AD-A175 292 DESIGN AND OPERATION OF THE FORWARD SCATTERING METER (U) NAVAL RESEARCH LAB WASHINGTON DC J E JAMES ET AL. 16 OCT 86 NRL-8996

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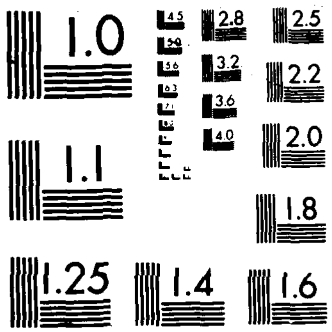


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Naval Research Laboratory

Washington, DC 20375-5000 NRL Report 8996 October 16, 1986



# Design and Operation of the Forward Scattering Meter

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*Atmospheric Physics Branch*
*Space Science Division*



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SECURITY CLASSIFICATION OF THIS PAGE

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED | 1b RESTRICTIVE MARKINGS |
| 2a. SECURITY CLASSIFICATION AUTHORITY<br>2b DECLASSIFICATION/DOWNGRADING SCHEDULE | 3. DISTRIBUTION/AVAILABILITY OF REPORT<br>Approved for public release; distribution unlimited. |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S)<br>NRL Report 8996 | 5. MONITORING ORGANIZATION REPORT NUMBER(S) |
| 6a NAME OF PERFORMING ORGANIZATION<br>Naval Research Laboratory<br>6b. OFFICE SYMBOL (If applicable)<br>Code 4110 | 7a. NAME OF MONITORING ORGANIZATION |
| 6c. ADDRESS (City, State, and ZIP Code)<br>Washington, DC 20375-5000 | 7b. ADDRESS (City, State, and ZIP Code) |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION<br>Space and Naval Warfare Systems Command<br>8b. OFFICE SYMBOL (If applicable)<br>PDW 106-8 | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER |
| 8c. ADDRESS (City, State, and ZIP Code)<br>Washington, DC 20363-5100 | 10. SOURCE OF FUNDING NUMBERS<br>PROGRAM ELEMENT NO. 63207N<br>PROJECT NO.<br>TASK NO.<br>WORK UNIT ACCESSION NO. DN480-588 |

11. TITLE (Include Security Classification)
Design and Operation of the Forward Scattering Meter

12. PERSONAL AUTHOR(S)
James, Jeffrey E. and Gerber, H.

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Year, Month, Day) | 15. PAGE COUNT |
|---|---|---|---|
| Interim | FROM ______ TO ______ | 1986 October 16 | 70 |

16. SUPPLEMENTARY NOTATION

| 17. COSATI CODES | | | 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) |
|---|---|---|---|
| FIELD | GROUP | SUB-GROUP | Extinction; Infrared; Forward scattered light; Maritime hazes; Fogs |
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Forward Scattering Meter (FSM) is a compact and ruggedized instrument developed to give estimates of the far-infrared extinction coefficient of maritime hazes and fogs. This device, developed in response to an operational requirement of the Shipboard Meteorological and Oceanographic Observation System (SMOOS), utilizes the light scattered out of a HeNe laser beam into the near forward direction to scale directly to the infrared extinction. The design and operation of the FSM are described in detail. The FSM was tested in the Calspan Corporation environmental test chamber. It was subjected to various aerosol size distributions and concentrations. Data obtained show the the FSM met its design specifications.

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| 20 DISTRIBUTION/AVAILABILITY OF ABSTRACT<br>☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS | 21. ABSTRACT SECURITY CLASSIFICATION<br>UNCLASSIFIED |
| 22a NAME OF RESPONSIBLE INDIVIDUAL<br>H. Gerber | 22b TELEPHONE (Include Area Code) (202) 767-2780<br>22c. OFFICE SYMBOL Code 4112 |

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

*U.S. Government Printing Office: 1985-507-047

## CONTENTS

# DESIGN AND OPERATION OF THE FORWARD SCATTERING METER

## INTRODUCTION

The Forward Scattering Meter (FSM) was developed for the Shipboard Meteorological and Oceanographic Observation System (SMOOS) program, in response to an operational requirement to measure the infrared (IR) extinction of maritime aerosol as specified in OPNAVINST 5000.42B [1]. The FSM measures visible laser light (632.8 nm) scattered by airborne particles into the near forward direction. This light is directly proportional to the extinction coefficient of the aerosol in the far infrared, such as at the 10.6 $\mu$m wavelength. The FSM is capable of measuring the forward scattered light down to one part per one hundred thousand of the direct laser intensity, which gives it a wide range of sensitivity including infrared estimates in hazes and fogs. The FSM's design reflects the need to protect optical instruments from the harsh environment found aboard ship.

The extinction coefficient is used to determine the performance of infrared systems such as Forward Looking Infrared Radar (FLIR) and to serve as a boundary value for modeling the vertical dependence of atmospheric optics that influence optically guided missiles and other optical devices.

This report is intended to be used as a guideline for the production of the FSM. It considers the theoretical aspects as well as the mechanical and electronics design. A field test was conducted at the Calspan Corp. test chamber in which the FSM was subjected to aerosols of various sizes and concentrations. Data obtained show that this instrument works as designed. Problems found during the construction and field test of the FSM are discussed, and recommendations are given to resolve them.

## THEORY OF OPERATION

Figure 1 gives a simplified schematic of the FSM and demonstrates its principle of operation. A collimated HeNe laser beam is passed through a length $L$ of ambient aerosol consisting of maritime haze or fog. The beam is aligned to pass into a light trap placed in front of a detector consisting of a photodiode. In this manner the detector does not see the direct light from the laser beam but only the light scattered into the near-forward direction by the aerosols passing through the beam. (Aerosols scatter light in all directions; in the present arrangement only the light scattered over a small range of angles in the direction of beam propagation is intercepted by the photodiode.) The fraction $F$ consisting of the intensity of the forward-scattered light divided by the intensity of the laser beam is given by the expression [2]:

$$F = \frac{\lambda^2}{4\pi} \int_{r_1}^{r_2} \int_{\theta_1}^{\theta_2} \int_{y_1}^{y_2} (i_1 + i_2) \cos\theta \, n(r) \, dr \, d\theta \, dy \, , \tag{1}$$

where $i_1$ and $i_2$ are the Mie intensity functions [3], $\theta$ is the angle between the optical axis and the line between the scattering point in the beam and the location on the detector, $n(r)$ is the size distribution of the aerosol particles, $y$ is the radial distance along the active surface of the photodiode, and $\lambda$ is the wavelength of light.

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Manuscript approved May 8, 1986.

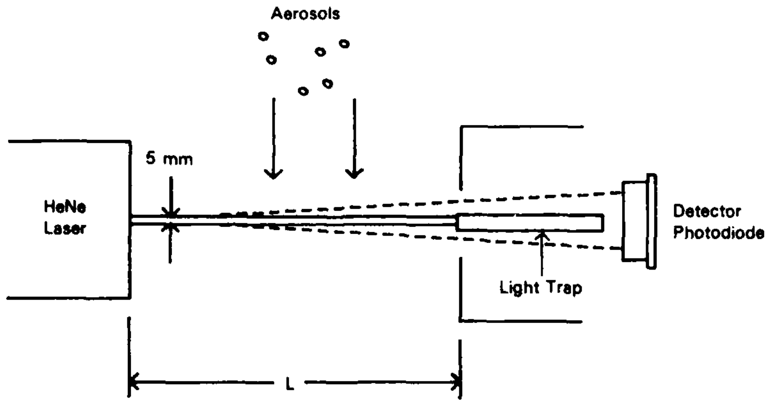



Fig. 1 — Simplified schematic diagram of the operation of the FSM

It was predicted [2,4] that Eq. (1) reduces to an approximately linear relationship between $F$ and the far-infrared aerosol extinction:

$$F = \frac{\sigma_e\ (10.6\ \mu\text{m})}{A}, \tag{2}$$

where $\sigma_e(10.6\ \mu\text{m})$ is the aerosol extinction coefficient at a wavelength of 10.6 $\mu$m; and $A$ is a constant that depends on the measured angular range of the forward scattered light, on the specific geometry of the instrument, and on the composition of the aerosol particles. Equation (2) is independent of $n(r)$ and is valid for aerosol particle sizes found in typical maritime hazes and fogs.

It was estimated [4] that Eq. (2) can predict $\sigma_e(10.6\ \mu\text{m})$ with an accuracy of $\pm 10\%$ for maritime aerosol, which usually consist of particles with a high water content and thus are of similar composition. It is expected that a relationship similar to Eq. (2) also holds for broad wavelength intervals in the 8 to 10 $\mu$m window.

## DESIGN OF FSM

### Transmitter

In designing the transmitter assembly, the optical and the mechanical aspects must be considered. The optics consist of three components (see Fig. 2); a Melles-Griot HeNe laser operating at 632.8 nm with an output intensity of 2 mW; a Melles-Griot spatial filter with a focal length of 12 mm, maximum aperture of 4.8 mm, wavelength range of 450 to 750 nm, and pinhole assembly with a pinhole diameter of 40 $\mu$m; and a Melles-Griot collimator modified for a focal length of 51 cm (20 in.) and outfitted with a synthetic, fused quartz singlet lens from the Republic Lens Company. Of utmost importance in the design of the transmitter is the use of a high-quality collimator lens. Background noise measured at the detector is directly related to the quality of this lens. Since the Melles-Griot collimator lens lacked the desired quality, it was replaced with the synthetic, fused quartz lens. A special adaptor was needed to accommodate the new lens. See Appendix B for detailed drawings.

The laser beam passes through a cylindrical chopper that has two holes drilled through it at right angles to each other (see drawing in Appendix B). The beam is chopped at 20 Hz. The laser beam then passes through the spatial filter and pinhole assembly, which filters out the higher order diffraction patterns from the beam and gives a precise Gaussian power distribution. Adjustment knobs are found on the spatial filter assembly for positioning the pinhole at the exact center of the beam and for focusing the beam onto the plane of the pinhole. The laser beam then passes through the collimator. The collimator focuses the beam to a small point in the light trap that is concentric with the detector. Modifications were made to the collimator to obtain a shorter focal length; see Appendix B.

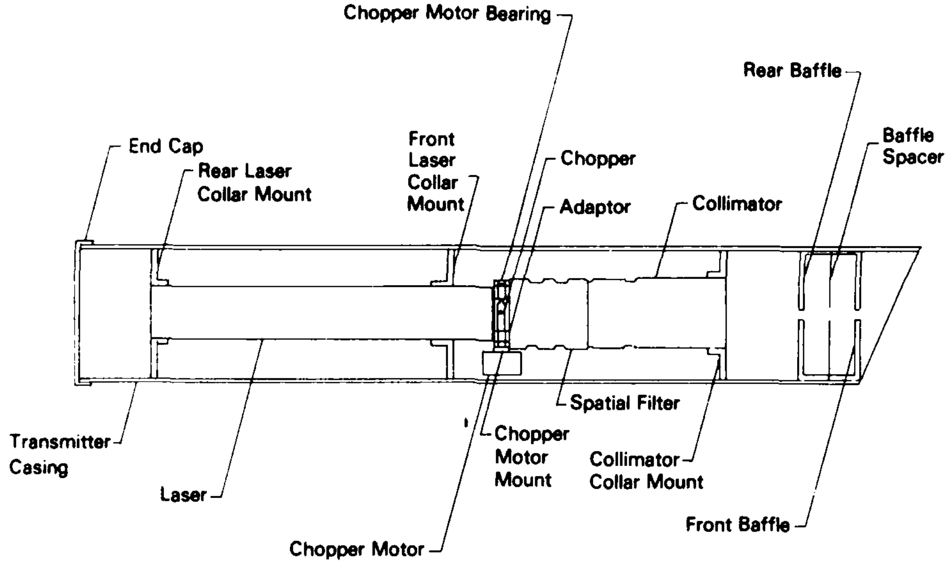



Fig. 2 — Cross-sectional view of the transmitter assembly

Mechanical aspects must also be considered in the design of the transmitter assembly. The laser and related optics are housed in a hinged, cylindrical casing that permits easy access to the focusing rings of the optics. Enough space must exist in the housing to allow access to the pinhole adjustments as well as for freedom of movement of the focusing rings. The optical components are mounted with circular aluminum collar mounts. Holes drilled in the mounts let filtered air pass through to the collimator lens. The chopper motor is mounted on the Melles-Griot adaptor with the chopper motor mount. The adaptor was modified at NRL to allow the chopper to pass through the optical axis. The chopper is mounted to the chopper motor and is inserted in a bearing at the top of the chopper motor mount. A reference photodiode is epoxied to the inside of the adaptor.

The transmitter is weatherproofed for the harsh marine environment. The rear cap has a 3/4 in. lip and a 1/16 in. neoprene gasket to prevent salt water, rain, or other contaminants from entering. The mating edges of the hinged housing are also gasketed. The front of the transmitter utilizes a baffle assembly that keeps out large particles such as rain and salt spray. The baffle consists of two chambers and three walls with 1/2 in. holes bored in each to permit the laser beam to pass through. A filtered air system is employed in the design. An air compressor blows filtered air through the rear of the transmitter and out the front, further protecting the lenses from contaminants.

**Detector**

The detector's optics consist of several components: three grade A fused silica laser lenses made by Optics for Research; a 632.8 nm narrowband laser filter made by Oriel Corporation; and an assembly designed for housing the lenses, focusing, and fixing the field of view (see Fig. 3). The field of view is determined by several components in the front detector housing. These components include the light trap, the front baffle, the front lens baffle, and the field stop. The forward scattered light that falls within the field of view is focused by lens A to a pinpoint in the same plane as the field stop. Lens B in the rear detector housing collimates the scattered light passing through the field stop. This gives the required, near-parallel light that passes through the laser-line filter. The filter gives a low-light background for all wavelengths of light other than the 632.8 nm wavelength of the laser. Lens C focuses the scattered light onto the sensitive area of the detector photodiode. The front and rear detector housings are threaded and are adjusted with respect to one another so that lens B focuses on the field stop. Lockrings are utilized to ensure permanent location of parts once they have been focused. All parts are black anodized aluminum.

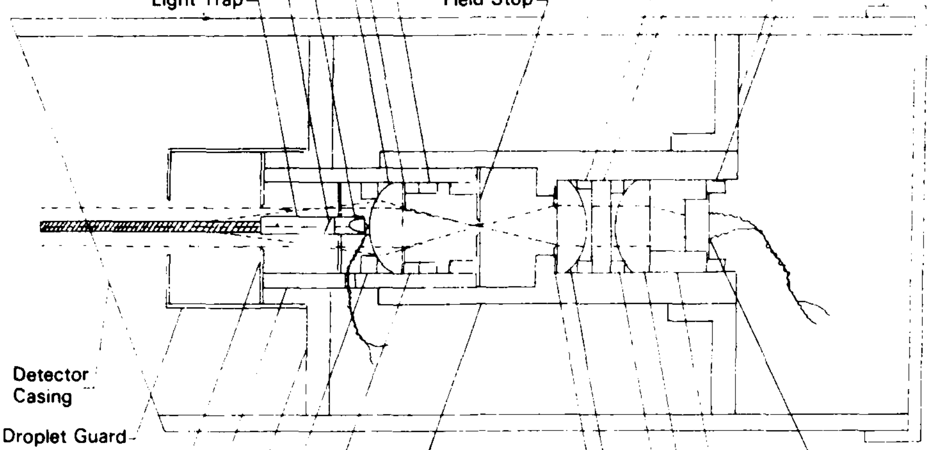



Fig. 3 — Cross-sectional view of the detector assembly

The detector is housed in a cylindrical casing and is mounted with circular aluminum collar mounts. The rear mount has several 1/2 in. holes bored in it to allow filtered air to pass along the casing. The front mount is solid so as to force the filtered air through the holes drilled in the detector front housing, which in turn passes the air over the front lens. The light trap is mounted with 20 gage piano wire. Holes are drilled through the light trap and the front detector housing at right angles to each other. The piano wire is passed through these holes and epoxied at the ends. Weatherproofing of the detector is accomplished much the same as with the transmitter. Filtered air is passed over lens A to keep out small airborne particles. A neoprene gasket is used on the rear cap to prevent salt water and rain from entering, and a droplet guard is used on the front of the detector to keep out large airborne particles. All aluminum parts are black anodized, and parts exposed to the elements are painted with a white, polyurethane base paint.

