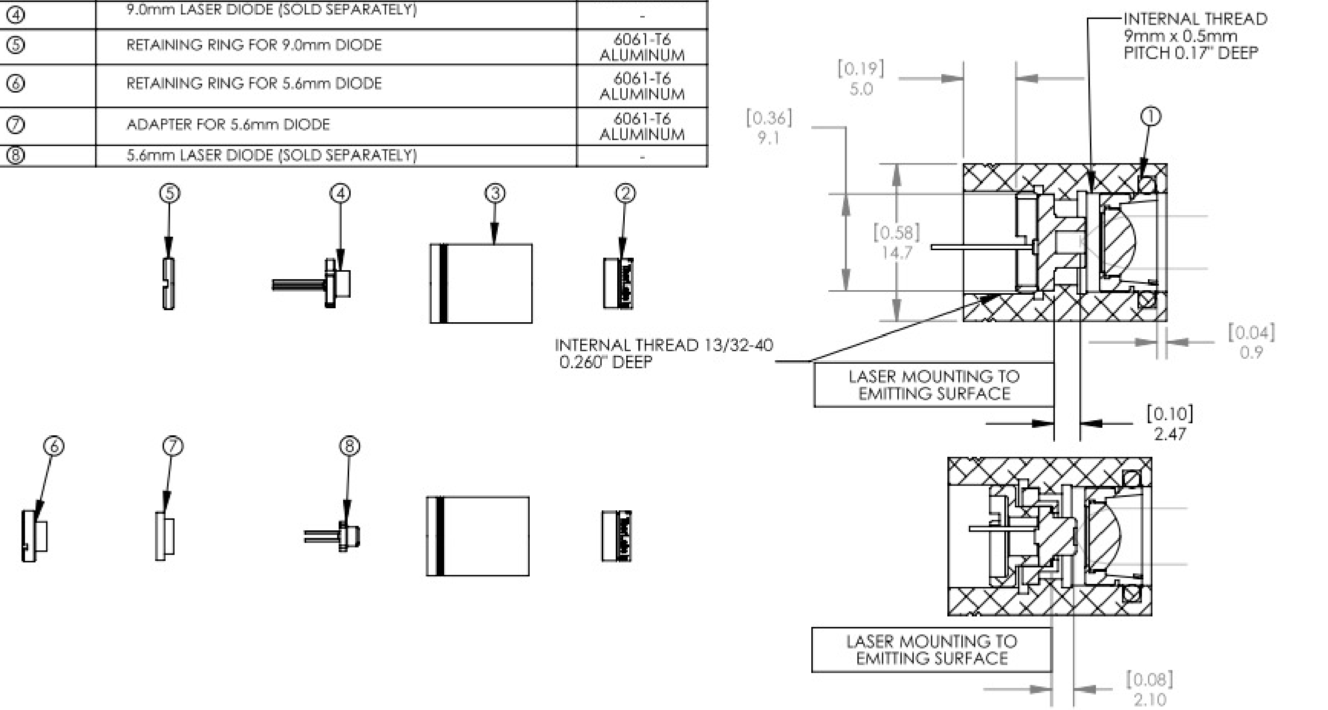
5 4 3 2 1



M9.5 X 0.5 THREAD
Ø0.31in
[7.9mm]
A
A
SPANNER WRENCH SLOTS
FOR USE WITH SPW801
0.03in
[0.8mm]
0.07in
[1.7mm]
SECTION A-A
24
FOR INFORMATION ONLY
NOT FOR MANUFACTURING PURPOSES
DRAWING PROJECTION
NAME
DATE
DRAWN
HP
18 OCT 10
APPROVAL
TC
18 OCT 10
COPYRIGHT © 2010 BY THORLABS
VALUES IN PARENTHESIS ARE CALCULATED AND MAY CONTAIN ROUNDOFF ERRORS
THORLABS
www.thorlabs.com
Ø9mm RETAINING RING
MATERIAL
ALUMINUM
REV
A
ITEM #
SM9RR
APPROX WEIGHT
0.0001 kg

25

NUMBER	PART	MATERIAL
①	O-RING (PROVIDES FRICTION FIT)	RUBBER
②	f=4.51mm NA=0.54 AR 650-1050nm MOUNTED ASPHERIC LENS	-
③	COLLIMATION TUBE	6061-T6 ALUMINUM
④	9.0mm LASER DIODE (SOLD SEPARATELY)	-
⑤	RETAINING RING FOR 9.0mm DIODE	6061-T6 ALUMINUM
⑥	RETAINING RING FOR 5.6mm DIODE	6061-T6 ALUMINUM
⑦	ADAPTER FOR 5.6mm DIODE	6061-T6 ALUMINUM
⑧	5.6mm LASER DIODE (SOLD SEPARATELY)	-



1. LENS CELL HAS ±1.0mm ADJUSTMENT RANGE FROM POSITION SHOWN, WHICH WAS DESIGNED FOR TOSHIBA STANDARD 9mm LASER PACKAGE
2. LT110A DESIGN REQUIRES THE EMITTING SURFACE OF THE LASER TO BE BETWEEN 1.7-3.2mm FROM THE Ø9mm MOUNTING FLANGE OF THE LASER
3. USE THORLABS SPANNER WRENCH SPW301 FOR RETAINING RINGS, AS WELL AS LENS
4. PRINCIPLE PLANE OF LENS IS NOMINALLY 8.7mm FROM LASER MOUNTING SURFACE