**Sensor Mount and Enclosure**

The transmitter and detector are mounted on a 5 in. wide aluminum H-beam with cradle mounts. See Fig. 4 and drawings in Appendix B. An H-beam was used for the sensor base because of the need for a rigid structure on which to align the transmitter and detector. The open section between the transmitter and detector was removed from the H-beam so there would be no significant surface area on which rain and sea spray could bounce off into the path of the laser beam as this would cause a faulty output. The sensor is mounted to the ship with the sensor mount. The sensor mount has a 1/2 in. rubber shock mount to reduce damage caused by vibration. The sensor mount will accept a standard 1-in. pipe, or the bracket mount can be installed so that the sensor can then be mounted on a horizontal or vertical rail from 1 to 3 in. in diameter. The sensor and mounts are painted with a white, polyurethane base paint to give added protection from the elements.

The electronics enclosure is made by General Metals Corp. and is constructed of 1/8 in. stainless steel. All seams are continuously welded to ensure a waterproof seal. The enclosure's outer door has a

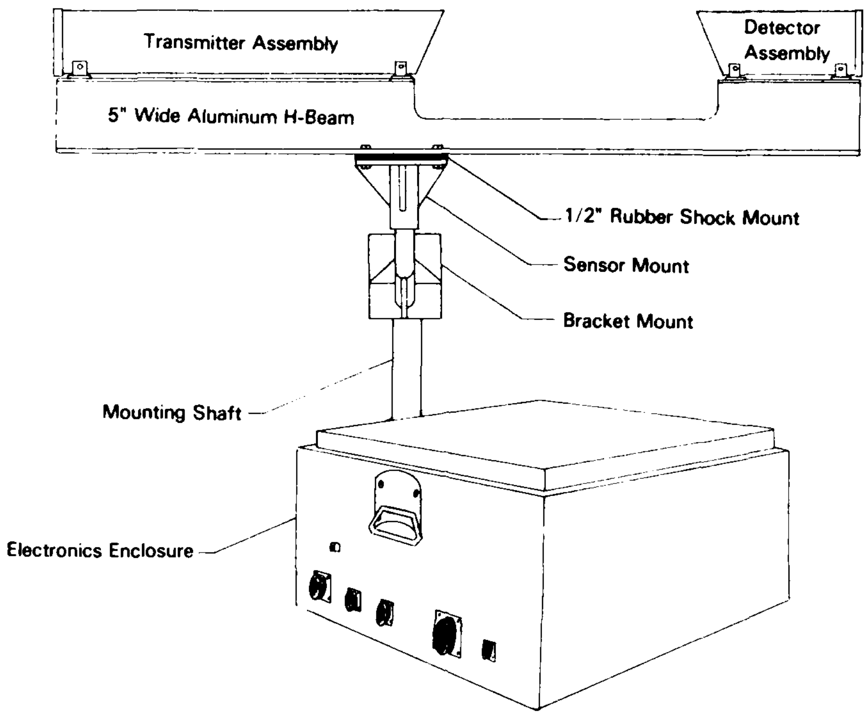



Fig. 4 — The FSM

built-in lip with a 1/8 in. neoprene gasket to keep water out. A continuous hinge on the outer door provides a strong, long-lasting outer door. The inner door is used to mount the power switches, fuses, and display. The electronics enclosure has a row of air filters mounted on one side to provide clean airflow to the electronics. A fan is mounted on the opposite side of the enclosure to circulate air and to help remove heat created by the air compressor and laser power supply. The enclosure is also painted with the white polyurethane base paint.

**Electronics**

*General Description*

The electronics of the FSM consists of two TIL78 Phototransistors, an RCA C30809 Photodiode, an amplifier circuit utilizing LM307's, an Evans Electronics Lock-in amplifier, and a Kiethly 195T Programmable Digital Multimeter. See Fig. 5 for a simplified schematic.

The detector signal is obtained by reverse biasing the RCA C30809 detector photodiode with 45 Vdc. This signal is then amplified and fed to switch 3. Switch 3 is a two-position switch whose common terminal is connected to the signal input of the lock-in amplifier. This switch is used to check for zero output of the FSM when the detector signal is grounded.

Two reference signals are used in the design. The light trap reference is obtained by reverse biasing the TIL78 located in the light trap with 30 Vdc and serves as the lock-in amplifier reference signal. This reference is then amplified and fed to switch 4. Switch 4 is utilized in the calibration of the FSM. It switches between the reference signal and the detector signal when the calibration assembly is attached. The common terminal of switch 4 is connected to the reference input of the lock-in amplifier.

The adaptor reference is obtained by reverse biasing the TIL78 located in the Melles-Griot adaptor with 30 Vdc and serves as a laser intensity reference. This reference is then amplified, converted to

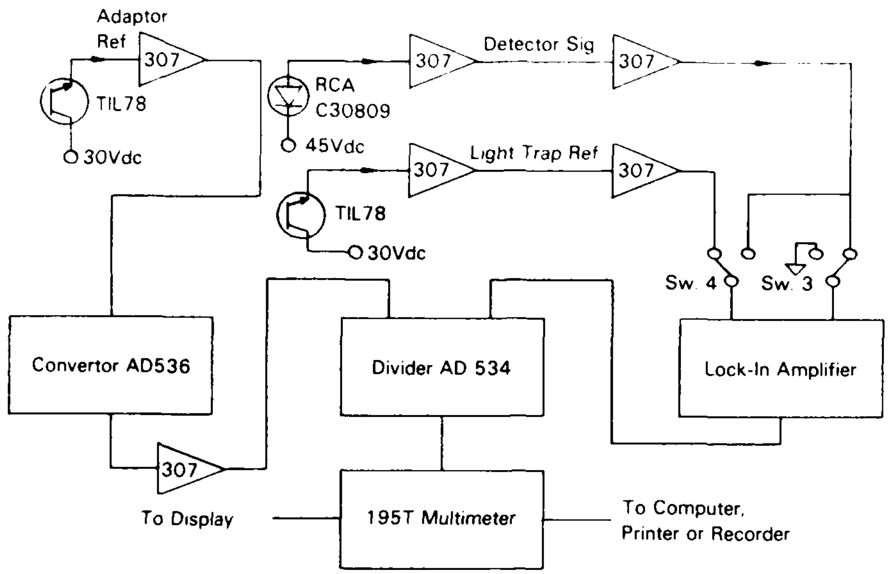



Fig. 5 — Simplified flow chart shows the paths of the light trap reference, the adaptor reference, and the detector signal

a dc voltage that corresponds to its RMS value, and amplified to the desired level. There were two reasons why two reference signals were used. First, any misalignment between the laser and the light trap due to the warping of the H-beam could significantly change the amplitude of the light-trap reference signal, therefore making questionable the use of the light-trap reference as a laser intensity reference. Second, the lock-in amplifier reference input must be in phase with the lock-in signal input. The adaptor reference is obtained by using light reflected off the chopper causing it to be distorted and partially out of phase with the detector signal, therefore making it undesirable as a lock-in reference input. The adaptor reference and the detector signal are then fed into the AD536 divider on the amplifier board. The divider ratios between the detector signal and the adaptor reference signal to rid the output of laser intensity fluctuations. The output of the divider is then sent to the digital multimeter for A/D conversion and output to the recording instrumentation.

### Amplifier Board and Lock-in Amplifier

The amplifier board consists of three signal amplifier circuits, a voltage regulator circuit, an AD534 divider, and an AD536 RMS to dc converter. Refer to Fig. 6 and Tables 1, 2, and 3 for the following description. The voltage regulator circuit uses an LM350K voltage regulator. The input to the regulator (pin 8 on the edge connector) is 45 Vdc. The output of the voltage regulator (pin 10 on the edge connector) should be set to 30 Vdc and is adjustable through potentiometer P1. This voltage is used for reverse biasing the TIL78 phototransistors.

The detector signal is fed into a two-stage inverting operational amplifier circuit (pin 12 on the edge connector) via shielded cable. Gain is adjustable through potentiometer P4. The output of the amplifier circuit (pin 16 on the edge connector) is then fed into the ac signal input (pin 18) of the Evans Electronics lock-in amplifier. The lock-in amplifier gives a dc voltage corresponding to the RMS value of the incoming signal. The lock-in amplifier reduces noise on the signal by only amplifying the signal in phase with the light-trap reference signal. The output of the lock-in amplifier (pin 10) is then fed into the AD534 divider IC (pin 14 on the edge connector) on the amplifier board.

The light-trap reference signal is fed into a two-stage inverting operational amplifier circuit via pin 3 of the amplifier board. It is then fed into the ac reference input (pin 3) of the lock-in amplifier. Gain is adjustable through potentiometer P3.

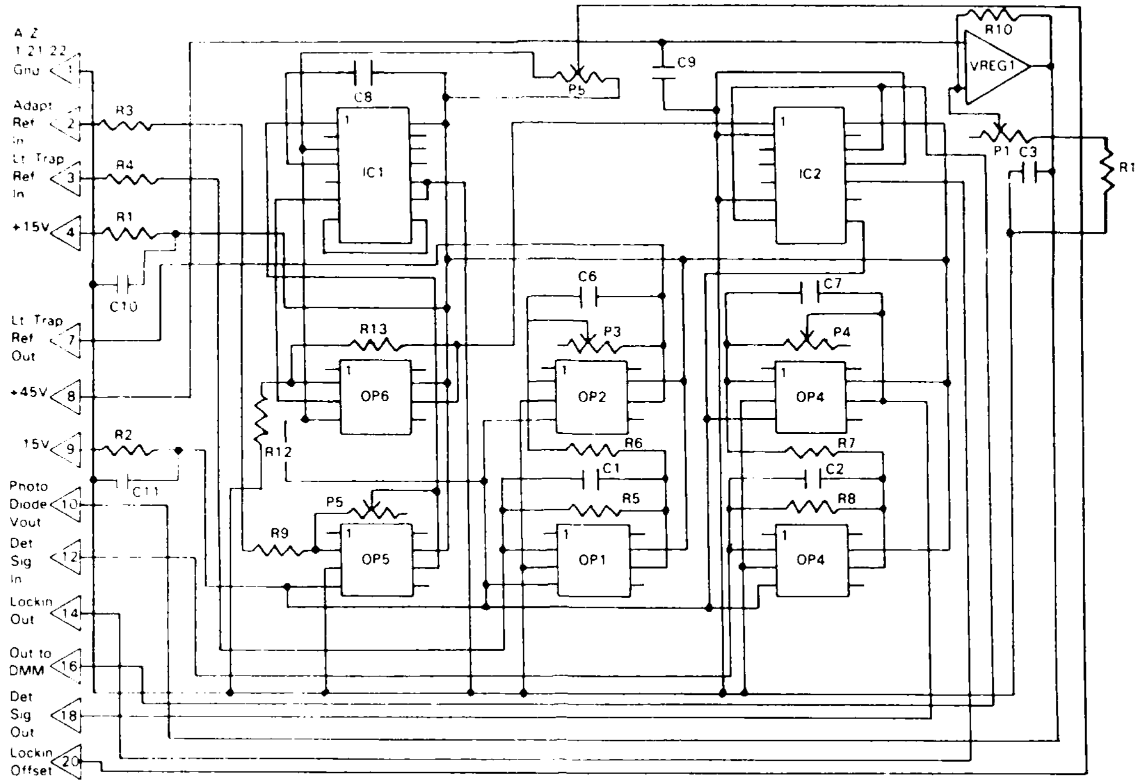



Fig. 6 — Schematic diagram of the FSM amplifier board

Table 1 — Amplifier Board Parts Identification

| Item | Quantity | Part Desc. | Part # | Board Loc. |
|---|---|---|---|---|
| 1. | 2 | Resistor | 100 | R1, R2 |
| 2. | 6 | Op. Amp. | LM307 | OP1-OP6 |
| 3. | 1 | Volt Reg. | LM350K | VREG 1 |
| 4. | 3 | Resistor | 1K | R3-R5 |
| 5. | 2 | Resistor | 5K | R6, R7 |
| 6. | 1 | Resistor | 200K | R8 |
| 7. | 1 | Resistor | 1K | R9 |
| 8. | 1 | Pot. | 2K | P1 |
| 9. | 1 | Pot. | 5K | P2 |
| 10. | 2 | Pot. | 50K | P3, P4 |
| 11. | 1 | Pot. | 20K | P5 |
| 12. | 1 | Edge Conn. | 22 pin | CON1 |
| 13. | 1 | Ckt. Board | Vector | B1 |
| 14. | 5 | I.C. Socket | 8 pin | S1-S5 |
| 15. | 2 | I.C. Socket | 14 pin | S6-S7 |
| 16. | 2 | Capacitor | 1.5$\mu$F 50V | C1, C2 |
| 17. | 1 | Capacitor | 1$\mu$F 50V | C3 |
| 18. | 2 | Capacitor | .1$\mu$F | C4, C5 |
| 19. | 1 | RMS/DC | AD534 | IC1 |
| 20. | 1 | Divider | AD536 | IC2 |
| 21. | 2 | Resistor | 120 | R10, R11 |
| 22. | 1 | Resistor | 2K | R12 |
| 23. | 1 | Resistor | 51K | R13 |
| 24. | 2 | Capacitor | .047$\mu$F | C6, C7 |
| 25. | 1 | Capacitor | 100 $\mu$F | C8 |
| 26. | 1 | Capacitor | .1 $\mu$F | C9 |

Table 2 — Amplifier Board Edge Connections

| Component Side | | | Soldered Side |
|---|---|---|---|
| Ground | 1 | A | Ground |
| Reference Signal In (Adapter) | 2 | B | Ground |
| Reference Signal In (Light Trap) | 3 | C | Ground |
| +15Vdc | 4 | D | Ground |
| No Connection | 5 | E | Ground |
| No connection | 6 | F | Ground |
| Reference Signal Out (Light Trap) | 7 | H | Ground |
| + 45Vdc | 8 | J | Ground |
| − 15Vdc | 9 | K | Ground |
| Voltage Out (For Photodiodes) | 10 | L | Ground |
| No Connection | 11 | M | Ground |
| Detector Signal In | 12 | N | Ground |
| No Connection | 13 | P | Ground |
| Output From Lock-In | 14 | R | Ground |
| No Connection | 15 | S | Ground |
| Output To Multimeter | 16 | T | Ground |
| No Connection | 17 | U | Ground |
| Signal Out (To Lock-In) | 18 | V | Ground |
| No Connection | 19 | W | Ground |
| Offset (Lock-In) | 20 | X | Ground |
| No Connection | 21 | Y | Ground |
| Ground | 22 | Z | Ground |

Table 3 — Lock-in Amplifier Edge Connections

| Soldered Side | | | Component Side |
|---|---|---|---|
| Ground | 22 | Z | Ground |
| AC Signal Input | 21 | Y | Ground |
| DC Signal Input | 20 | X | Ground |
| Ground | 19 | W | Ground |
| No Connection | 18 | V | Ground |
| Offset | 17 | U | Ground |
| 20 DB | 16 | T | Ground |
| 40 DB | 15 | S | Ground |
| Filter | 14 | R | Ground |
| DC | 13 | P | Ground |
| 20 DB Post | 12 | N | Ground |
| Overload | 11 | M | Ground |
| Output | 10 | L | Ground |
| Signal Monitor | 9 | K | Ground |
| CB | 8 | J | Ground |
| CA | 7 | H | Ground |
| −15 V | 6 | F | −15 V |
| +15 V | 5 | E | +15 V |
| Logic Reference Input | 4 | D | Ground |
| AC Reference Input | 3 | C | Ground |
| DC Reference Input | 2 | B | Level Shift |
| Ground | 1 | A | Ground |

The adaptor reference signal is fed into a single-stage inverting operational amplifier circuit via pin 2 of the amplifier board with gain adjustable through potentiometer P2. It is then fed into the input of the AD536 RMS to dc converter. The AD536 gives a dc voltage corresponding to the RMS value of the incoming signal. The output of the RMS to dc converter is fed into a noninverting operational amplifier for amplification to the desired voltage level of approximately 8 V. The adaptor reference signal is then fed into the AD534 divider. This divider ratios between the output of the RMs to dc converter and the output of the Evans Electronics Lock-In amplifier, reducing detector signal errors caused by laser intensity fluctuation errors.

Output of the AD534 Divider IC:

$$\text{Output} = 10 * \frac{(X1 - X2)}{(Z2 - Z1)} + Y1 \quad (3)$$

where

10 = Gain of AD534 Divider IC
X1 = Detector signal
X2 = Ground (0)
Z2 = Adaptor reference signal
Z1 = Ground (0)
Y1 = Ground (0)

The output of the AD534 divider is then fed into the input of the Keithly 195T Programmable Digital Multimeter. The 195T is programmed to fill a 100-point buffer and do a running average of the data stored. This average is then sent over the IEEE-488 bus when signaled to do so.