ALL DIMENSIONS ARE IN [in] mm

THIS DRAWING IS FOR INFORMATION ONLY
NOT INTENDED FOR MANUFACTURING

	NAME	DATE
DRAWN	MG	03/09/2010
ENG APPR.	DJ	03/22/2010
MFG APPR.	DD	04/14/2010

PROPRIETARY AND CONFIDENTIAL

THORLABS INC. PO BOX 366 NEWTON NJ

TITLE: LT230P-B COLLIMATION TUBE

MATERIAL: SEE TABLE

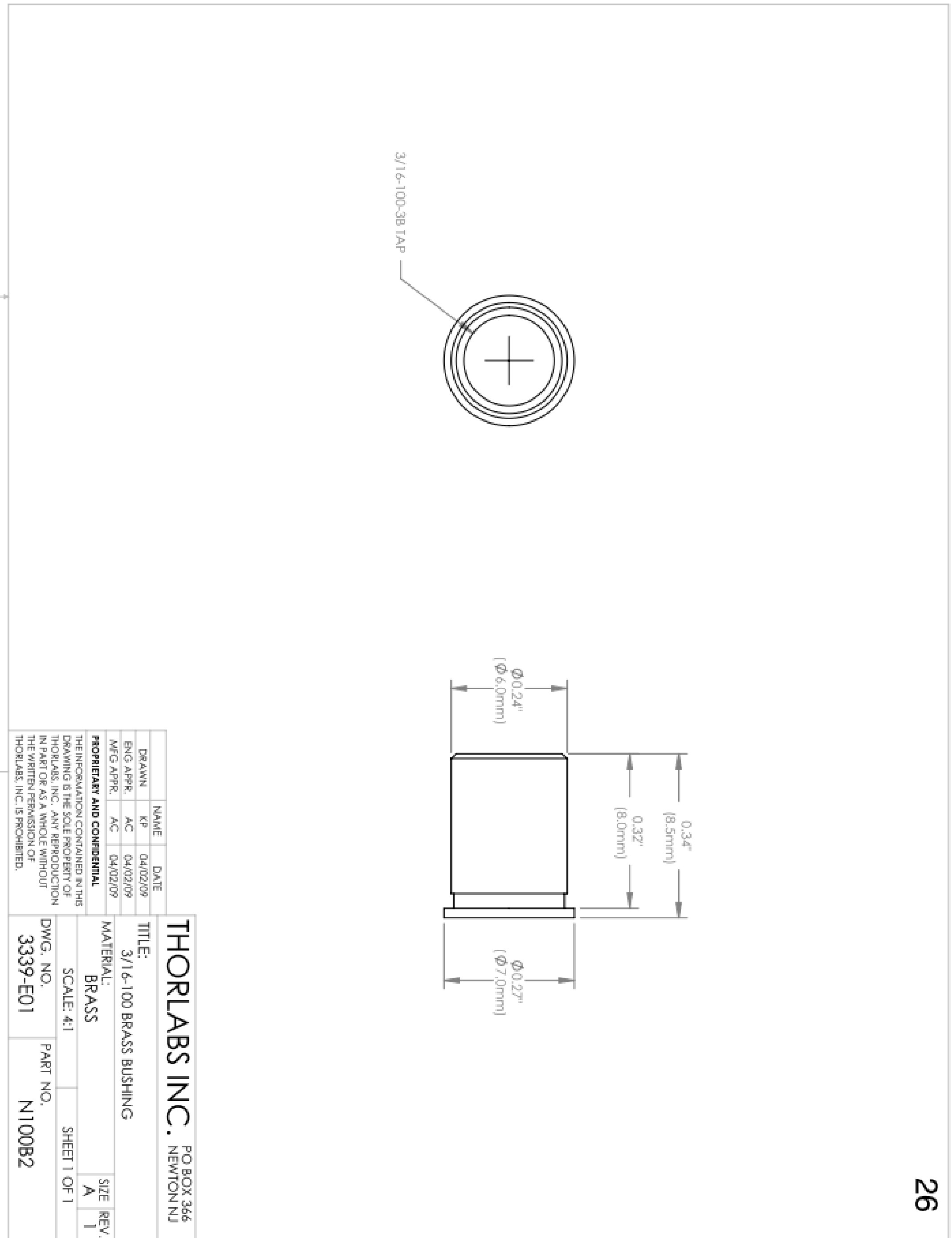
SIZE A REV. C

SCALE: 2:1 SHEET 1 OF 1

DWG. NO. 0897-E01

PART NO. LT230P-B

5 4 3 2 1


3/16-100-38 TAP
Ø0.24"
(Ø6.0mm)
0.34"
(8.5mm)
0.32"
(8.0mm)
Ø0.27"
(Ø7.0mm)
26
NAME DATE
DRAWN KP 04/02/09
ENG APPR. AC 04/02/09
MFG APPR. AC 04/02/09
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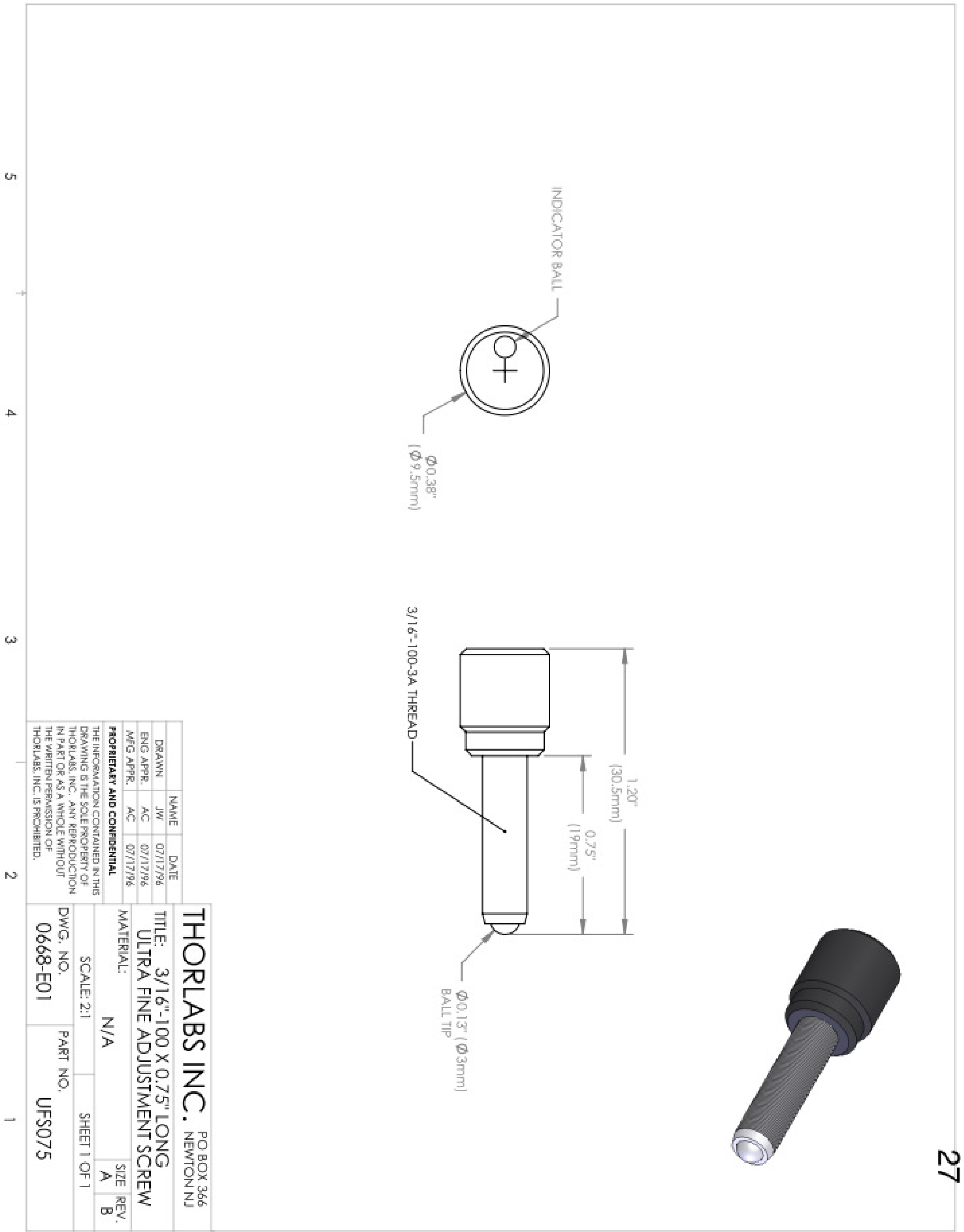
THORLABS INC. PO BOX 366 NEWTON NJ
TITLE:
3/16-100 BRASS BUSHING
MATERIAL:
BRASS
SIZE A
REV. 1
SCALE: 4:1
SHEET 1 OF 1
DWG. NO.
3339-E01
PART NO.
N100B2


27
1.20"
(30.5mm)
0.75"
(19mm)
INDICATOR BALL
Ø0.38"
(Ø9.5mm)
3/16"-100-3A THREAD
Ø0.13" (Ø3mm)
BALL TIP
NAME DATE
DRAWN JW 07/17/96
ENG APPR. AC 07/17/96
MFG APPR. AC 07/17/96
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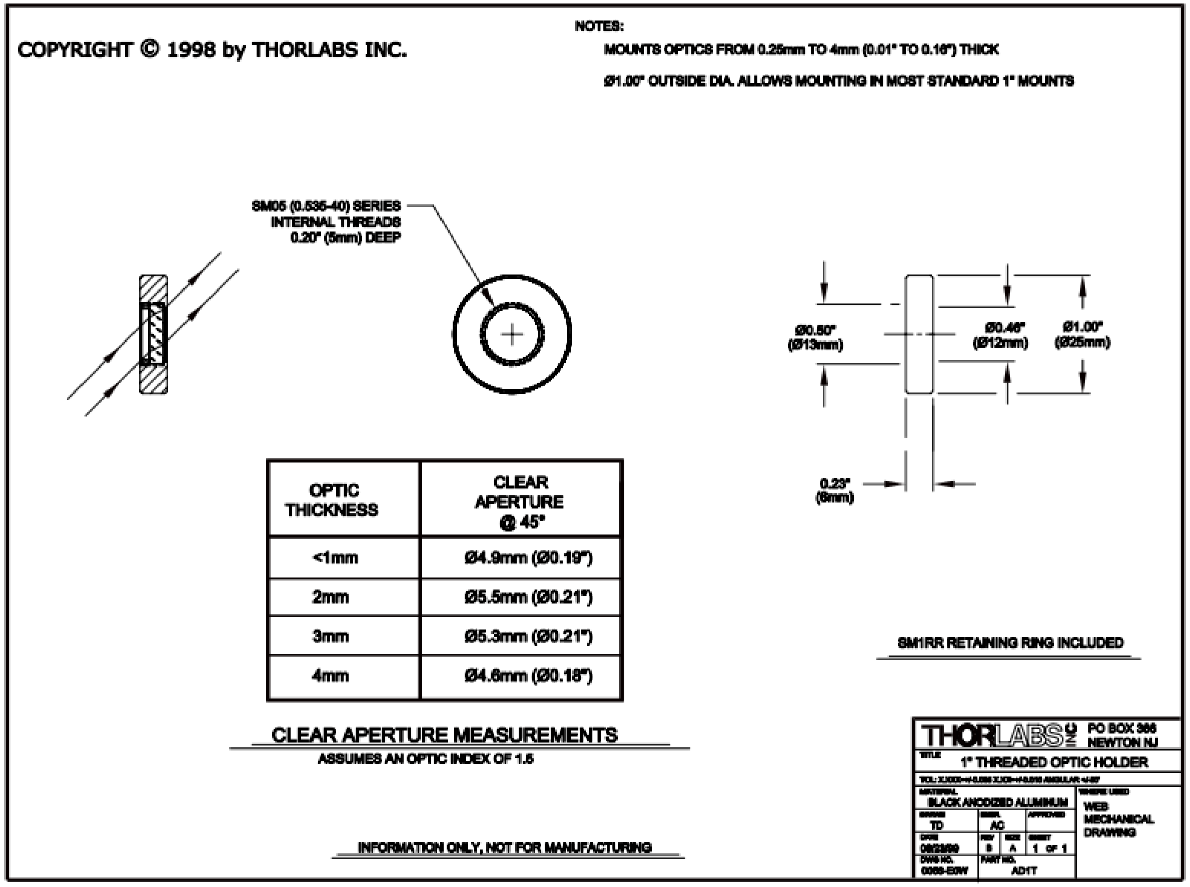
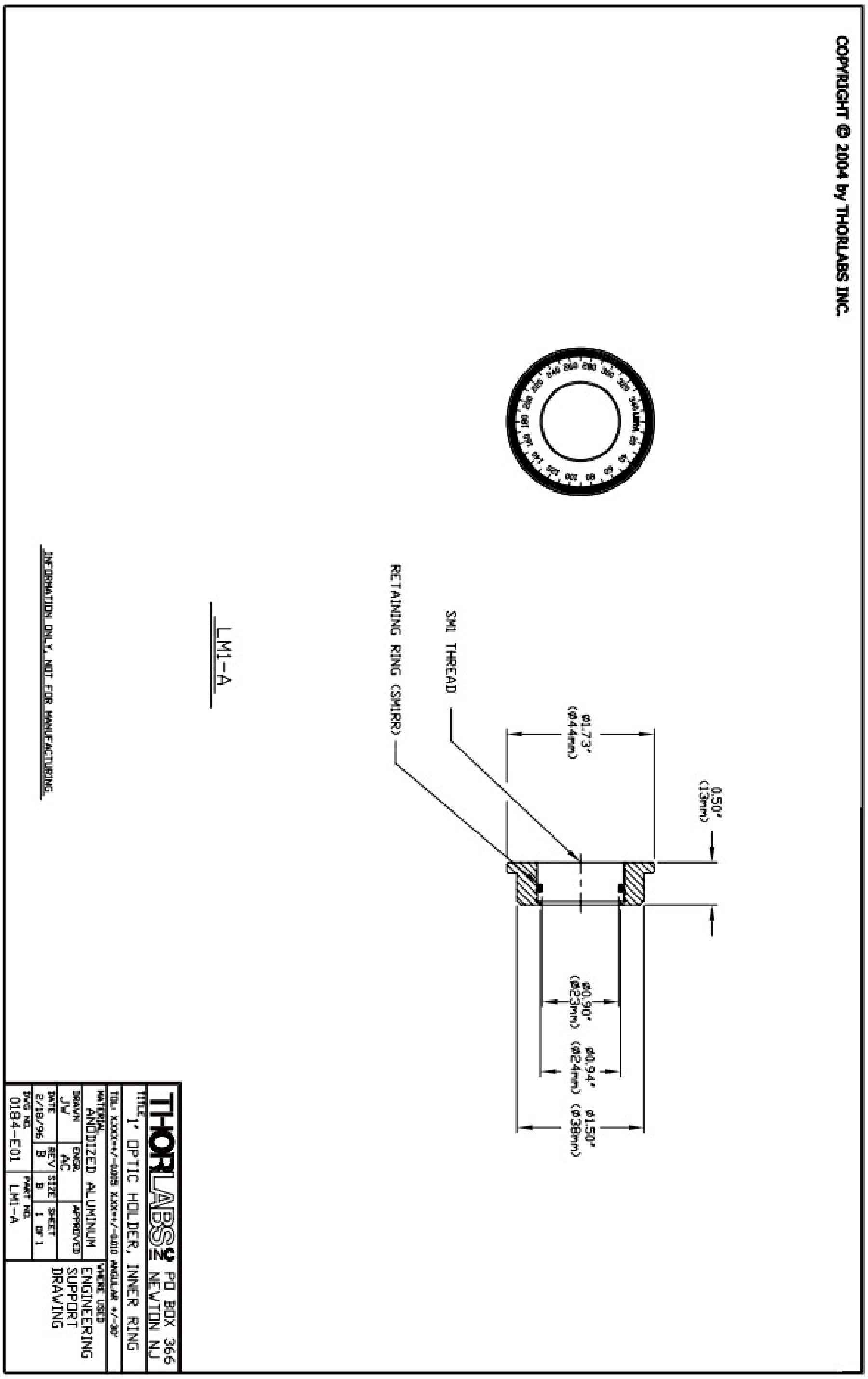
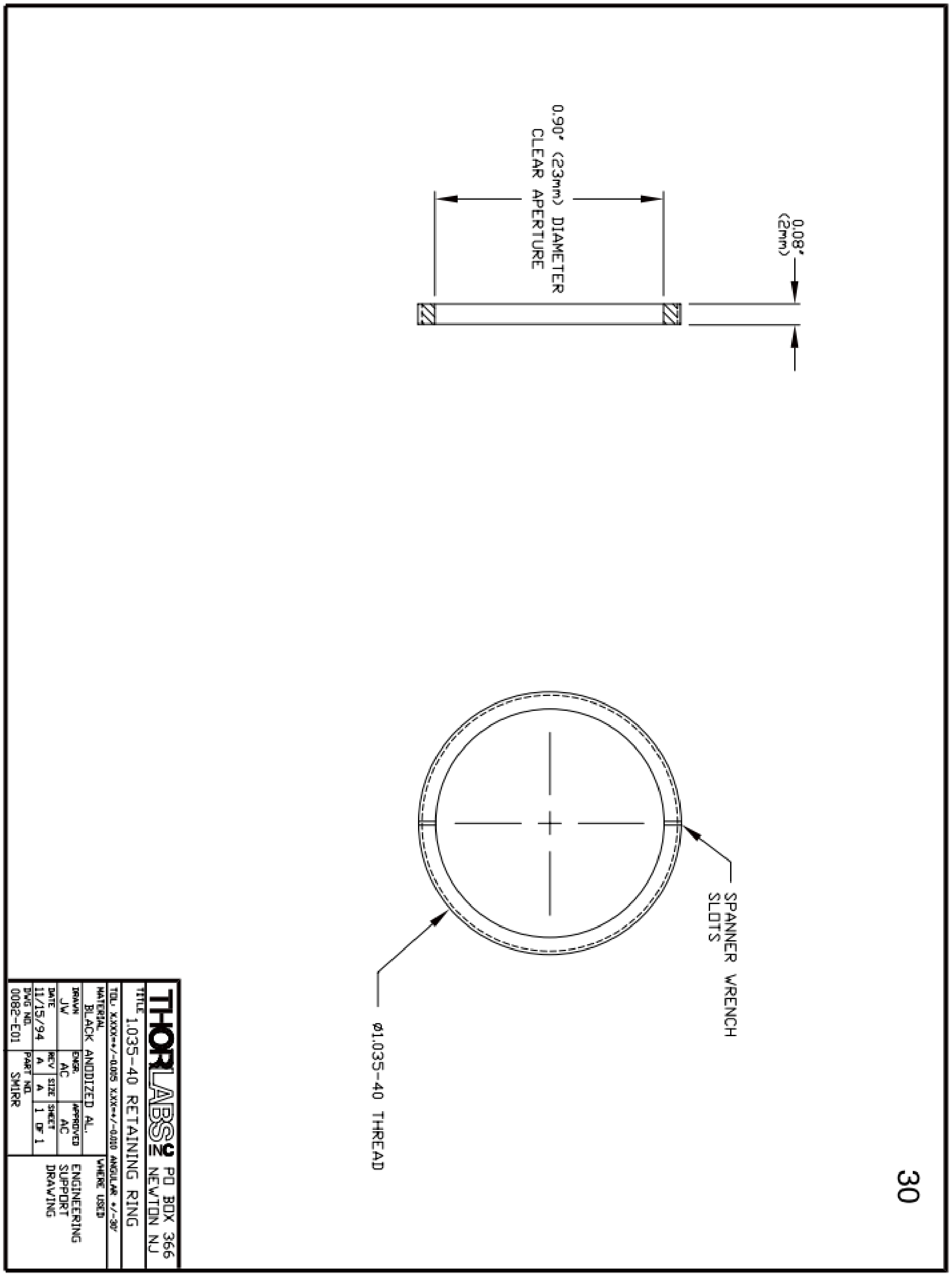
THORLABS INC. PO BOX 366 NEWTON NJ
TITLE: 3/16"-100 X 0.75" LONG ULTRA FINE ADJUSTMENT SCREW
MATERIAL: N/A
SIZE A
REV. B
SCALE: 2:1
SHEET 1 OF 1
DWG. NO. 0668-E01
PART NO. UFS075
5
4
3
2
1



OPTIC THICKNESS	CLEAR APERTURE @ 45°
<1mm	Ø4.9mm (Ø0.19")
2mm	Ø5.5mm (Ø0.21")
3mm	Ø5.3mm (Ø0.21")
4mm	Ø4.6mm (Ø0.18")

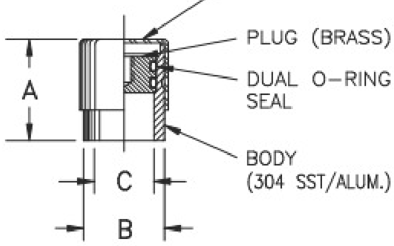

COPYRIGHT © 2004 by THORLABS INC.
SM1 THREAD
RETAINING RING (SM1RR)
Ø1.73" (Ø44mm)
0.50" (13mm)
Ø0.90" (Ø23mm)
Ø0.94" (Ø24mm)
Ø1.50" (Ø38mm)
LM1-A
INFORMATION ONLY, NOT FOR MANUFACTURING
THORLABS INC PO BOX 366 NEWTON NJ
TITLE 1" OPTIC HOLDER, INNER RING
MATERIAL ANODIZED ALUMINUM
WHERE USED ENGINEERING SUPPORT DRAWING
DRAWN JW
ENGR. AC
APPROVED
DATE 2/18/96
REV B
SIZE B
SHEET 1 OF 1
DWG NO. 0184-E01
PART NO. LM1-A


0.90" (23mm) DIAMETER
CLEAR APERTURE
0.08"
(2mm)
SPANNER WRENCH
SLOTS
Ø1.035-40 THREAD
30
THORLABS INC PO BOX 366
NEWTON NJ
TITLE 1.035-40 RETAINING RING
TOL. X.XXX=+/-0.005 X.XX=+/-0.010 ANGULAR +/-30'
MATERIAL
BLACK ANODIZED AL.
WHERE USED
DRAWN JW
ENGR. AC
APPROVED AC
DATE 11/15/94
REV A
SIZE A
SHEET 1 OF 1
DWG NO. 0082-E01
PART NO. SM1RR
ENGINEERING
SUPPORT
DRAWING

V1000 VACUUM SEAL-OFF VALVE AND OPERATOR SERIES

V1000 Series Seal-off Valve

The V1000 vacuum seal-off valve is an evacuation valve which provides an extra dimension to the vacuum system designer because it is compact, vacuum tight, has excellent capacitance and offers the additional feature of positive pressure relief. The basic weld on installation and simple operation will compliment any production evacuation design by reducing installation and evacuation time, improving vacuum reliability and reducing product cost.