*Cables and Connectors*

The FSM uses shielded cable to reduce noise pickup and interference. The detector cable and adaptor reference/chopper cable use a 6-conductor, 18-gage, individually shielded pair Belden cable (part number 9773). The shield used in this cable is of the continuous foil type and gives 100% coverage. The power cable to the Melles-Griot laser is Belden RG213 coaxial cable rated at 5000 V. The GPIB cable used is a standard 24 conductor, shielded, IEEE 488 interface cable at a modified length of 30 ft. The AC power line is a standard 18 gage, three-conductor cable. For cable connection diagram refer to Fig. 7.

All connectors used in the FSM are Bendix weatherproof connectors. The following pages identify the functions of the connector pins. For part numbers see the parts list in Appendix B of this report; also see the Recommendations section of this report.

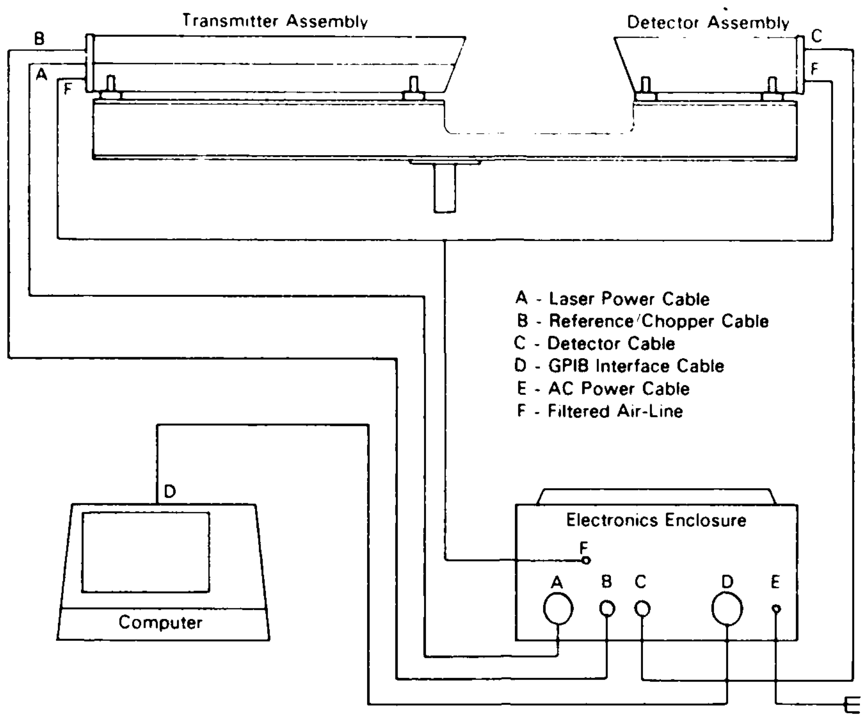
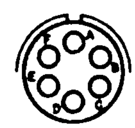



Fig. 7 — Cable connections of the FSM

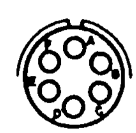
**Detector Signal Cable**

| Bendix Conn. Pin | Signal Type |
|---|---|
| A | Light trap reference signal |
| B | Detector signal |
| C | Shield (detector signal) |
| D | +45 Vdc (detector bias) |
| E | Shield (light trap reference signal) |
| F | +30 Vdc (light trap reference bias) |



**Reference/Chopper Cable**

| Bendix Conn. Pin | Signal Type |
|---|---|
| A | 110 Vac hot (chopper motor) |
| B | Shield (adapter reference) |
| C | Adapter reference signal |
| D | 30 Vdc (adapter reference) |
| E | AC ground (chopper motor) |
| F | 110 Vac neutral (chopper motor) |

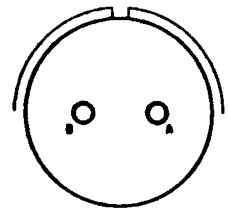


**AC Power Cable**

| Bendix Conn. Pin | Signal Type |
|---|---|
| A | AC ground |
| B | 110 Vac (hot) |
| C | 110 Vac (neutral) |

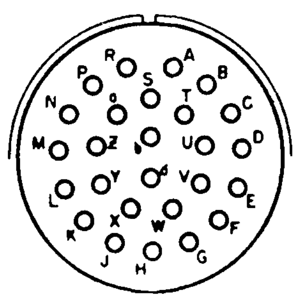

**Laser Power Cable**

| Bendix Conn. Pin | Signal Type |
|---|---|
| A | 2000 Vdc |
| B | Ground |



**FSM GPIB Computer Interface Cable**

| Contact Number | IEEE-488 Designation | Type | Wire Color | Bendix Connection |
|---|---|---|---|---|
| 1 | DI01 | Data | Brown | A |
| 2 | DI02 | Data | Red | B |
| 3 | DI03 | Data | Orange | C |
| 4 | DI04 | Data | Yellow | D |
| 5 | EOI | Management | Green | E |
| 6 | DAV | Handshake | Blue | F |
| 7 | NRFD | Handshake | Purple | G |
| 8 | NDAC | Handshake | Gray | H |
| 9 | IFC | Management | White | J |
| 10 | SRQ | Management | W/Black | K |
| 11 | ATN | Management | W/Brown | L |
| 12 | SHIELD | Ground | Uncoated | M |
| 13 | DI05 | Data | W/Orange | N |
| 14 | DI06 | Data | W/Yellow | P |
| 15 | DI07 | Data | W/Green | R |
| 16 | DI08 | Data | W/Blue | S |
| 17 | REN | Management | W/Violet | T |
| 18 | Gnd | Ground | W/Grey | u |
| 19 | Gnd | Ground | W/Bla/Bro | v |
| 20 | Gnd | Ground | W/Bla/Red | w |
| 21 | Gnd | Ground | W/Bla/Ora | x |
| 22 | Gnd | Ground | W/Bla/Yel | y |
| 23 | Gnd | Ground | W/Bla/Gre | z |
| 24 | Gnd | Ground | W/Bla/Blue | a |
| | SHIELD | Shield | Uncoated | b |



## OPERATION OF FSM

### Deployment

The FSM consists of:

1. Sensor
2. Neoprene shock mount
3. 1-in. female sensor mount
4. Vertical/horizontal bar mount
5. Electronics enclosure
6. 20-ft. T connection air line
7. 20-ft. laser power cable
8. 20-ft. signal cable
9. 20-ft. reference/chopper power cable
10. 30-ft. ac power cable
11. 30-ft. GPIB cable
12. Calibration assembly

The FSM was designed to be mounted aboard ship and is weatherproofed for the harsh marine environment. It should be mounted high enough off the deck of the ship so as to reduce the chance of being doused with green water. A 1-in. female mount and a 3-in. bracket mount are provided for ease of mounting. Cables should be attached as in Fig. 7 with 90° connectors at the sensor end. The ac power cable should be attached last so as not to create a shock hazard. Cables should be taped to the mounting shaft to relieve cable tension on connectors.

A good coat of automobile wax on the outside of the sensor and electronics enclosure as well as silicone grease applied to all bolts will ensure a longer lasting instrument. The electronics enclosure is weatherproofed as is the sensor. It was designed to be welded or bolted to the deck of the ship with 3/8 in. × 16 studs welded on the deck corresponding to the mounting holes of the electronics enclosure.

### Front Panel Controls

The front panel controls are located on the front panel under the electronic enclosures outer door. Access to these controls is obtained by loosening the seven outer door hold-down bolts. Ensure that you are well familiarized with all front panel controls before operating the FSM. The following describes the front panel controls and their functions, see Fig. 8.

1. Power on/off (SW 1)—This switch turns on main power to FSM subassemblies.

2. Laser Power on/off (SW 2)—This keyed switch turns the HeNe laser on or off regardless of main power switch being on.

3. Signal/Ground (SW 3)—This switch is used for zeroing any noise in the amplifier circuit by grounding the signal input. For more information see the Calibration section.

4. Reference/Signal (SW 4)—This switch is used during calibration. It switches between the reference signal and the detector signal for use as the reference. For more information see the Calibration section.

5. Power On Indicator (L 1)—This indicator is lit when power switch (SW 1) is in the on position.

6. Laser On Indicator (L 2)—This indicator is lit when switches (SW 1) and (SW 2) are in the on position.

7. Fuse A (F 1)—This 5A, 250 Vac fuse is for Gast air pump.

8. Fuse B (F 2)—This 3A, Vac fuse is for electronics.

9. Display (D 1)—Six 5 in. LED displays give address, bus information, and data readout. For more information read the Keithley manual.

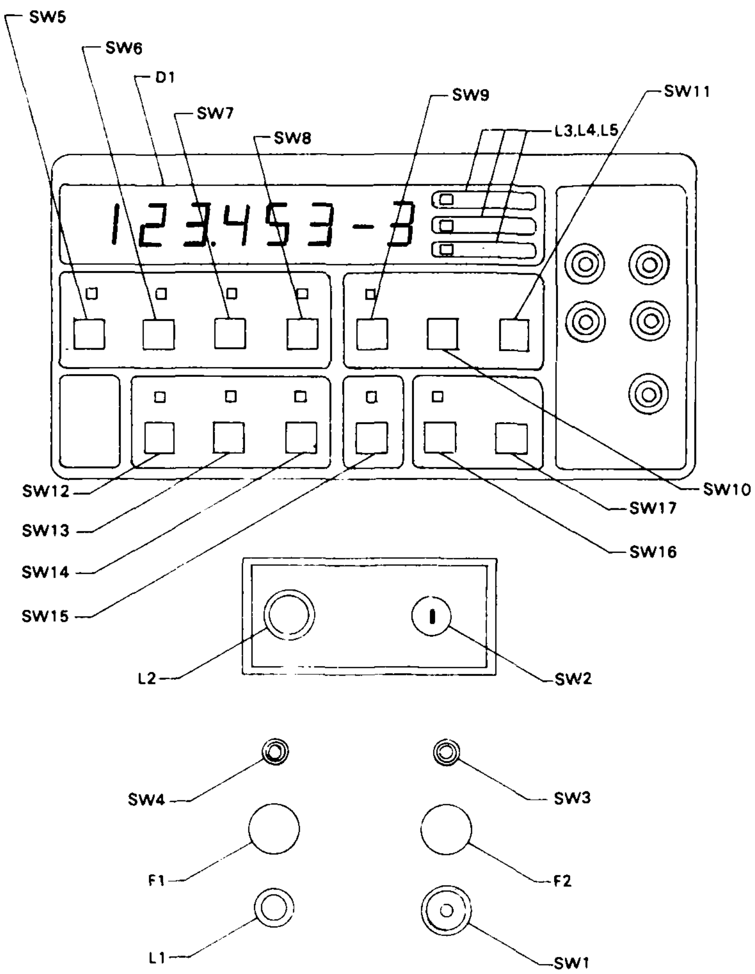



Fig. 8 — Front panel controls

10. Function (SW 5-8)—The four function push buttons control the type of measurement being made.

    Volts (SW 5)—For proper FSM operation this push button must be depressed.

    Ohms-Amps-AC (SW 6-8)—These push buttons are not used during FSM operation. For more information on these push buttons, see the Keithley 195T Operators Manual.

11. Range (SW 9-11)—The range buttons select the operating ranges of the instrument.

    Auto (SW 9)—The auto push button places the 195T in the autoranging mode. This push button should be depressed for FSM operation.

    Down-Up (SW 10-11)—These push buttons are not used during FSM operation. For more information on these buttons see the Keithley 195T Operators Manual.

12. Modifiers (SW 12-14)—The modifier buttons control the zero, filter, and resolution modes.

    Zero (SW 12)—The zero button controls a zero offset for baseline suppression. Not used during FSM operation.

    Filter (SW 13)—The filter button controls the line frequency filter.

Resolution (SW 14)—The resolution button controls the display resolution and should be set for maximum resolution.

13. Trig (SW 15)—This button is not used during FSM operation. See the Keithley 195T Operators Manual for more information.

14. Program (SW 16-17)—The program buttons are used with the front panel programs. The Buffer program is described in Section 5.3. For information on other programs see the Keithley 195T manual.

    PRGM (SW 16)—The PRGM button is used as the first step in entering front panel programs 0 to 9.

    Recall/Ent (SW 17)—The Recall/Ent button is used to enter and recall data associated with the front panel programs. See the Keithley 195T manual.

15. Terminal Inputs (T1-T5)—The Terminal Inputs are disconnected. The signal is connected via the rear input terminals.

16. IEEE Status (L3-L5) The Remote, Talk, and Listen indicators are used during remote IEEE bus programming. See the Keithley 195T manual for more information.

**Start-Up Procedure**

1. Ensure that the Reference/Signal switch (SW 4) is in the reference position.

2. Ensure that the Signal/Ground switch (SW 3) is in the signal position.

3. Ensure that the laser power cable is connected *before turning the laser power supply on, otherwise* dangerous arcing may occur.

4. Turn the Laser Power switch (SW 2) to the on position.

5. Turn the Main Power switch (SW 1) to the on position. Note that the red power indicator (L1), laser power supply indicator (L2), and the display panel (D1) illuminate.

6. The display panel (D1) will illuminate with F60A0. The F60 corresponds to the line frequency to which the FSM is set. The A0 is the software revision level of the 195T. In a few seconds it will display the IEEE-488 address, then the 195T will start taking and displaying data.

7. If you are running the FSM by means of a computer capable of operating the GPIB bus, then the following line of code must be sent over the bus.

"FOROS6Q21X"

The F0 sets the 195T to the dc volts scale, and R0 puts the 195T in the autoranging mode. S6 sets the read rate of the 195T. See the rate table in the Kiethly 195T manual. Q21 sets the internal buffer to recycle mode for continuously updated data. X tells the 195T that that is the end of command input and to start operating in the selected mode. When an average of the internal buffer is desired, the computer must address the 195T to listen and then send the following line of code.

"U2X"

When this line of code is received by the 195T, it will take the average of the 100-point buffer and send it over the GPIB bus. Your computer must be set up to read this string in and store it. For continuous data acquisition you need not repeat the first line of code, but the second line must be repeated each time an average is desired.

**Manual Operation**

If operation of the FSM is to be by the front panel controls, then follow these steps.

1. Depress the volts button (SW 5) once to ensure that the FSM is in the dc volts mode.

2. Depress the autoranging button (SW 9) once to ensure that the autoranging mode is selected.

3. Depress the program button (SW 16). The display (D1) will respond with:
   Pro ?
   Depress the key numbered 7 (SW 13) to specify the data logger program.

4. Depress the Recall/Ent button (SW 17) once. The 195T will display r = ?. Using the keys numbered 0 to 9 enter the read rate desired.

See the following table for read-rate information. Also see the Keithley manual.

| r Value | Read Rate |
|---|---|
| 0 | Conversion Rate |
| 1 | Same as r = 0 |
| 2 | 1-s interval |
| 3 | 5-s interval |
| 4 | 10-s interval |
| 5 | 1-min interval |
| 6 | 5-min interval |
| 7 | 10-min interval |
| 8 | 30-min interval |
| 9 | 1 h interval |

Once you have entered the read rate, you must depress the enter key once again to start the program. The FSM is now in operation. Once the data logger program has filled the 100-point buffer, the display will show BFULL intermittently along with data being taken. At this point you can look at each individual buffer location or get the highest, average, or lowest reading of the buffer.

5. Press the Recall/Ent button (SW 17). The 195T display (D1) will respond with 1 to 100 of the last stored buffer reading as follows:

   $$n = (1 \text{ to } 100)$$

6. To read each buffer location continue to press the Recall/Ent button (SW 17); holding the Recall/Ent button down will scroll through the readings rapidly.

7. To obtain an average of the buffer readings, depress the key numbered 3 (SW 9). The instrument will respond with bA. Following this message, the average will be displayed.

8. To obtain the lowest buffer reading press the key numbered 2 (SW 8). The message bL0 will be displayed. Following this message, the lowest buffer reading will be displayed.

9. To obtain the highest reading in the buffer, press the key numbered 1 (SW 7). The message bHI will be displayed. After this message, the highest buffer reading will be displayed. Return to step 1 to restart the data logging process.

10. If any problems are encountered, see the Keithley 195T operators manual.

## Calibration

*Field Calibration*

1. Slide the FSM calibration assembly onto the front of the droplet.

2. Power up the FSM. Read the Operation Section for the power-up procedure.

3. Allow a few minutes warm-up time.

   Set the Reference/Signal switch (SW 4) to the Signal position. The output of the FSM should be reading within 0.1 V of 2.5 V. If not see the Prime Calibration section.