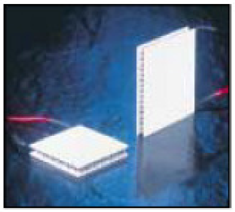
OPERATING SPECIFICATIONS

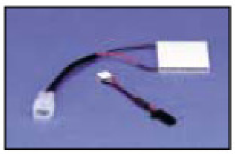
- SERVICE: High Vacuum.
- PRESSURE: 1 X 10-8 TORR Vacuum up to 15 PSIG Positive.
- TEMPERATURE: +150°F TO -60°F.
- LEAK RATE: 1 X 10^{8} STD. CC GHe/SEC. (Seal Permeability).
- CONNECTION: Weld junction is standard. Thread and flange junctions available on special request.

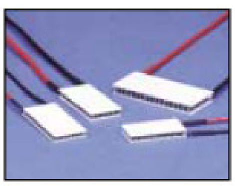
PART NUMBERS					
SIZE	STAINLESS STEEL	ALUMINUM	A	B	C
1/4"	V1025-1	V1021-1	.59	.38	.19
1/2"	V1045-1	V1041-1	.81	.62	.46
1"	V1085-1	V1081-1	1.5	1.19	0.9
2"	V1165-1	V1161-1	2.25	2.5	2.0
3"	V1245-1	V1241-1	3.0	3.38	2.9

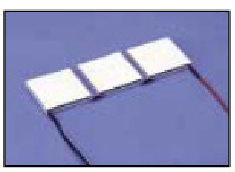
For valves with integral TC port, see data sheet for V1045-5 and V1085-5

CP Series TECs









CP Series Specifications

Catalog Number	Imax (Amps)	Th = 25˚C			N	Dimensions (mm)			
		Qmax[1] (Watts)	Vmax (Volts)	ΔTmax (˚C)		A	B	C	D[2]
CP0.8-7-06L	2.1	1.0	0.85	67	7	6	6	6	3.4
CP0.8-17-06L	2.1	2.4	2.06	67	17	9	9	9	3.4
CP0.8-31-06L	2.1	4.4	3.75	67	31	12	12	12	3.4
CP0.8-63-06L	2.1	9.0	7.62	67	63	12	25	12	3.4
CP0.8-71-06L	2.1	10.1	8.60	67	71	18	18	18	3.4
CP0.8-127-06L	2.1	18.1	15.40	67	127	25	25	25	3.4
‡ CP0.8-254-06L	2.1/4.2	36.2	30.8/15.4	67	254	50	25	50	3.4
CP0.8-127-05L	2.6	22.4	15.40	67	127	25	25	25	3.1
‡ CP0.8-254-05L	2.6/5.2	44.8	30.8/15.4	67	254	50	25	50	3.1
CP1.0-7-08L	2.5	1.2	0.85	67	7	8	8	8	4.0
CP1.0-17-08L	2.5	2.9	2.06	67	17	12	12	12	4.0
CP1.0-31-08L	2.5	5.3	3.75	67	31	15	15	15	4.0
CP1.0-63-08L	2.5	10.6	7.62	67	63	15	30	15	4.0
CP1.0-71-08L	2.5	12.0	8.60	67	71	23	23	23	4.0
CP1.0-127-08L	2.5	21.4	15.40	67	127	30	30	30	4.0
‡ CP1.0-254-08L	2.5/5.0	42.8	30.8/15.4	67	254	60	30	60	4.0
CP1.0-7-06L	3.0	1.4	0.85	67	7	8	8	8	3.6
CP1.0-17-06L	3.0	3.4	2.06	67	17	12	12	12	3.6
CP1.0-31-06L	3.0	6.3	3.75	67	31	15	15	15	3.6
CP1.0-63-06L	3.0	12.7	7.62	67	63	15	30	15	3.6
CP1.0-71-06L	3.0	14.4	8.60	67	71	23	23	23	3.6
CP1.0-127-06L	3.0	25.7	15.40	67	127	30	30	30	3.6
‡ CP1.0-254-06L	3.0/6.0	51.4	30.8/15.4	67	254	60	30	60	3.6
CP1.0-7-05L	3.9	1.8	0.85	67	7	8	8	8	3.2
CP1.0-17-05L	3.9	4.5	2.06	67	17	12	12	12	3.2
CP1.0-31-05L	3.9	8.2	3.75	67	31	15	15	15	3.2
CP1.0-63-05L	3.9	16.6	7.62	67	63	15	30	15	3.2
CP1.0-71-05L	3.9	18.7	8.60	67	71	23	23	23	3.2
CP1.0-127-05L	3.9	33.4	15.40	67	127	30	30	30	3.2
‡ CP1.0-254-05L	3.9/7.8	66.8	30.8/15.4	67	254	60	30	60	3.2
CP1.4-11-10L	3.9	2.9	1.33	68	11	10	15	10	4.7
CP1.4-17-10L	3.9	4.5	2.06	68	17	15	15	15	4.7
CP1.4-31-10L	3.9	8.2	3.75	68	31	20	20	20	4.7
CP1.4-35-10L	3.9	9.2	4.24	68	35	15	30	15	4.7
CP1.4-51-10L	3.9	13.4	6.18	68	51	9.5	62	9.5	4.7
CP1.4-71-10L	3.9	18.7	8.60	68	71	30	30	30	4.7
CP1.4-127-10L	3.9	33.4	15.40	68	127	40	40	40	4.7
CP1.4-11-06L	6.0	4.4	1.33	67	11	10	15	10	3.8
CP1.4-17-06L	6.0	6.9	2.06	67	17	15	15	15	3.8
CP1.4-31-06L	6.0	12.5	3.75	67	31	20	20	20	3.8
CP1.4-35-06L	6.0	14.2	4.24	67	35	15	30	15	3.8
CP1.4-51-06L	6.0	20.6	6.18	67	51	9.5	62	9.5	3.8
CP1.4-71-06L	6.0	28.7	8.60	67	71	30	30	30	3.8
CP1.4-127-06L	6.0	51.4	15.40	67	127	40	40	40	3.8

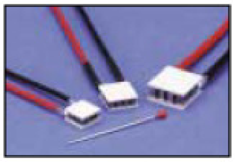
More specifications on following page.

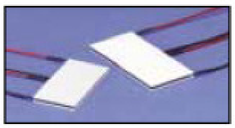
CP Series

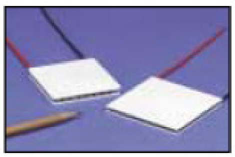
- For higher current, larger heat pumping applications
- Low-Cost, High-Performance
- The standard for consumer product and industrial cooling
- Ideal for instrumentation, laboratory apparatus, consumer appliances
- Excellent for applications from commercial to military

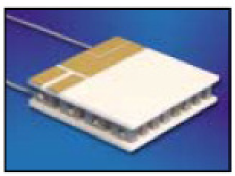
MELCOR

CP Series TECs









CP Series Specifications

Catalog Number	Imax (Amps)	Th = 25˚C			N	Dimensions (mm)			
		Qmax[1] (Watts)	Vmax (Volts)	ΔTmax (˚C)		A	B	C	D[2]
CP1.4-11-045L	8.5	6.0	1.33	65	11	10	15	10	3.3
CP1.4-17-045L	8.5	9.2	2.06	65	17	15	15	15	3.3
CP1.4-31-045L	8.5	16.8	3.75	65	31	20	20	20	3.3
CP1.4-35-045L	8.5	19.0	4.24	65	35	15	30	15	3.3
CP1.4-51-045L	8.5	28.9	6.18	65	51	9.5	62	9.5	3.3
CP1.4-71-045L	8.5	38.5	8.60	65	71	30	30	30	3.3
CP1.4-127-045L	8.5	72.0	15.40	65	127	40	40	40	3.3
CP2-17-10L	9.0	10.3	2.06	68	17	22	22	22	5.6
CP2-31-10L	9.0	18.8	3.75	68	31	30	30	30	5.6
CP2-49-10L	9.0	29.7	5.93	68	49	36	36	36	5.6
CP2-71-10L	9.0	43.1	8.60	68	71	44	44	44	5.6
CP2-127-10L	9.0	77.1	15.40	68	127	62	62	62	5.6
CP2-17-06L	14.0	16.0	2.06	67	17	22	22	22	4.6
CP2-31-06L	14.0	29.3	3.75	67	31	30	30	30	4.6
CP2-49-06L	14.0	46.2	5.93	67	49	36	36	36	4.6
CP2-71-06L	14.0	67.0	8.60	67	71	44	44	44	4.6
CP2-127-06L	14.0	120.0	15.40	67	127	62	62	62	4.6
CP2.8-31-06L	24.0	50.2	3.75	67	31	40	40	40	5.0
CP5-31-10L	39.0	81.5	3.75	68	31	55	55	55	5.8
CP5-31-06L	60.0	125.0	3.75	67	31	55	55	55	4.9

Interfacing and Options:

Both hot and cold faces non-metallized flat, Type L. Both faces metallized and tinned, Type TT. Hybrid, hot face tinned, cold faced non-metallized, Type TL. Hot face non-metallized, cold face tinned, Type LT. Two face soldering (Type TT) in sizes larger than 12 x 12 mm is not recommended. Consult MELCOR for details. See chart on page 24.