*Prime Calibration*

1. Using a digital voltmeter set to dc volts scale, measure the output (pin 10) of the voltage regulator (VREG1) located on the amplifier board. The output should be set to 30 Vdc and is adjustable through potentiometer P1 (see Fig. 6).

2. Set the Signal/Ground switch (SW 3) to the ground position and the Reference/Signal switch (SW 4) to the reference position (see Fig. 8). The output of the 195T Digital Multimeter should read 0.000 Vdc. If this is not the case, the offset should be zeroed out through potentiometer P5 located on the amplifier board (see Fig. 6).

3. Return the Signal/Ground switch (SW 3) to the Signal position and place the Reference/Signal switch (SW 4) in the Signal position. The output of the 195T Digital Multimeter should read 2.5 Vdc. If it does not, then:

   a) Use a digital voltmeter set to the dc volts scale, and check for 8 Vdc at the output of OPAMP6 on the amplifier board. If the output is not 8 Vdc, then set it by use of potentiometer P3 on the amplifier board (see Fig. 6).

   b) Use a digital voltmeter set to the dc volts scale, and check for 2 Vdc at the output of the Evans Electronics Lock-In Amplifier (Pin 10). If not set to 2 Vdc, then adjust through potentiometer P2 on the amplifier board (see Fig. 6). The output of the FSM should read 2.5 Vdc.

   c) Power down the FSM. Set the Reference/Signal switch (SW 4) to the Reference position. Remove the FSM calibration assembly. The FSM is now calibrated and ready for operation.

4. If this procedure fails to give a correct output, then the lenses may be contaminated or the electronics could be faulty.

## Precautions

1. Do not look directly into the path of the Melles-Griot HeNe laser. Direct eye contact with laser light can cause permanent eye damage.

2. Laser operating voltages may exceed 5000 Vdc, and care should be taken when working near the laser power lines.

3. Line voltages are present in the sensor and the electronics enclosure. Caution should be taken in these areas.

4. Care should be taken not to touch or to contaminate lens surfaces in the transmitter and detector. Clean lenses are a must for accurate operation.

5. Ensure that all cable connections are made before connecting the ac power cable.

6. Be sure that the laser power cable is connected at both ends before turning the laser power supply on. If not, dangerous arcing may occur.

7. The Gast Air Pump will automatically shut off when overheated; it will automatically reset and resume running when cooled to a safe operating temperature.

## FIELD TEST

To validate the predicted performance of the FSM, and to test the practicality of the present FSM design, the output of the instrument was tested against other similar optical measurements in an environmental chamber. A 600-$m^3$ chamber, located at Arvin/Calspan Corp., was filled with aerosols with a wide variety of size distributions and concentrations, and with a composition similar to what is expected in fogs and hazes of the maritime atmosphere. Simultaneous optical measurements in the chamber consisted of the estimated extinction coefficient at 10.6 $\mu$m measured with the FSM, and the photopic extinction coefficient ($\lambda = 0.55 \mu m$) and the extinction coefficient at 10.6 $\mu$m measured with Arvin/Calspan transmissometers.

The results of the visible-light and infrared transmissometers are compared in Fig. 9. The data points denoted by circles correspond to cases in which a fog was produced in the chamber by withdrawing air from the chamber during near-saturated conditions. The types of the fog ranged between fogs with few but very large droplets to fogs with many but smaller droplets, also some fogs consisted of a mixture of fog droplets and a large number of haze particles. The data points denoted by x are for cases in which the chamber only contained haze. Various concentration ratios of Salty-Dog pyrotechnic salt particles and nebulizer salt-solution droplets were used to obtain haze-particle size distributions that peaked between about 0.5 to 5 $\mu$m. Figure 9 demonstrates, as expected, that aerosol extinction in the visible spectrum is poorly correlated to aerosol extinction in the far infrared, and that no useful scaling relationship between those wavelength regions can be applied.

Figure 10 compares the infrared extinction coefficient at 10.6 $\mu$m to the output of the FSM (which measures a fraction of the visible light scattered in the forward direction). The data points have the same interpretation as in Fig. 9. A good correlation exists between the quantities in Fig. 10, and the predicted relationship given by Eq. (2) is essentially verified. The variance of the log of the data points in the direction of the ordinate is $6.02 \times 10^{-3}$, which is larger than predicted by theory. The difference can be explained by the variability of the infrared transmissometer measurements owing to systematic instrumentation error, and by the variability of measurements of both instruments owing to the inhomogeneity of the hazes and fogs in the chamber. When the variance caused by these effects is estimated and subtracted from the measured value, the remaining variance approaches the theoretical value that predicts an uncertainty of $\pm 10\%$ (confidence level of 90%) in the value of the estimated extinction coefficient at 10.6 $\mu$m for maritime-type aerosols.

Red phosphorous smoke was used in one of the chamber trials. Again a linear relationship was indicated between the FSM and the infrared transmissometer data; however, in this case the proportionality constant, A, used to scale the FSM reading, was different as expected.

The FSM was run nearly continuously in the chamber for the 1-week period of the trials, with actual exposure to dense aerosols lasting about 15 h. During this period there was no noticeable deterioration in its performance. A major reason for this success was due to the optics of the FSM remaining unaffected by the harsh environment in the chamber. This was accomplished by the FSM's special feature that flushes filtered air past the optics. The precision limit of the FSM measurements, demonstrated in these tests, is given by the observed variation of the instrument's background signal. This variation was about 10 mV at the output of the divider (see the Electronics section of this report), which corresponds to a fraction, F, of forward scattered light of $\mp 5 \times 10^{-6}$ and an infrared extinction coefficient at 10.6 $\mu$m of $\pm 7 \times 10^{-5}$ 1/m.

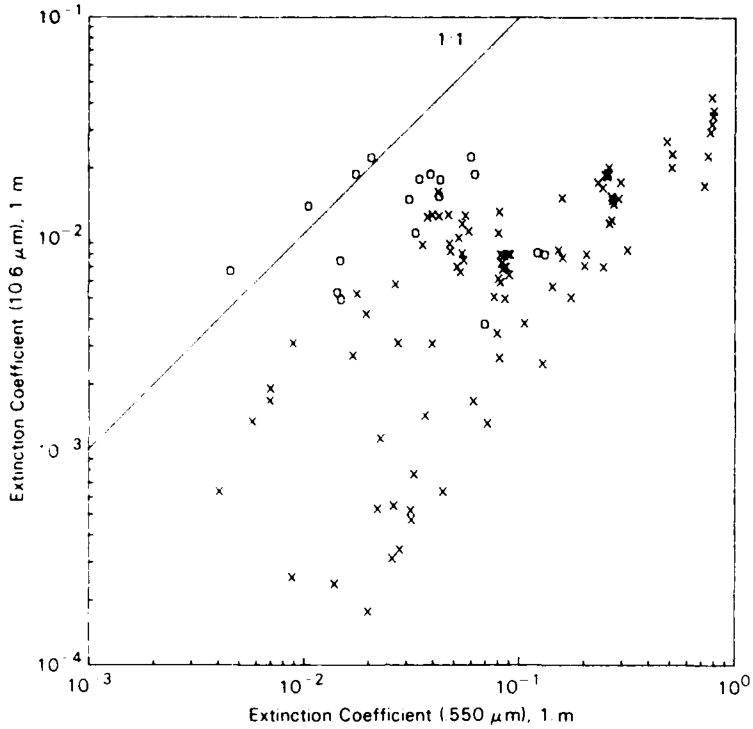



Fig. 9 — Correlation between extinction coefficients measured at 10.6 $\mu$m in the infrared and in the visible spectrum. Measurements in the Arvin/Calspan environmental chamber corresponding to fogs are given by circles (○), and those for hazes are given by crosses (×).

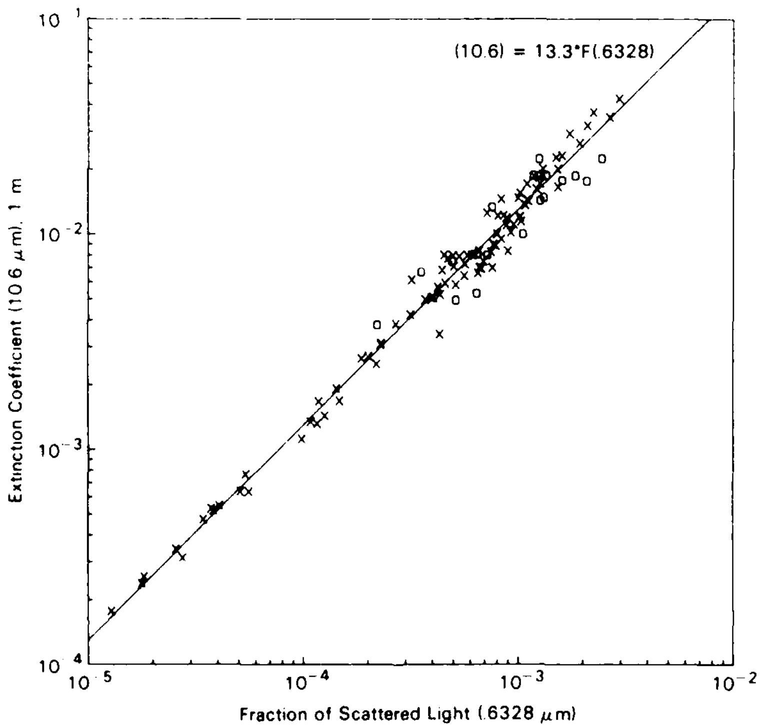



Fig. 10 — Correlation between the aerosol extinction coefficient at 10.6 $\mu$m in the infrared and the fraction of visible forward-scattered light measured with the FSM. Data points mean the same as in Fig. 9. The equation gives the geometrical least squares fit of a linear relationship to the data points.

Several improvements in the design of the FSM were suggested by its performance during this field trip; these are given in the next section.

## RECOMMENDATIONS

### Laser High-Voltage Supply

During the field test at the Calspan chamber, problems arose with the high-voltage supply. Relative humidities of 100% and above were present in the test chamber, which caused condensation to form on the inside of the high-voltage connector at the sensor end. This in turn short circuited the high-voltage supply thus disabling the FSM Meter until the connector could be dried out. It is recommended that a dc to dc upconverter be used in place of the ac-powered high-voltage supply. The upconvertor could be mounted near the laser on the H-beam thus eliminating the need for an exposed connector carrying high voltage. A dc to dc upconvertor would also reduce the high-frequency noise associated with the ac power supply.

### Detector Signal Amplifiers

During the initial testing of the FSM it was found that the detector circuit picked up a significant amount of 60 Hz noise and some distortion caused by the length of the signal cable (20 ft) and the low voltage level of the signal. This noise, when amplified by the detector signal amplifying circuit, causes background noise at the output, reducing the amount of discernible signal. It is therefore recommended that the signal amplifiers be moved as close as possible to the detector photodiode. The amplifiers could be mounted directly on the H-beam. This would significantly reduce the amount of 60 Hz noise. Further reduction would result by using a chopper motor that gives a chopping rate other than an even fraction of 60Hz.

### Sensor Outer Casing

During the initial testing of the FSM it was found that the cylindrical housings used for both the detector and the laser made it difficult to gain access to several areas where easy access is necessary. Such areas are the laser and detector components that must be focused. With the present design, the FSM must be partially dismantled to gain access to these controls. It is recommended that a shroud be used in place of the cylindrical housings, and that the laser, its optics, and the detector assembly be mounted directly onto the H-beam with no contact with the shroud or its supports (see Fig. 11). In this design one would only need to remove several screws to remove the shroud and would then have full access to all adjustments.

### Cables and Connectors

It was found during use of the FSM that using a single, sensor cable would be beneficial for several reasons. First, a single cable would reduce the number of exposed connectors, which in turn reduces the chance of downtime due to corroded connectors and cables. Second, setup time would be reduced by limiting the number of cables. Also, the chances of outside noise interference would also be reduced. A dc chopper motor could be used, so no ac line voltage need be present on the single cable.

### Future Development

The present FSM and the results of the initial field test in the environmental chamber indicate that this approach shows significant promise in resulting in a rugged, reliable, small-sized, and moderately priced device to estimate aerosol far-infrared extinction on Navy ships. Field testing of the FSM in a maritime environment should be undertaken, and a future version of the FSM should implement the preceding recommendations.

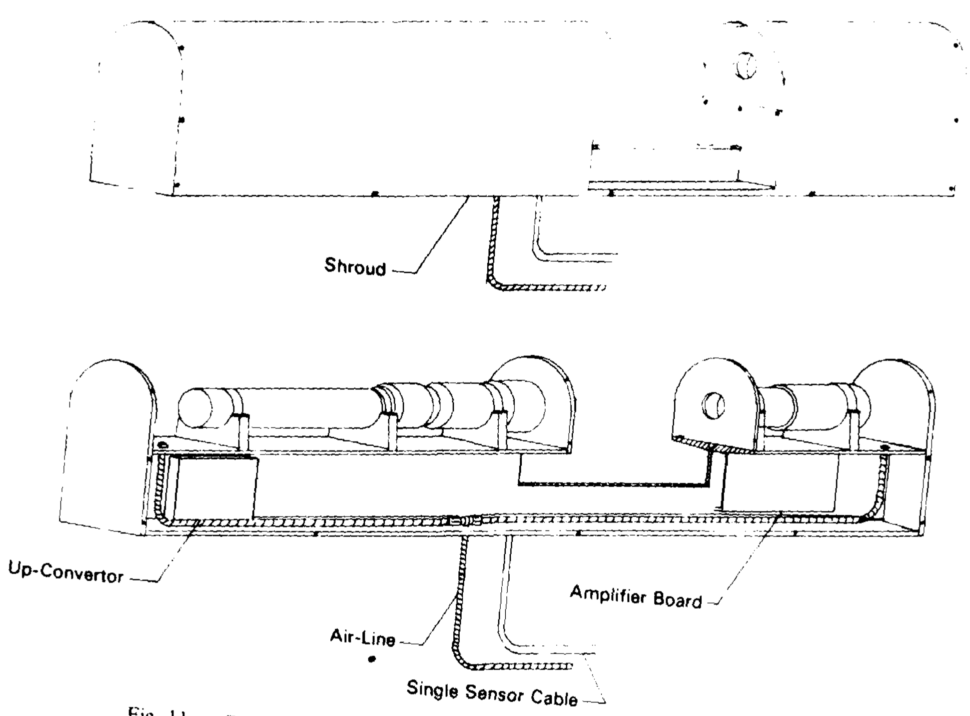



Fig. 11 — Concept of FSM after implementation of recommendations

## ACKNOWLEDGMENTS

We thank Ted Czuba for supporting the development of the Forward Scattering Meter as part of the SMOOS project (Project No. 63207N PDW106-8-058C-6X0514) of NAVAIR. We thank Gene Mack and Bruce Wattle of Calspan Corporation for their help in the testing and calibration of the FSM and for the use of their atmospheric test chamber. We also thank George D. Robertson and Kenneth L. Nicodemus of the Naval Research Laboratory's machine shop for their help in constructing the FSM.

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2. H. Gerber, "Liquid Water Content of Fogs and Hazes from Visible Light Scattering," J. Climate and Appl. Meteoro. **23**, 1247-1252 (1984).

3. H.C. Van De Hulst, *Light Scattering by Small Particles* (Academic Press, New York, 1957).

4. H. Gerber, "Infrared Aerosol Extinction from Visible and Near-infrared Light Scattering," Appl. Opt. **24** 4155-4166 (1985).

5. Keithley Model 195T Instruction Manual, Document No. 195A-901-01A, Mar. 1984.

## APPENDIX A—SPECIFICATIONS

1. Display
   Six .5-in. LED digits with decimal point, exponent, and polarity. Function and IEEE-488 bus status are also displayed.

2. Warm-up
   1 hour to rated accuracy

3. Operating Environment
   -20° to 50° C 0 to 100% relative humidity

4. Power
   110 Vac/60 Hz    5 A maximum on air compressor circuit
                    3 A maximum on electronics circuit

5. Connectors
   Electrical
     Bendix weatherproof connectors olive drab anodized
   Air line
     Red and blue anodized aluminum

6. Dimensions
   *Sensor*
     55L × 5W × 10H (in.)  Weight 30 lb
   Electronics enclosure
     24L × 20D × 10H (in.)  Weight 50 lb

7. Cables
   Detector/Reference and Reference/Chopper
     Shielded individual pairs 20 ft long
   Laser Power
     RG/213 Coaxial    20 ft long
   Air Line
     #6 Braided Stainless Steel Tubing  20 ft long
   AC Power Cable
     3 Conductor 18 Gage   30 ft long
   GPIB Cable
     24 Conductor 24 Gage   30 ft long

8. Weatherproofing
   Enclosure
     Solid Seam-Welded Stainless Steel
     Gasketed Cover
     White Polyurethane Based Paint
   Sensor
     Gasketed End Caps
     Gasketed Laser Tube
     Baffled Laser Opening
     Cleaning Air Flushing System
     White Polyurethane Based Paint

9. Measurement Capability

Capable of measuring forward scattered light between one part per one hundred and one part per one hundred thousand of the direct laser intensity, and of giving the infrared aerosol extinction coefficient, $\sigma e$, at about the 11-$\mu$m wavelength by use of the scaling relationship:

$$\sigma e = AF$$

where $A$ is a system constant and $F$ is the fraction of scattered light.

## APPENDIX B—PARTS LIST

| Item | Part# | Desc. | Quant. | Manufacturer |
|---|---|---|---|---|
| 1. | TBF-22-11PS | Thru-bulkhead conn. | 1 | Bendix corp. |
| 2. | TBF-14S-6PS | Thru-bulkhead conn. | 2 | Bendix corp. |
| 3. | 10-40450-14 | Plain flat gasket | 9 | Bendix corp. |
| 4. | 10-40450-22 | Plain flat gasket | 6 | Bendix corp. |
| 5. | 10-40450-10SL | Plain flat gasket | 2 | Bendix corp. |
| 6. | 10-40450-28 | Plain flat gasket | 2 | Bendix corp. |
| 7. | 10-72814-6P | 90° plug | 2 | Bendix corp. |
| 8. | 10-72822-11P | 90° plug | 1 | Bendix corp. |
| 9. | MS3106R14S-6S | Straight plug | 2 | Bendix corp. |
| 10. | MS3106R22-11S | Straight plug | 1 | Bendix corp. |
| 11. | 10-72614-14S-6S | Straight plug | 1 | Bendix corp. |
| 12. | 10-72614-14S-6P | Straight plug | 1 | Bendix corp |
| 13. | 10-72622-22-11S | Straight plug | 2 | Bendix corp. |
| 14. | 10-72611-10SL-3S | Straight plug | 1 | Bendix corp. |
| 15. | 10-72628-28-12S | Straight plug | 1 | Bendix corp. |
| 16. | MS3102R-14S-6P | Wall mount recept. | 1 | Bendix corp. |
| 17. | MS3102R-14S-6S | Wall mount recept. | 2 | Bendix corp. |
| 18. | MS3102R-22-11P | Wall mount recept. | 1 | Bendix corp. |
| 19. | MS3102R-10SL-3P | Wall mount recept. | 1 | Bendix corp. |
| 19. | MS3102R-28-12P | Wall mount recept. | 1 | Bendix corp. |
| 20. | 5 × 5 × .313 in. | Alum. H-beam | 5' | Metal Goods Inc. |
| 21 | 1000203 | 4 × 4 in. Air filter | 3 | Aluminum Filter |
| 22. | Model 4110 | Phase sensitive detector | 1 | Evans Elec. Inc. |
| 23. | Model 195T | Digital multimeter | 1 | Kiethly Inst. |
| 24. | 09-LCM-001 | Laser collimator | 1 | Melles-Griot |
| 25. | 09-LSF-001 | Spatial filter | 1 | Melles-Griot |
| 26. | 05-LPL-340 | Laser power supply | 1 | Melles-Griot |
| 27. | 05-LHP-1121 | Cylyndrical laser head | 1 | Melles-Griot |
| 28. | C30809 | Silicon photodiode | 1 | RCA Semiconduct. |
| 29. | DOA-P101-AA | Air compressor | 1 | Gast Pumps |
| 30. | AF887 | Pressure regulator | 1 | Gast Pumps |

| Item | Part# | Desc. | Quant. | Manufacturer |
|---|---|---|---|---|
| 31. | K294 | Repair kit | 1 | Gast Pumps |
| 32. | B81339 | 300 Rpm synchronous motor | 1 | Teledyne Acoust. |
| 33. | 09-LSP-27 | Pinhole assembly | 1 | Melles-Griot |
| 34. | 09-LAR-001 | Adapter ring | 1 | Melles-Griot |
| 35. | 09-LSR-007 | Focusing optics | 1 | Melles-Griot |
| 36. | .1 m 400 Vdc | Motor capacitor | 1 | General Instr. |
| 37. | 6044 | 1/4-6 Pipe-flare conn. | 3 | Speed Unlimited |
| 38. | 1016 | #6 Ninety degree conn. | 4 | Speed Unlimited |
| 39. | 1002 | Straight female conn. | 6 | Speed Unlimited |
| 40. | 6102 | #6 T connector | 1 | Speed Unlimited |
| 41. | 6035 | #6 Flare union | 2 | Speed Unlimited |
| 42. | #6 | #6 Steel braid. tub. | 20' | Speed Unlimited |
| 43. | #6 | #6 Steel braid. tub. | 6' | Speed Unlimited |
| 44. | LL-25-25-632.8 | Laser Lenses | 3 | Optics for Res. |
| 45. | 45EB03 | 45 Vdc power supply | 1 | Acopian Corp. |
| 46. | | Collimator lens adaptor | 1 | NRL Machine Shop |
| 47. | | Detector tube | 1 | NRL Machine Shop |
| 48. | | Front detector housing | 1 | NRL Machine Shop |
| 49. | | Rear detector housing | 1 | NRL Machine Shop |
| 50. | | Front collar mount | 1 | NRL Machine Shop |
| 51. | | Rear collar mount | 1 | NRL Machine Shop |
| 52. | | Droplet guard | 1 | NRL Machine Shop |
| 53. | | Light trap | 1 | NRL Machine Shop |
| 54. | | Lens stop | 1 | NRL Machine Shop |
| 55. | | 5/32-1 spacer | 3 | NRL Machine Shop |
| 56. | | 1-in. lockring | 2 | NRL Machine Shop |
| 57. | | 1-5/8-in. lockring | 1 | NRL Machine Shop |
| 58. | | 1-in. baffle | 2 | NRL Machine Shop |
| 59. | | 1-5/16-in. baffle | 1 | NRL Machine Shop |
| 60. | | 5/8-1-in. spacer | 1 | NRL Machine Shop |
| 61. | | Field stop | 1 | NRL Machine Shop |
| 62. | | Detector cradle mount | 2 | NRL Machine Shop |
| 63. | | Detector tube end cap | 1 | NRL Machine Shop |
| 64. | TIL78 | Phototransistor | 2 | Diplomat Elect. |
| 65. | | Detector tube gasket | 1 | NRL Machine Shop |
| 66. | | Laser tube hinge | 1 | NRL Machine Shop |

| Item | Part# | Desc. | Quant. | Manufacturer |
| --- | --- | --- | --- | --- |
| 67. | | Laser tube housing | 1 | NRL Machine Shop |
| 68. | | Laser end cap | 1 | NRL Machine Shop |
| 69. | | Laser collar mounts | 2 | NRL Machine Shop |
| 70. | | Collimator collar mount | 1 | NRL Machine Shop |
| 71. | | Rear baffle | 1 | NRL Machine Shop |
| 72. | | Baffle spacer | 1 | NRL Machine Shop |
| 73. | | Front baffle | 1 | NRL Machine Shop |
| 74. | | Laser beam chopper | 1 | NRL Machine Shop |
| 75. | | Chopper motor mount | 1 | NRL Machine Shop |
| 76. | | Rear cap gasket | 1 | NRL Machine Shop |
| 77. | | Sensor base | 1 | NRL Machine Shop |
| 78. | | Sensor mount | 1 | NRL Machine Shop |
| 79. | | Sensor vibration mount | 1 | NRL Machine Shop |
| 80. | | Sensor mount base | 1 | NRL Machine Shop |
| 81. | | Laser tube cradle mount | 2 | NRL Machine Shop |
| 82. | | ±15 V power supply | 2 | Acopian Corp. |
| 83. | | Laser lens extender | 1 | NRL Machine Shop |
| 84. | | Laser lens lock ring | 1 | NRL Machine Shop |
| 85. | | Filter cover | 1 | NRL Machine Shop |
| 86. | | Calibrator | 1 | NRL Machine Shop |
| 87. | | Beam splitter mount | 1 | NRL Machine Shop |
| 88. | | Chopper mount | 1 | NRL Machine Shop |
| 89. | | Chopper bearing | 1 | |
| 90. | | Chopper | 1 | NRL Machine Shop |
| 91. | | Chopper reflector | 1 | NRL Machine Shop |
| 92. | | Beam cube splitter | 2 | Melles-Griot |
| 93. | | 3/8-in. Rubber Tubing | 1' | |
| 94. | LL-25-25-632.8 | Detector lenses | 3 | Optics for Res. |
| 95. | 001-LQS-004 | Collimator lens | 1 | Melles-Griot |

## APPENDIX C—DRAWINGS

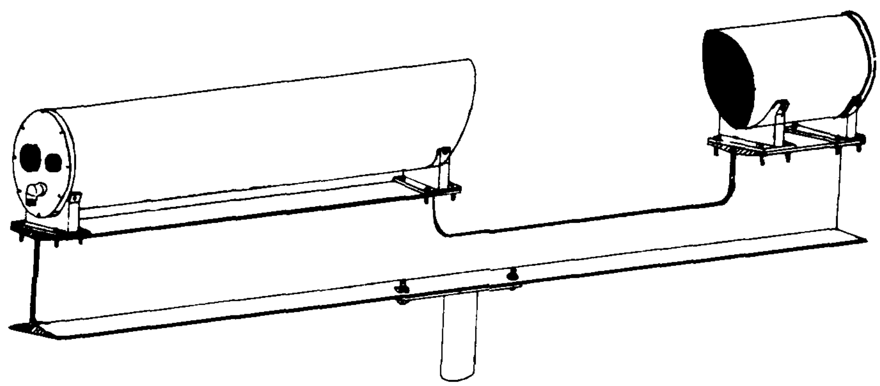
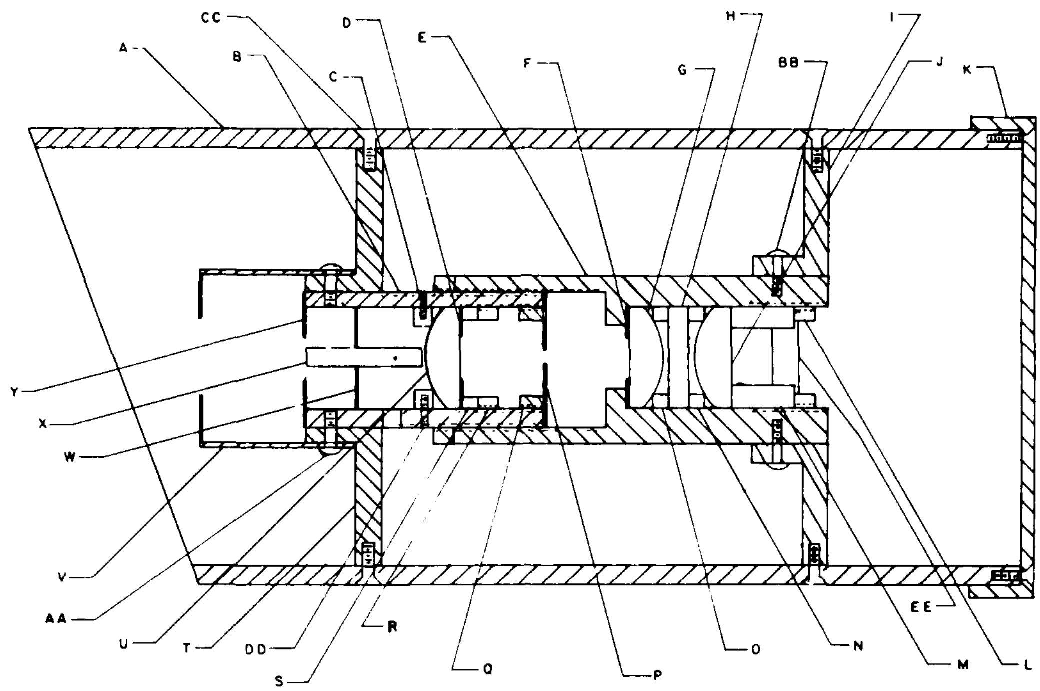


Fig. C1 — Forward Scattering Meter (FSM)

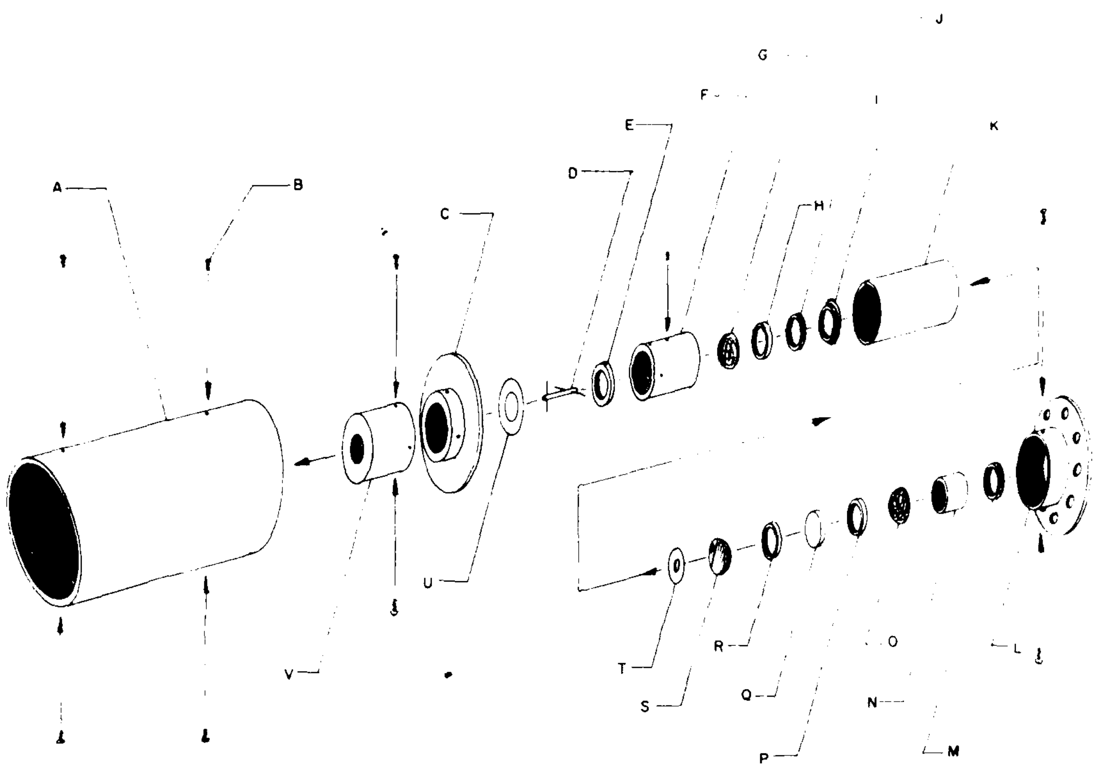



(a)

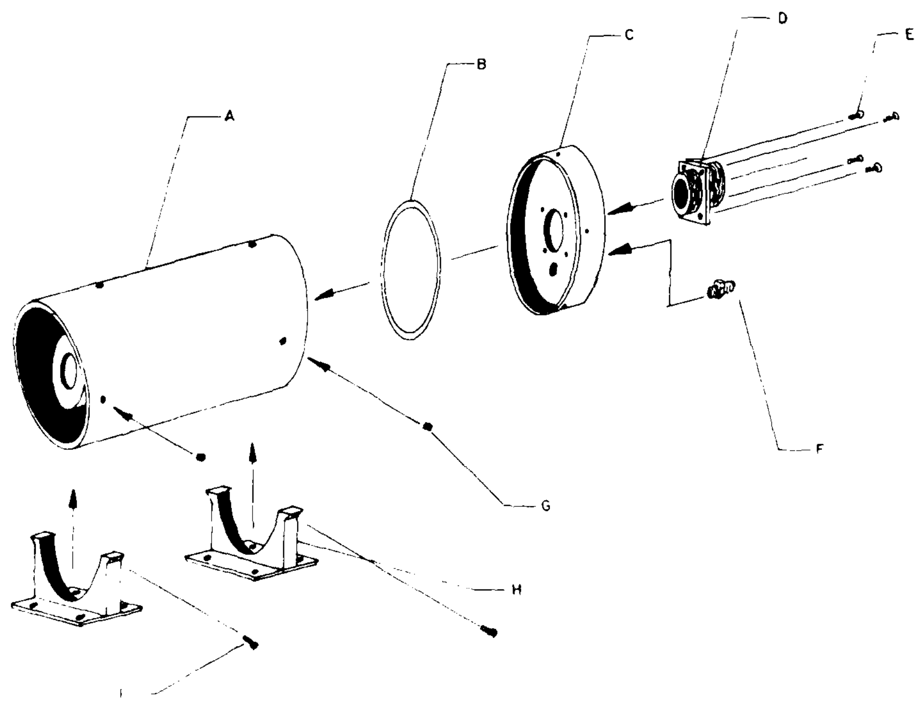
A. Detector tube 4.5" O.D. 4.125" I.D. aluminum tubing
B. Detector front housing aluminum bar stock
C. Detector lens stop aluminum bar stock
D. Detector front lens baffle aluminum shim stock
E. Detector rear housing aluminum bar stock
F. Detector rear lens baffle aluminum shim stock
G. Detector lens B
H. Detector filter
I. Detector rear collar mount aluminum bar stock
J. Detector lens C
K. Detector tube cap aluminum bar stock
L. Detector lockring aluminum bar stock
M. Detector photodiode mount aluminum bar stock
N. Detector lens spacer aluminum bar stock
O. Detector lens spacer aluminum bar stock
P. Detector threaded baffle aluminum bar stock
Q. Detector threaded baffle aluminum bar stock
R. Detector lockring aluminum bar stock
S. Detector lens spacer aluminum bar stock
T. Detector front collar mount aluminum bar stock
U. Detector lens A
V. Detector droplet cover aluminum bar stock
W. Detector light trap mount piano wire
X. Detector light trap 3/16" stainless steel thinwall tubing
Y. Detector front baffle aluminum shim stock
AA. 4-40 round head screw
BB. 4-40 round head screw
CC. 4-40 flat head screw
DD. 4-40 set screw

(b)

Fig. C2 — FSM detector; unless otherwise specified tolerances are ±.002:
(a) side section view and (b) parts list




(a)




(b)

Fig. C3 — ESM detector: (a) exploded view and (b) assembly

1. Machine from 4 1/2" O.D. aluminum tubing with an I.D. of 4 1/8".
2. Black anodize and paint outer area with white polyurethane paint.