Example: CP1.0-127-05TL
Hot face tinned with 118˚C solder
Cold face non-metallized

Notes:

1) Qmax rated value at ΔT = 0°, Imax and Vmax, Th = 25°C.
2) Thickness for Type L only.

Definitions:

Imax	Input current resulting in greatest ΔT (ΔTmax)[amps]
N	Number of thermocouples (p- and n-type pairs)
Qmax	Maximum amount of heat that can be absorbed at cold face (occurs at I = Imax, ΔT = 0°)[watts]
Th	Temperature of the TEC hot face during operation [°C]
ΔTmax	Maximum temperature difference a TEC can achieve (occurs at I = Imax, Q_C = 0)[°C]
Vmax	Voltage at ΔTmax

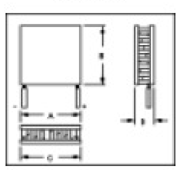
Wire Standards:

Module Type	Wire Gauge (AWG)
CP0.8-ALL	26
CP1.0-ALL	24
CP1.4-ALL	18
CP2-ALL	18
CP2.8-ALL	16
CP5-_ _-10	14 (Teflon™)
CP5-_ _-06	12 (Teflon™)
‡ CP_ _-254-_ _	Contact Melcor

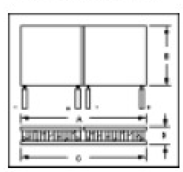
For all CP Series modules, wire is stranded, 114 mm (4.5 in.) long and PVC insulated, except CP5.

‡ These modules have four leads and can be wired in series or parallel. The Specifications table indicates maximum values for V and I when "Wired in Series/Wired in Parallel".

CP Series



‡CP_ _-254-_ _



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GE SENSING / THERMOMETRICS Products

Products may be RoHS compliant.
Check mouser.com for RoHS status.

GE
Sensing & Inspection Technologies
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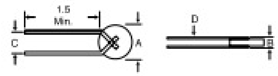
NTC THERMISTORS

NTC (Negative Temperature Coefficient) thermistors decrease in resistance as temperature increases. The maximum operating temperature is 150°C. Zero-power resistance values at 25°C range from 10Ω to 250KΩ; other values available upon request.

※Resistance tolerance is ±10%, except where denoted by an asterisk which is ±20%



DIMENSIONS: in.

For quantities of 100 and up, call for quote.

MOUSER STOCK NO.	GE Part Number	Ohms (Ω)	A (In.)	B (In.)	C (In.)	D (AWG)	Price Each 1	Price Each 10
* 527-1004-100	RL1004-65.6-59-D1	100	.110	.120	.100	26	1.38	1.31
527-1003-500	RL1003-312-73-D1	500	.110	.110	.100	26	1.35	1.29
527-1007-1K	RL1007-624-73-D1	1K	.110	.150	.100	26	1.35	1.29
527-1003-2K	RL1003-1157-95-D1	2K	.110	.110	.100	26	1.35	1.29
527-1003-3K	RL1003-1746-97-D1	3K	.110	.110	.100	26	1.35	1.29
527-1004-5K	RL1004-2910-97-D1	5K	.110	.120	.100	26	1.35	1.29
527-1009-10K	RL1009-5820-97-D1	10K	.110	.170	.100	26	1.35	1.29
527-1005-10K	RL1005-5744-103-D1	10K	.110	.130	.100	26	1.35	1.29
527-1007-25K	RL1007-13.8K-120-D1	25K	.110	.150	.100	26	1.02	.96
527-1003-50K	RL1003-26.7K-140-D1	50K	.110	.110	.100	26	1.46	1.39
527-1006-100K	RL1006-53.4K-140-D1	100K	.110	.140	.100	26	1.46	1.39
527-1004-200K	RL1004-104.7K155-D1	200K	.110	.120	.100	26	1.46	1.39
527-1006-250K	RL1006-135.2K-138-D1	250K	.110	.140	.100	26	1.46	1.39
* 527-2004-25	RL2004-16.4-59-D1	25	.220	.130	.156	24	.98	.88
* 527-2007-50	RL2007-32.8-59-D1	50	.220	.160	.156	24	.98	.88
527-2003-100	RL2003-62.4-73-D1	100	.220	.120	.156	24	.93	.85

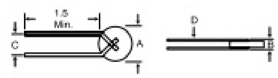
For quantities of 100 and up, call for quote.

MOUSER STOCK NO.	GE Part Number	Ohms (Ω)	A (In.)	B (In.)	C (In.)	D (AWG)	Price Each 1	Price Each 10
527-2006-200	RL2006-125-73-D1	200	.220	.150	.156	24	.93	.85
527-2003-500	RL2003-289-95-D1	500	.220	.120	.156	24	.93	.85
527-2004-1K	RL2004-582-97-D1	1K	.220	.130	.156	24	.93	.85
527-2007-2K	RL2007-1164-97-D1	2K	.220	.160	.156	24	1.03	.98
527-2006-2786	RL2006-1600-103-D1	2.786K	.220	.150	.156	24	.93	.85
527-2006-5K	RL2006-2753-120-D1	5K	.220	.150	.156	24	2.37	2.26
527-2006-25K	RL2006-13.3K-140-D1	25K	.220	.150	.156	24	1.06	.93
527-2008-100K	RL2008-52.3K-155-D1	100K	.220	.170	.156	24	1.06	.93
* 527-3004-10	RL3004-6.56-59-D1	10	.320	.130	.250	24	1.02	.97
527-3504-50	RL3504-31.2-73-D1	50	.370	.130	.250	24	.98	.88
527-3006-100	RL3006-59.4-85-D1	100	.320	.150	.250	24	.98	.88
527-3004-250	RL3004-144-95-D1	250	.320	.130	.250	24	.98	.88
527-3004-500	RL3004-291-97-D1	500	.320	.130	.250	24	.98	.88
527-3005-1K	RL3005-574-103-D1	1K	.320	.140	.250	24	.98	.88
527-3005-13.1K	RL3005-13.1K-155-D1	13.1K	.320	.050	.250	24	1.11	.97

INRUSH CURRENT LIMITERS

Limiters protect against extremely high peak inrush current, especially in AC/DC switching power supplies. These NTC thermistors effectively control surge currents because the thermal time constant of the current limiter is longer than the electrical time constant (RC) of the thermistor and the capacitor.

Also available, by special order, with kinked leads.



DIMENSIONS: in.

For quantities of 250 and up, call for quote.

MOUSER STOCK NO.	GE Part Number	Ohms (Ω)	Amps	A Max. (In.)	B Max. (In.)	C Ref. (In.)	D (AWG)	Price Each 1	Price Each 10	Price Each 100
527-CL30	CL30	2.5	8	.77	.22	.328	18	1.31	1.25	1.12
527-CL40	CL40	5	6	.77	.22	.328	18	1.37	1.31	1.25
527-CL50	CL50	7	5	.77	.26	.328	18	1.39	1.24	.86
527-CL60	CL60	10	5	.77	.22	.328	18	1.39	1.24	.86
527-CL70	CL70	16	4	.77	.22	.328	18	1.39	1.24	.86
527-CL80	CL80	47	3	.77	.22	.328	18	1.39	1.24	.86
527-CL90	CL90	120	2	.93	.22	.328	18	1.72	1.54	1.06

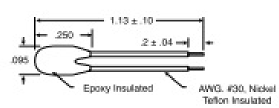
For quantities of 250 and up, call for quote.

MOUSER STOCK NO.	GE Part Number	Ohms (Ω)	Amps	A Max. (In.)	B Max. (In.)	C Ref. (In.)	D (AWG)	Price Each 1	Price Each 10	Price Each 100
527-CL110	CL110	10	3.2	.40	.17	.250	24	1.22	1.09	.75
527-CL120	CL120	10	1.7	.40	.17	.250	24	1.22	1.09	.75
527-CL130	CL130	50	1.6	.45	.17	.250	24	1.22	1.09	.75
527-CL140	CL140	50	1.1	.45	.17	.250	24	1.22	1.09	.75
527-CL150	CL150	5	4.7	.55	.18	.328	22	1.25	1.12	.77
527-CL160	CL160	5	2.8	.55	.18	.328	22	.84	.73	.63
527-CL170	CL170	16	2.7	.55	.18	.328	22	.84	.73	.63
527-CL180	CL180	16	1.7	.55	.18	.328	22	.84	.73	.63
527-CL190	CL190	25	2.4	.55	.18	.328	22	1.25	1.12	.77
527-CL200	CL200	25	1.7	.55	.18	.328	22	1.61	1.44	.99
527-CL210	CL210	30	1.5	.40	.20	.250	24	.82	.72	.62

MINIATURE SENSORS 1°C ACCURACY

Features:
- Temperature accuracy: ±1°C @ 25°C
- Dissipation constant: 1.4mW/°C
- Time constant: 15 sec.
- Operating range: -50°C to +150°C

DIMENSIONS: in.

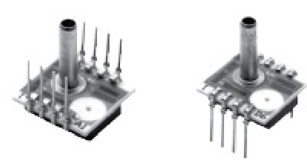


For quantities of 250 and up, call for quote.

MOUSER STOCK NO.	GE Part Number	GE Type (RL0503)	Material	R® @ 25°C	Temp. Coef. %/°C @ 25°C	Price Each 1	Price Each 10	Price Each 25	Price Each 100
527-0503-2K	RL0503-1248-73-MS	1248-73-MS	MS73	2K	-3.83	1.52	1.45	1.38	1.31
527-0503-5K	RL0503-2890-95-MS	2890-95-MS	MS95	5K	-4.43	1.52	1.45	1.38	1.31
527-0503-10K	RL0503-5820-97-MS	5820-97-MS	MS97	10K	-4.40	1.52	1.45	1.38	1.31
527-0503-30K	RL0503-17.56K-96-MS	17.56K-96-MS	MS96	30K	-4.32	1.52	1.45	1.38	1.31
527-0503-50K	RL0503-27.53K-120-MS	27.53K-120-MS	MS120	50K	-4.84	1.52	1.45	1.38	1.31
527-0503-100K	RL0503-55.36K-122-MS	55.36K-122-MS	MS122	100K	-4.78	1.52	1.45	1.38	1.31

GLASS ENCAPSULATED DO-35

Features:
- For reel taping "R" suffix
- Nickel leads for welding
- Other resistancesin the range 250Ω to 5Ω
- Other tolerances, tolerances at other temperatures
- Alternative lead lengths, lead materials
- Can be expanded to 572°F (300°C) with nickel leads
- Standard resistance tolerance: ±10% @ 77°F (25°C)
- Time constant: 7 seconds
- Operating range: '-58°F to 400°F ('-50°C to 204°C)



For quantities of 250 and up, call for quote.

MOUSER STOCK NO.	GE Part Number	Material System	Beta 25/85	Ohms (Ω) @ 25°C	Dissipation Constant	Price Each 1	Price Each 10	Price Each 25	Price Each 100
527-AL3006-1M	AL03006-535K-145-G1	GE14.5	4661	1M	3.0mW/K	1.54	1.46	1.39	1.32
527-AL3006-100K	AL03006-58.2K-97-G1	GE9.7B	3952	100K	3.0mW/K	1.54	1.46	1.39	1.32
527-AL03006-5818	AL03006-5818-97-G1	GE9.7A	3992	10K	3.0mW/K	1.54	1.46	1.39	1.32

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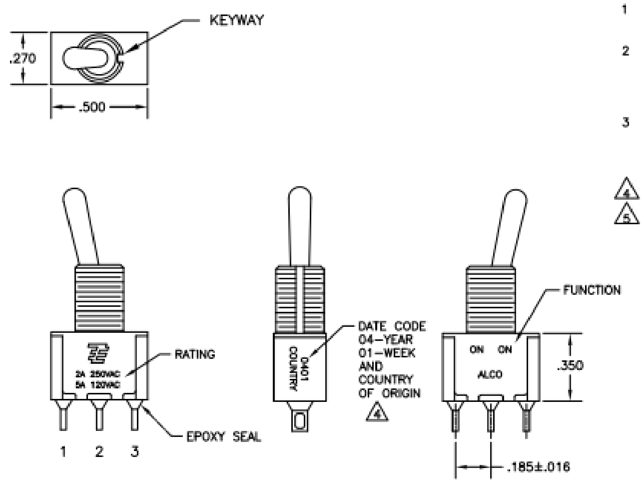

NOTES:

1 ALL MATERIALS AND FINISHES SHALL COMPLY WITH EU DIRECTIVE 2002/95/EC OF 27JAN2003 (ROHS).

2 EACH SWITCH WITH THREDED BUSHINGS SUPPLIED WITH THE FOLLWING MOUNTING HARDWARE:
(2) HEX NUTS
(1) INTERNAL TOOTH LOCKWASHER
(1) LOCATING RING.

3 G CONTACT OPTION CAN BE USED FOR SIGNAL OR POWER LEVEL SWITCHING. IF SWITCH IS USED AT LEVELS EXCEEDING .4VA @ 20V AC/DC, SWITCH IS RENDERED FOR POWER SWITCHING ONLY DUE TO ARC REMOVAL OF GOLD PLATING. RATING STAMPED ON FRAME IS 2A 250VAC, 5A 120VAC.

4 DATE CODE AND COUNTRY OF ORIGIN MAY APPEAR ON EITHER SIDE OF SWITCH.

5 LENGTH OF TOGGLE REDUCED BY .020 WITH A, AV2, V30 OR V40 VERTICAL SUPPORT BRACKET OPTIONS.

FUNCTION CHART

FUNCTION	1 2 3	1 2 3	1 2 3
01	ON	NONE	ON
08	ON	NONE	(ON)
TERMINALS CONNECTED	2-3	---	1-2

None: No mechanical position
Off: Mechanical position with no electrical connection
(On): Momentary action

SPECIFICATIONS CHART

RATING, B CONTACTS	.4VA MAX @20V MAX. AC OR DC
RATING, G CONTACTS-SEE NOTE 3	.4VA MAX @20V MAX. AC OR DC OR 5A @120 VAC OR 28 VDC (RESISTIVE)
	2A @250 VAC (RESISTIVE)
RATING, Q CONTACTS	5A @120 VAC OR 28 VDC (RESISTIVE)
	2A @250 VAC (RESISTIVE)
ELECTRICAL LIFE	6,000 CYCLES AT RATED LOAD
CONTACT RESISTANCE	10 MILLIOHMS MAX INITIAL @ 2-4VDC, 100ma
INSULATION RESISTANCE	1,000 MEGOHMS MIN
DIELECTRIC WITHSTANDING VOLTAGE	1,000 V RMS AT SEA LEVEL
OPERATING TEMPRATURE	-30C TO 85C

PART NUMBER SEQUENCE CHART

MODEL	FUNCTION	TOGGLE	BUSHING	TERMINAL	CONTACT	RoHS
A1	01	K	CW	A	B	04
	08	K1	D	AV2	G	
		L	D9	C	Q	
		L1	H	V30		
		L2	Y	V40		
		M	Y9	W		
		P3		W4		
		S		Z		
		T		Z3		
		T1				

EXAMPLE: A101SYCQ04

REVISIONS

LTR	DESCRIPTION	DATE	DWN	APVD
A4	REVISED PER ECO-11-004567	11MAR11	RK	HMR

LOC AD DIST 00

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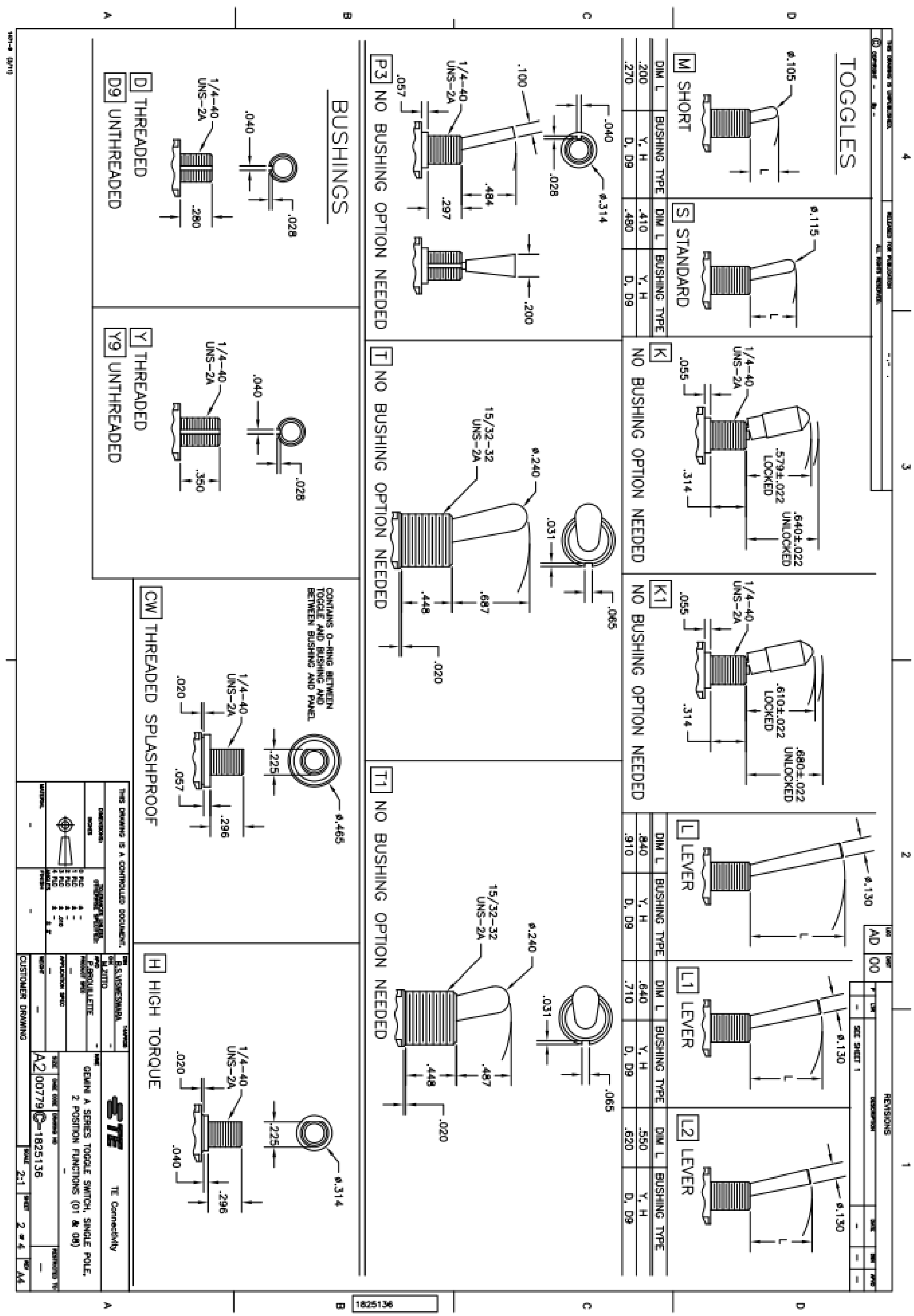
DWN B.S.VISWESWARA
CHK M.ZITTO
APVD P.BROUILLETTE
TE Connectivity
NAME GEMINI A SERIES TOGGLE SWITCH, SINGLE POLE, 2 POSITION FUNCTIONS (01 & 08)
SIZE A2 CAGE CODE 00779 DRAWING NO C-1825136
CUSTOMER DRAWING SCALE 3:1 SHEET 1 of 4 REV A4