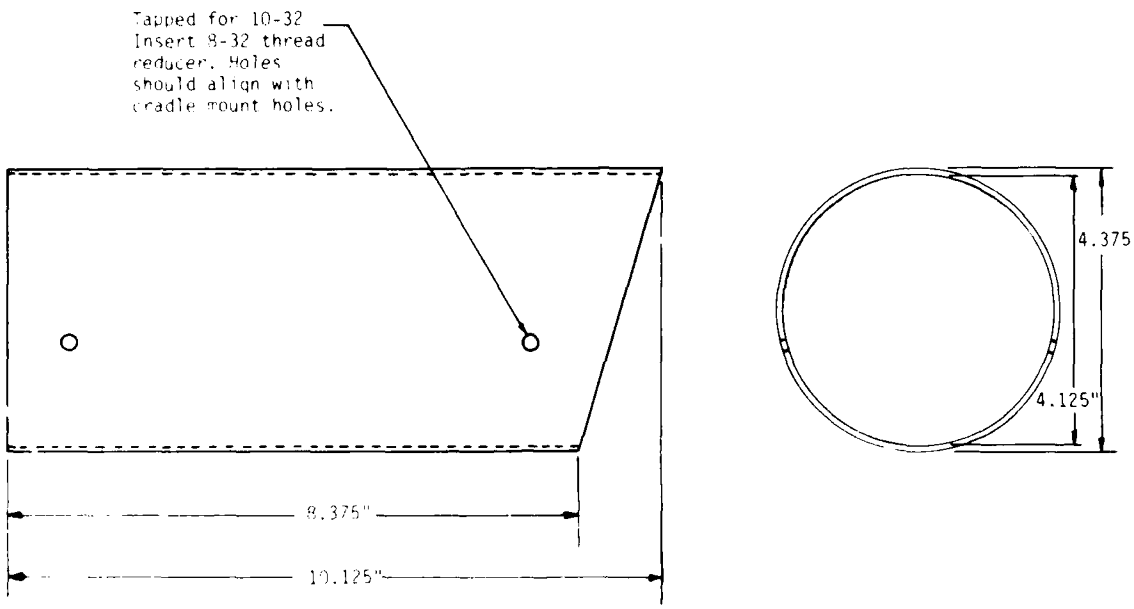
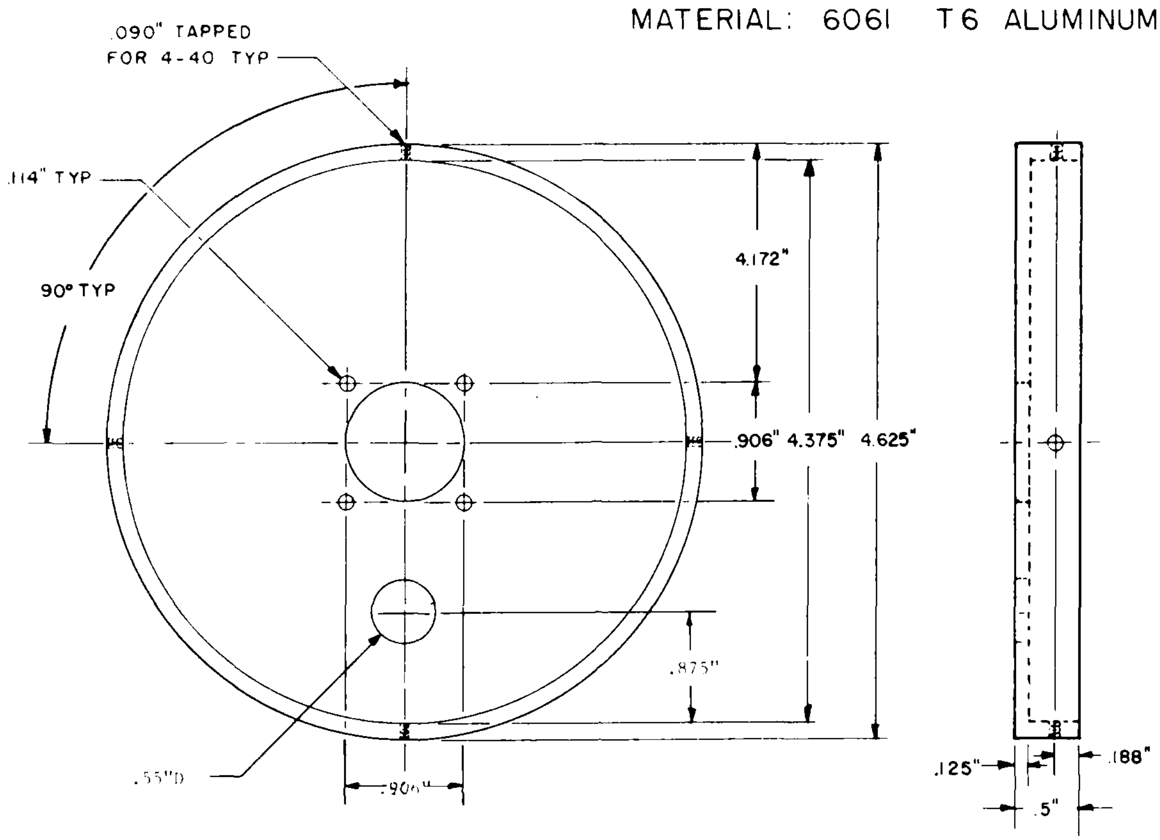



Fig. C4 — FSM detector tube; unless otherwise specified, tolerances are ± .02

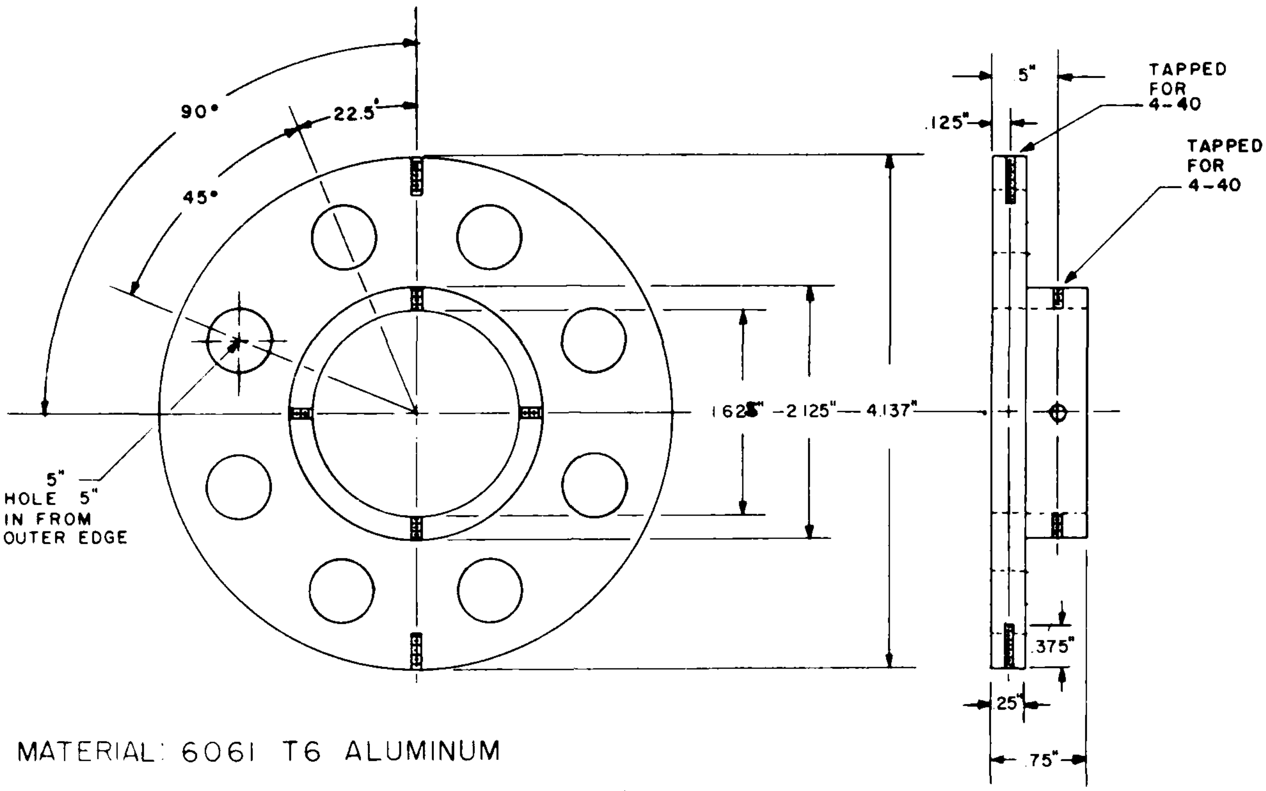



(a)

1. Machine 5.0" aluminum bar stock to specified dimensions and tolerances.
2. Inner diameter of tube cap lip must be sliding fit with outer diameter of detector tube.
3. All dimensions specified are after finish.
4. Piece should be free of all burrs and sharp edges.
5. Piece should have fine finish and overall good appearance.
6. Black anodize after machining.

(b)

Fig. C5 — FSM detector tube cap, unless otherwise specified, tolerances are ± .002
(a) front and side views and (b) notes

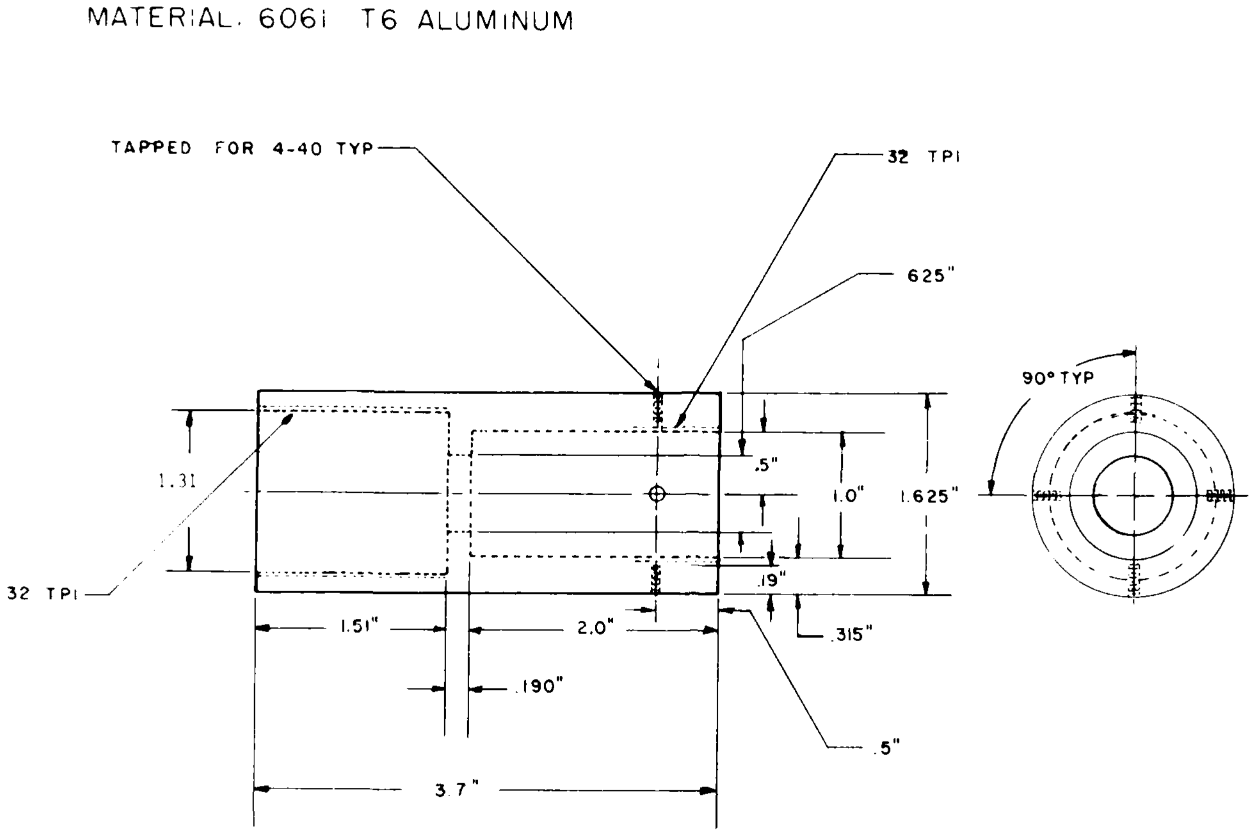



(a)

1. Machine to specified dimensions and tolerances.
2. Piece should be free from all burrs and sharp edges.
3. All dimensions are after finish.
4. Inner diameter of piece should be tight sliding fit with outer diameter of detector rear housing.
5. Outer diameter of piece should be sliding fit with inner diameter of detector tube.
6. Piece should have fine finish and overall good appearance.
7. Black anodize after machining.

(b)

Fig. C6 — FSM detector; unless otherwise specified, tolerances are ± .002:
(a) collar mount and (b) notes




(a)

1. Machine to specified dimensions and tolerances from 1.75" aluminum bar stock.
2. Tolerance for the 1.0" inner diameter is +.002 -.000.
3. Outer diameter of piece must be sliding fit with inner diameter of detector collar mount.
4. Piece must be free from burrs and sharp edges.
5. All dimensions are after finish.
6. Black anodize after machining.
7. Piece should have fine finish and overall good appearance.