1825136

1471-9 (3/11)


TOGGLES
M SHORT
S STANDARD
K NO BUSHING OPTION NEEDED
K1 NO BUSHING OPTION NEEDED
L LEVER
L1 LEVER
L2 LEVER
P3 NO BUSHING OPTION NEEDED
T NO BUSHING OPTION NEEDED
T1 NO BUSHING OPTION NEEDED
BUSHINGS
D THREADED
D9 UNTHREADED
Y THREADED
Y9 UNTHREADED
CW THREADED SPLASHPROOF
H HIGH TORQUE
CONTAINS O-RING BETWEEN TOGGLE AND BUSHING AND BETWEEN BUSHING AND PANEL
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TE Connectivity
GEMINI A SERIES TOGGLE SWITCH, SINGLE POLE, 2 POSITION FUNCTIONS (01 & 08)
CUSTOMER DRAWING
A2 00779 C-1825136
2:1
2 of 4
A4
1825136
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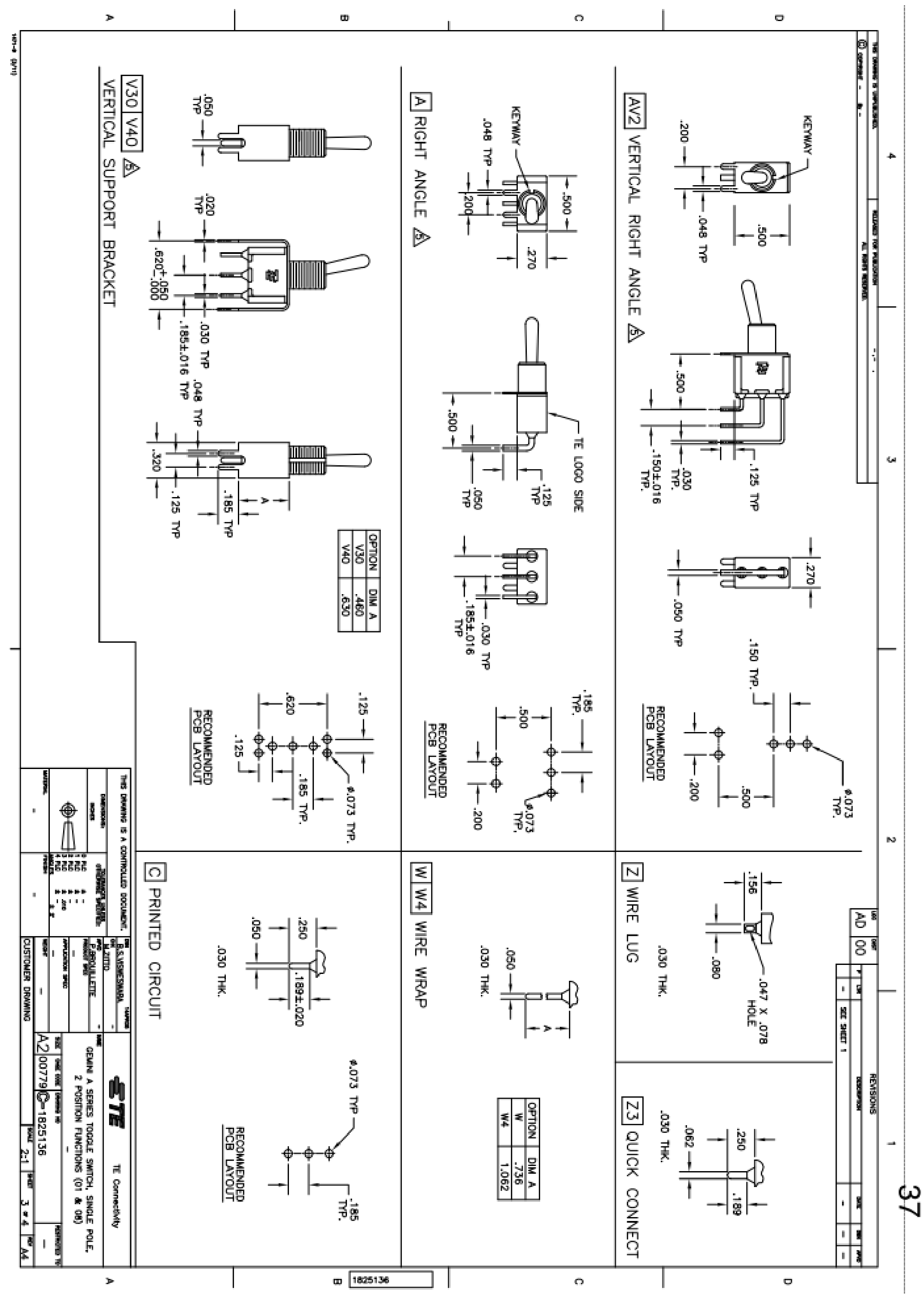

AV2 VERTICAL RIGHT ANGLE
KEYWAY
TE LOGO SIDE
A RIGHT ANGLE
V30 V40 VERTICAL SUPPORT BRACKET
RECOMMENDED PCB LAYOUT
OPTION DIM A
V30 .460
V40 .630
Z WIRE LUG
.047 X .078 HOLE
Z3 QUICK CONNECT
W W4 WIRE WRAP
OPTION DIM A
W .736
W4 1.062
C PRINTED CIRCUIT
REVISIONS
SEE SHEET 1
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GEMINI A SERIES TOGGLE SWITCH, SINGLE POLE, 2 POSITION FUNCTIONS (01 & 08)
CUSTOMER DRAWING
A2 00779 C-1825136
1825136
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38

Alco P/N	P/N
A101K1V30B04	1825136-1
A101KAB04	1825136-2
A101KAQ04	1825136-3
A101P3YV30B04	1825136-4
A101KCQ04	1825136-5
A101KD9AQ04	1825136-6
A101KZQ04	1825136-7
A101SYAV2B04	1825136-8
A101L1D9V30Q04	1825136-9
A101L1YZB04	1-1825136-0
A101LDZQ04	1-1825136-1
A101MD9AB04	1-1825136-2
A101MD9AG04	1-1825136-3
A101MD9AQ04	1-1825136-4
A101MD9AV2B04	1-1825136-5
A101MD9AV2G04	1-1825136-6
A101MD9AV2Q04	1-1825136-7
A101MD9V30B04	1-1825136-8
A101MDAQ04	1-1825136-9
A101MDAV2B04	2-1825136-0
A101MDCG04	2-1825136-1
A101MDZQ04	2-1825136-2
A101MYCQ04	2-1825136-3
A101MYZQ04	2-1825136-4
A103SYAV2B04	2-1825136-5
A101P3CB04	2-1825136-6
A101P3ZQ04	2-1825136-7
A101KAV2Q04	2-1825136-8
not assigned	2-1825136-9
A101SCWCQ004	3-1825136-0
A101SCWZQ04	3-1825136-1
A101SD9AB04	3-1825136-2
A101SD9AQ04	3-1825136-3
A101SD9AV2B04	3-1825136-4
A101SD9AV2Q04	3-1825136-5
A101SD9V30B04	3-1825136-6
A101SD9V30Q04	3-1825136-7
A101SDCQ04	3-1825136-8
A101SDZQ04	3-1825136-9
A101SHZQ04	4-1825136-0
A101SY9CQ04	4-1825136-1
A101SYAB04	4-1825136-2
A101SYAQ04	4-1825136-3
A101SYCB04	4-1825136-4
A101SYCQ04	4-1825136-5
not assigned	4-1825136-6
A101SYWQ04	4-1825136-7
A101SYZB04	4-1825136-8

Alco P/N	P/N
A101SYZQ04	4-1825136-9
not assigned	5-1825136-0
not assigned	5-1825136-1
A101T1ZB04	5-1825136-2
A101T1ZQ04	5-1825136-3
A101TCQ04	5-1825136-4
A101TZQ04	5-1825136-5
A108MD9AB04	5-1825136-6
not assigned	5-1825136-7
A108P3CQ04	5-1825136-8
A108P3ZQ04	5-1825136-9
A108SD9AQ04	6-1825136-0
A108SDZQ04	6-1825136-1
A108SYCB04	6-1825136-2
A108SYCQ04	6-1825136-3
A108SYZQ04	6-1825136-4
not assigned	6-1825136-5
A101SYAG04	6-1825136-6