(b)

Fig. C7 — FSM detector rear housing; unless otherwise specified, tolerances are ± .002
(a) side and front views and (b) notes

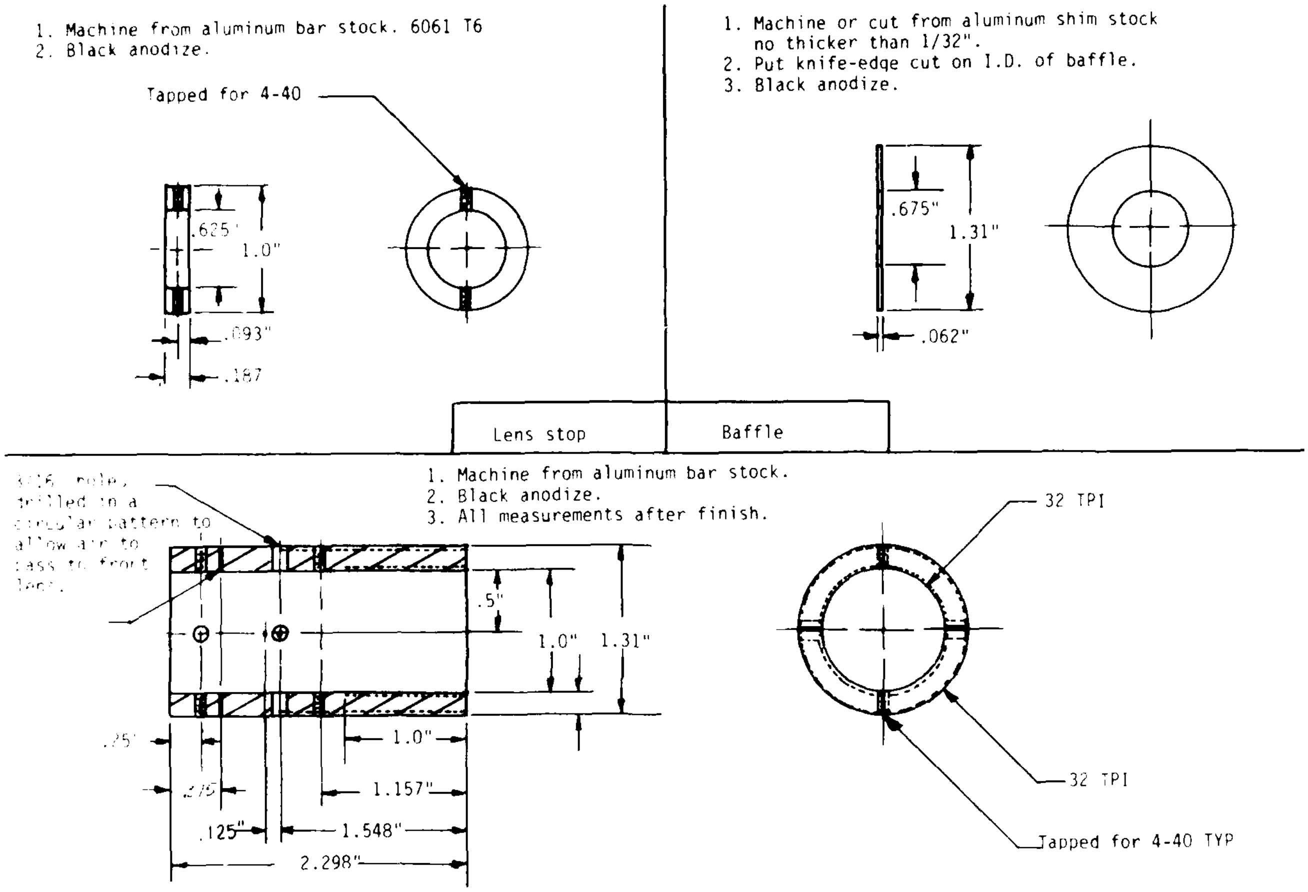



Fig. C8 — FSM detector front housing; unless otherwise specified, tolerances are ± .002

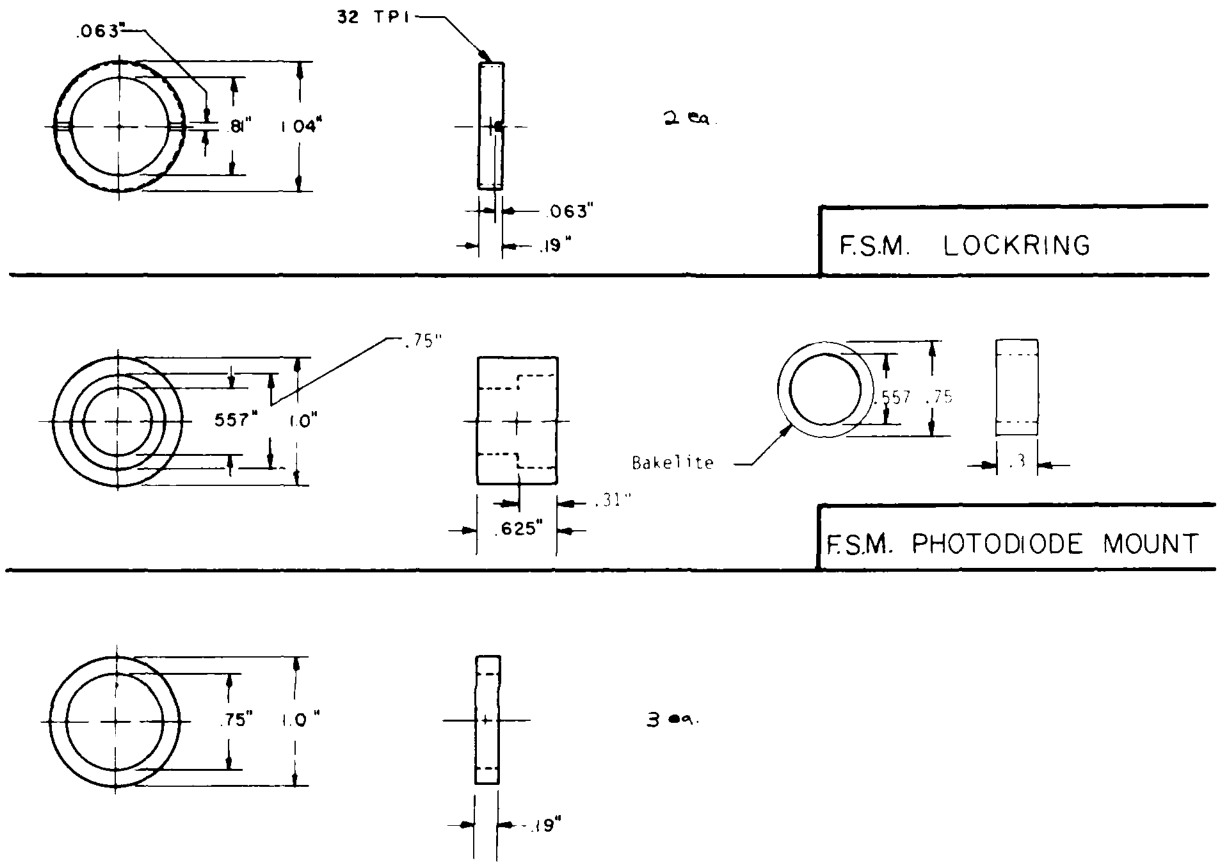



Fig. C9 — FSM detector lens spacer, unless otherwise specified, tolerances are ± 002

1. Machine from aluminum bar stock (6061 T6 alloy or equivalent).
2. Should be good sliding fit with front detector collar mount.
3. Front opening should be cut to sharp edge.
4. Black anodize after finish.
5. All dimensions are after finish.

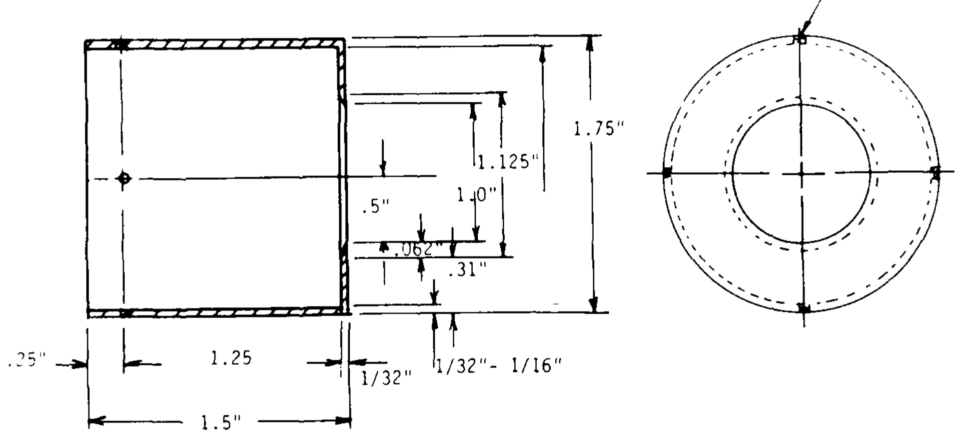



Fig. C10 — Detector droplet guard; unless otherwise specified, tolerances are ±.002

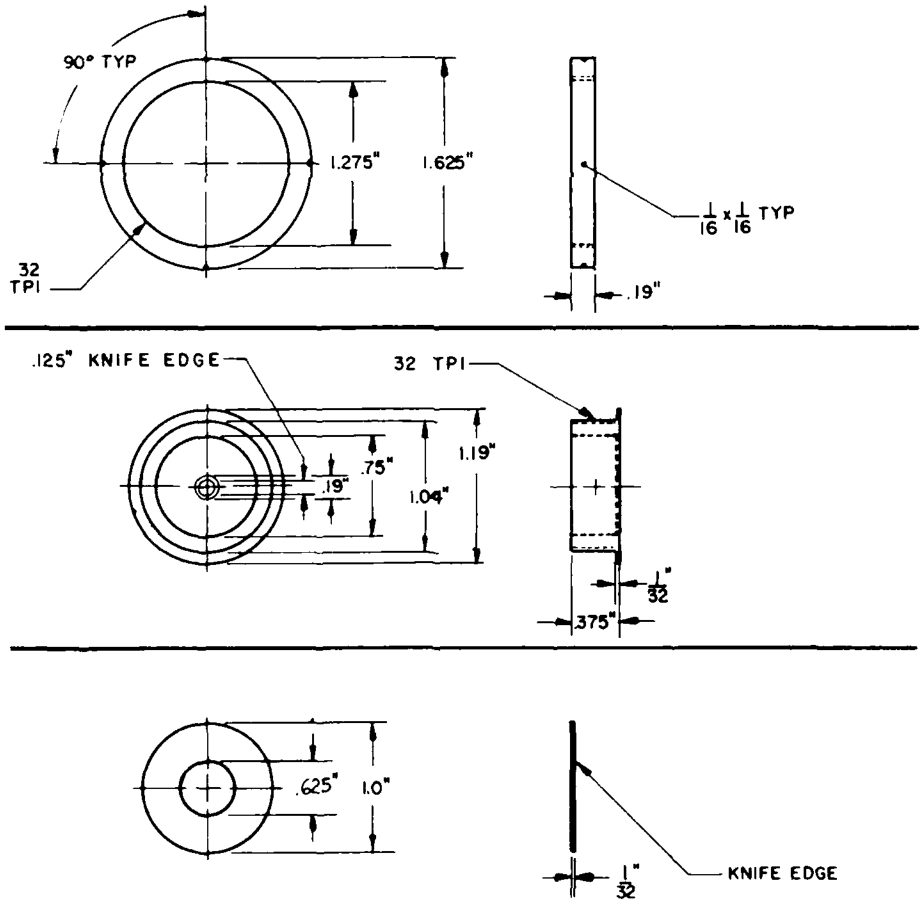



Fig C11 — FSM detector; unless otherwise specified, tolerances are ±.002: (a) front housing outer lockring and (b) threaded baffle and (c) front lens baffle

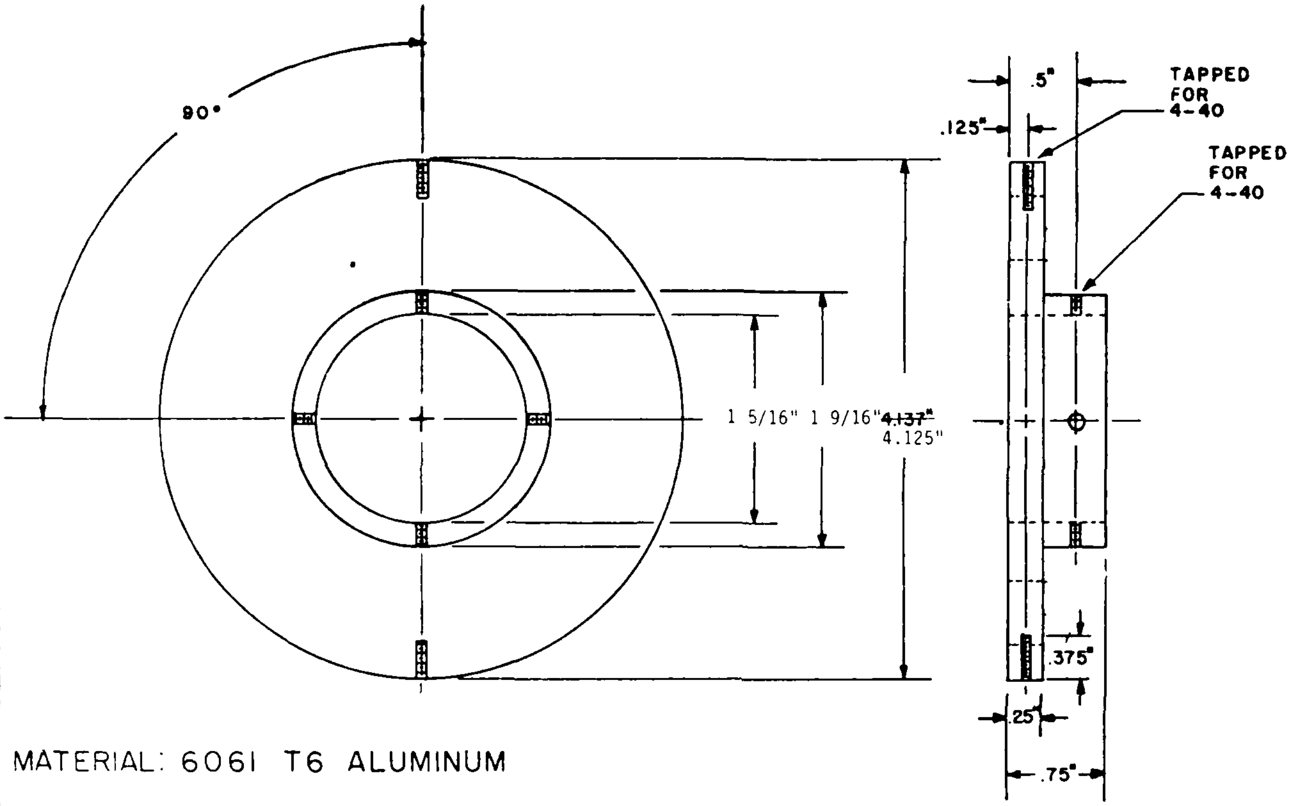



Fig. C12 — Detector front collar mount; unless otherwise specified, tolerances are ± .002