REVISIONS

LTR	DESCRIPTION	DATE	DWN	APVD
-	SEE SHEET 1	-	-	-

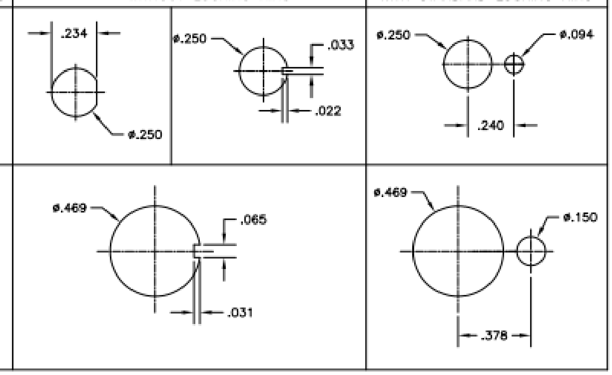
LOC AD DIST 00

RECOMMENDED PANEL CUT-OUTS

BUSHING SIZE | WITHOUT LOCKING RING | WITH STANDARD LOCKING RING

1/4

15/32



MATERIALS CHART

COMPONENT NAME	BASE MATERIAL	FINISH
CASE	DAP, RED, UL94 V-0	
FRAME	STAINLESS STEEL	
B TERMINALS & CONTACTS	COPPER	GOLD OVER NICKEL
G TERMINALS & CONTACTS	COPPER	GOLD OVER SILVER
Q TERMINALS & CONTACTS	COPPER	.000400 SILVER
ACTUATOR	PHENOLIC, BLACK, UL94 V-1	
LEVER	BRASS	CHROME
BUSHING	BRASS	NICKEL
SPRING	MUSIC WIRE	
SUPPORT BRACKET	BRASS	TIN
PIVOT PIN	STEEL	NICKEL
LOCK WASHER	STAINLESS STEEL	
LOCKING RING	STAINLESS STEEL	
NUTS	C3604BD BRASS	NICKEL
TERMINAL SEAL	EPOXY	

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TE Connectivity

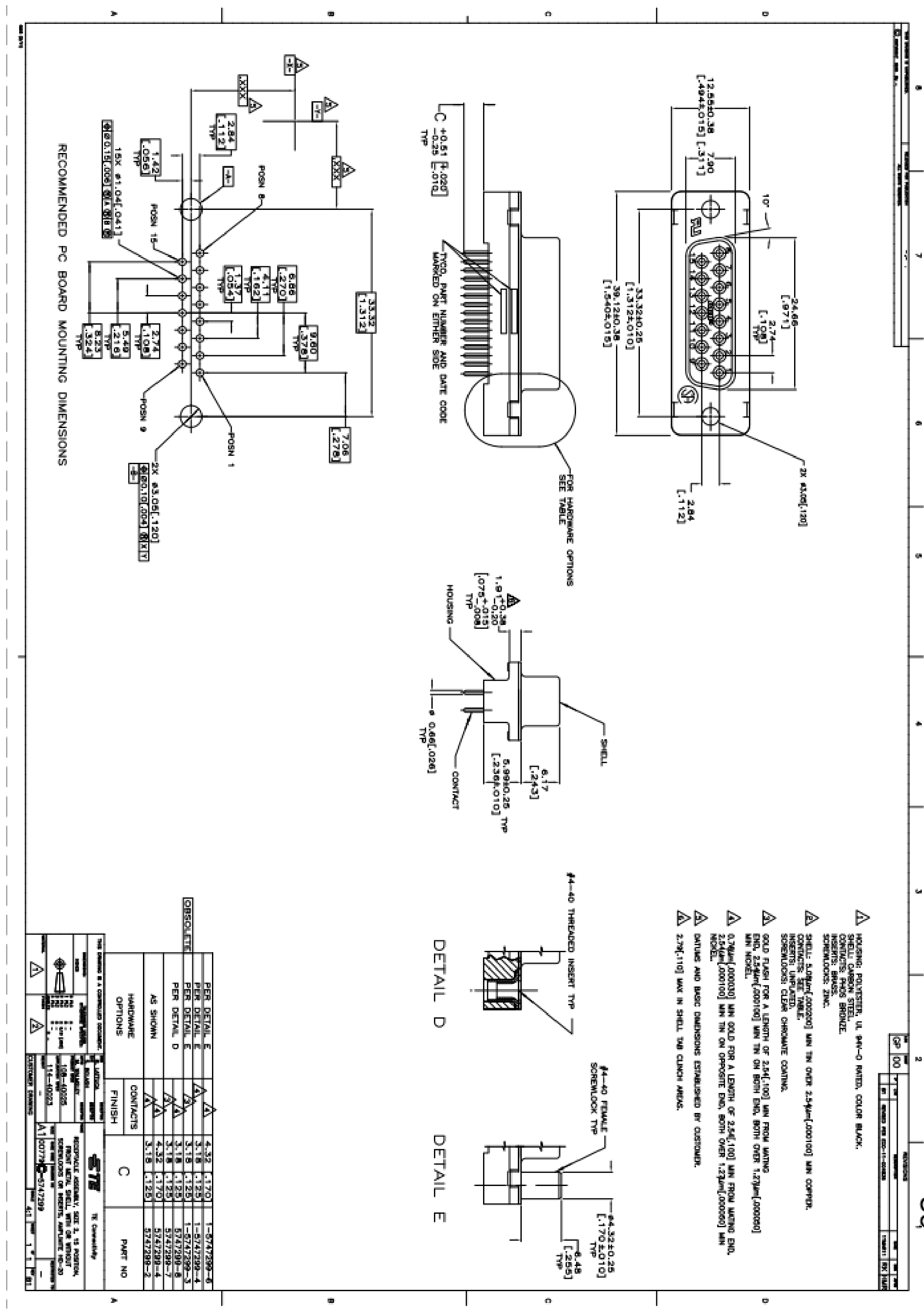
GEMINI A SERIES TOGGLE SWITCH, SINGLE POLE, 2 POSITION FUNCTIONS (01 & 08)

A2 00779 C-1825136

CUSTOMER DRAWING

SCALE 3:1 SHEET 4 of 4 REV A4

1825136


RECOMMENDED PC BOARD MOUNTING DIMENSIONS
DETAIL D
DETAIL E
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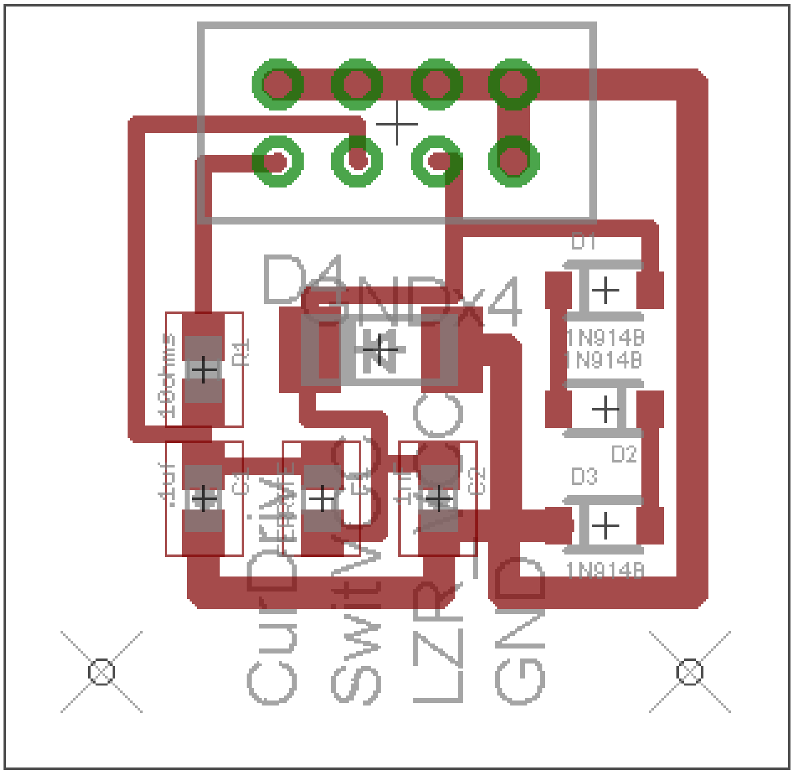
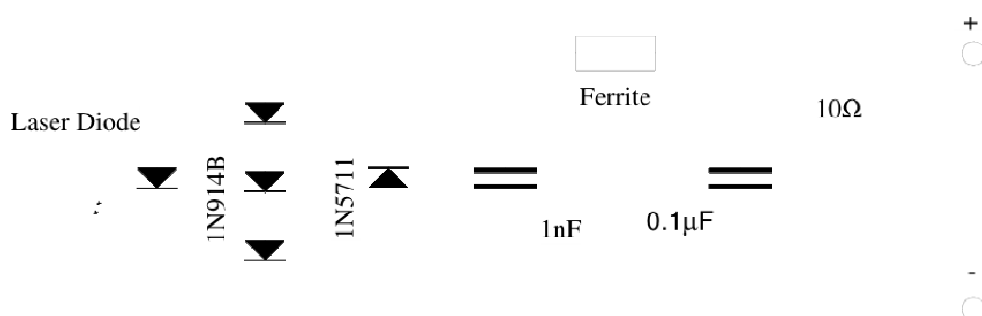
Appendix C: Diode Protection Circuit





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