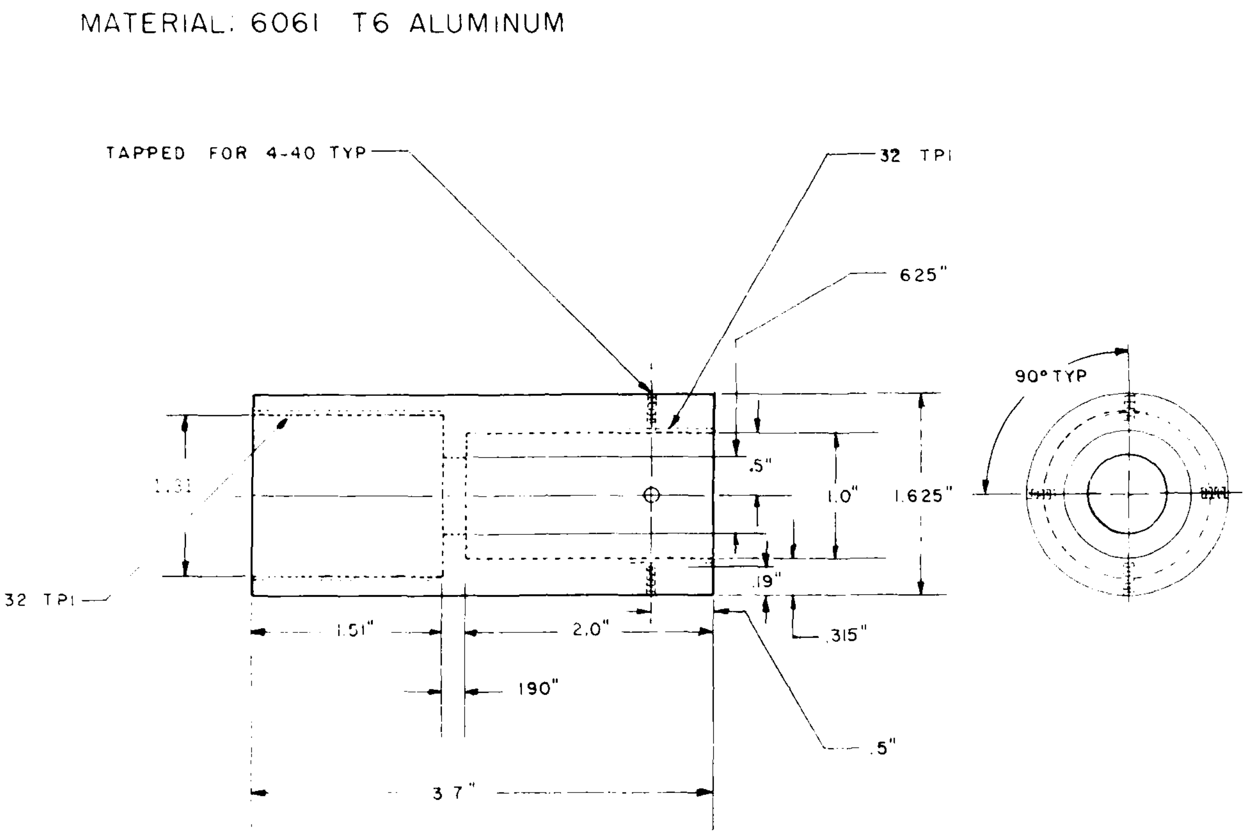
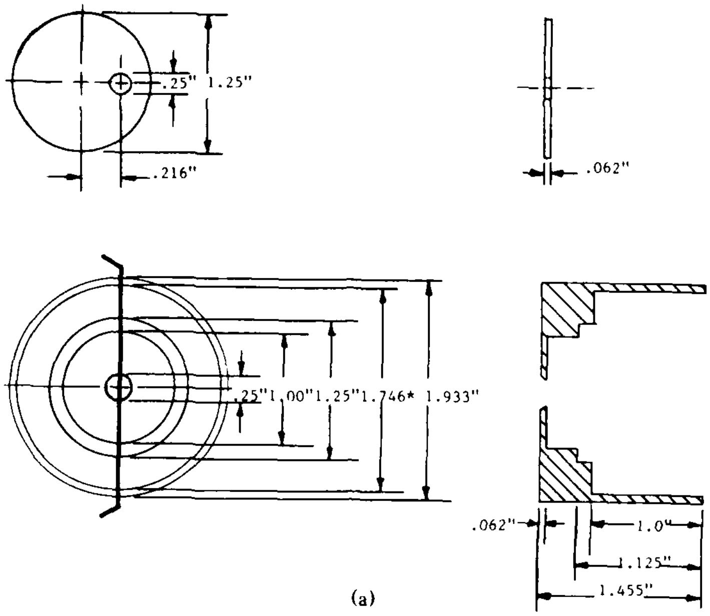



Fig. C13 — Detector rear housing, side and front views; unless otherwise specified, tolerances are ± 002

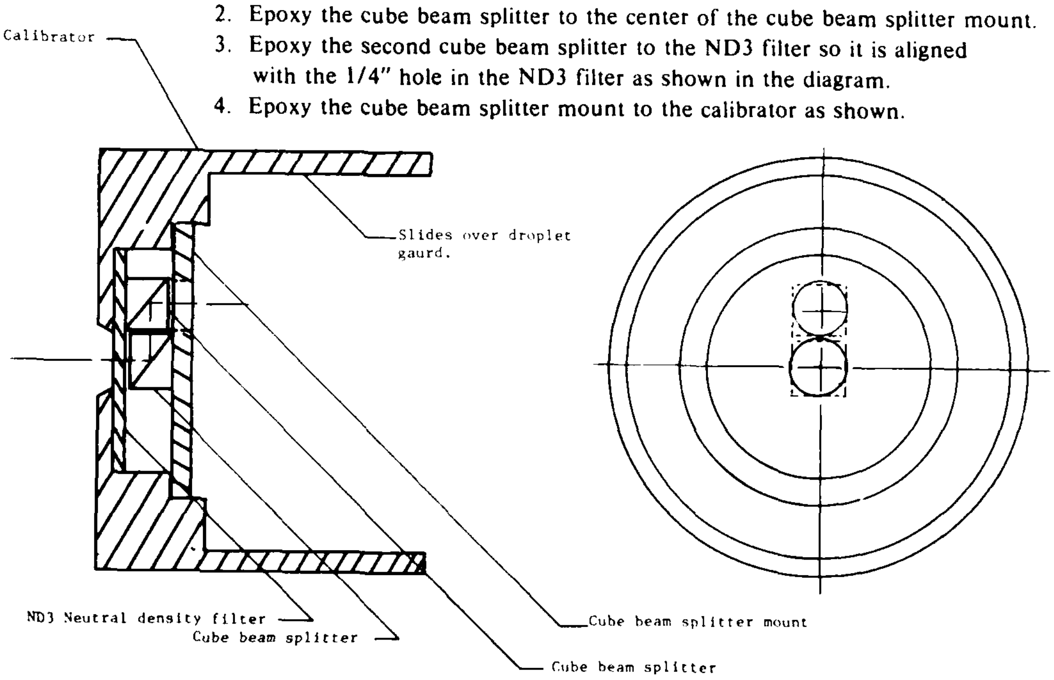
*Must be good sliding fit with outer diameter of droplet guard.

1. Machine from 2" aluminum bar stock.
2. Piece must be free from all burrs and sharp edges.
3. All dimensions are after finish.
4. Black anodize.
5. Assemble as described on preceding figure.




(a)

1. Epoxy the ND3 filter in place.
2. Epoxy the cube beam splitter to the center of the cube beam splitter mount.
3. Epoxy the second cube beam splitter to the ND3 filter so it is aligned with the 1/4" hole in the ND3 filter as shown in the diagram.
4. Epoxy the cube beam splitter mount to the calibrator as shown.




(b)

Fig. C14 — Calibration assembly; unless otherwise specified, tolerances are ± .002: (a) front and side views and (b) assembly view

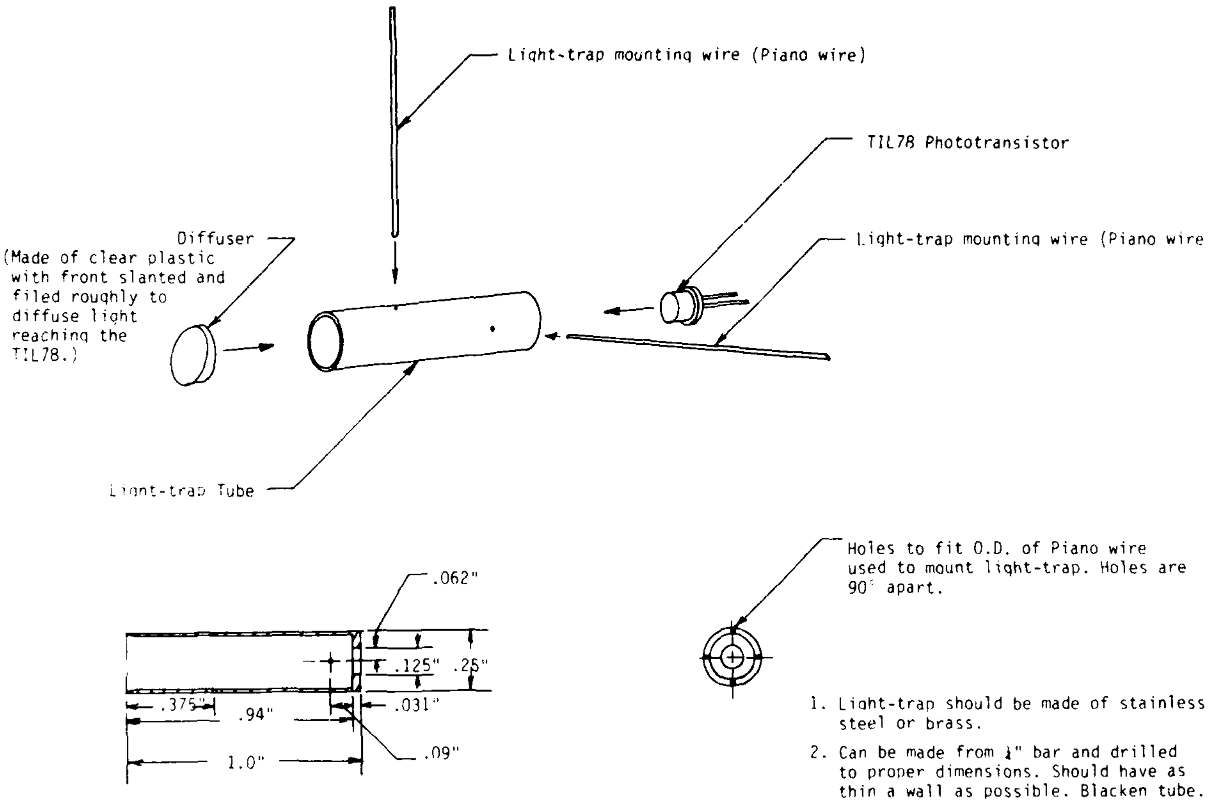
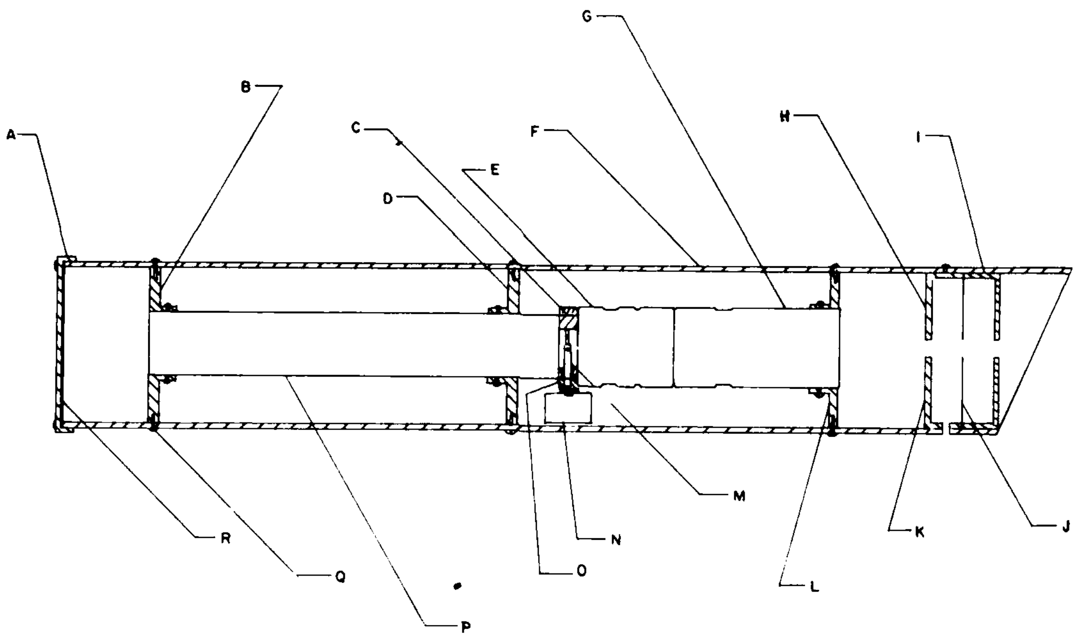



Fig. C15 — Light-trap dimensions and assembly; unless otherwise specified, tolerances are ± 002

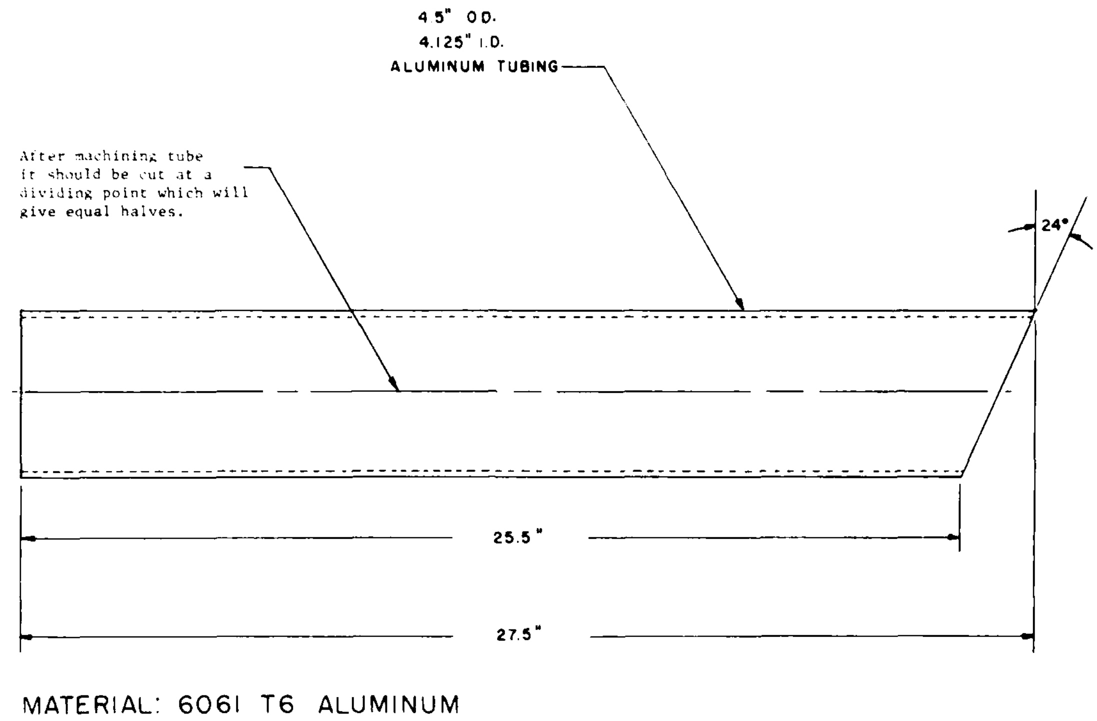



(a)

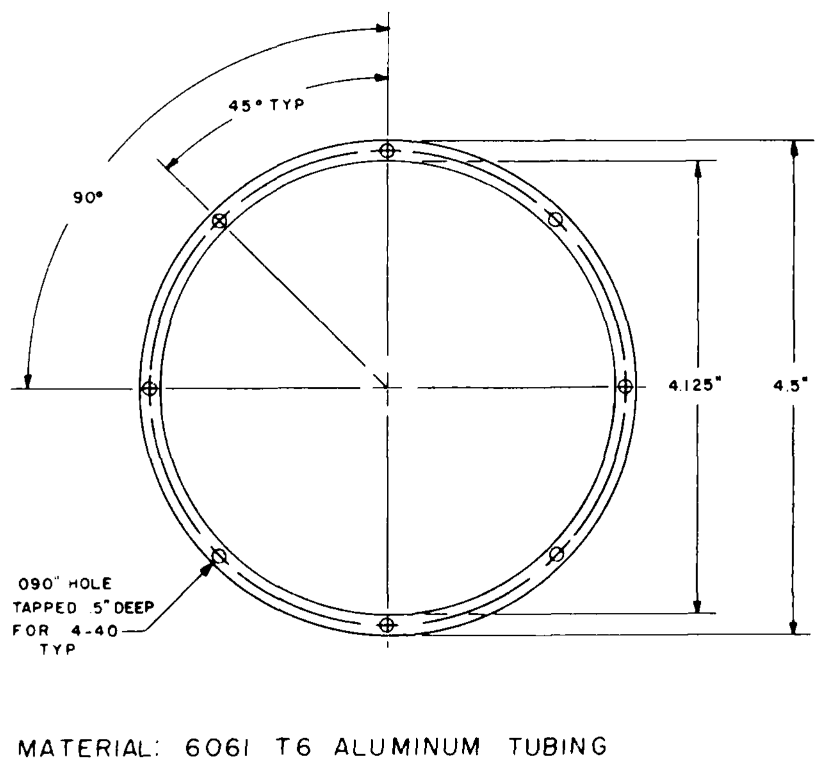
A. Laser tube end cap 6061 T6 aluminum bar stock
B. Rear laser collar mount 6061 T6 aluminum bar stock
C. Modified Melles-Griot 09LAR001 adaptor ring
D. Front laser collar mount 6061 T6 aluminum bar stock
E. Melles-Griot spatial filter
F. Laser tube 6061 T6 aluminum tubing 4.5" O.D. 4.125" I.D.
G. Melles-Griot collimator
H. Laser cylinder baffle A 6061 T6 aluminum bar stock
I. Laser cylinder baffle B 6061 T6 aluminum bar stock
J. Laser cylinder spacer 1/16" aluminum sheet stock
K. Laser cylinder baffle A 6061 T6 aluminum bar stock
L. Collimator collar mount 6061 T6 aluminum bar stock
M. Chopper blade extension shaft 6061 T6 aluminum bar stock
N. 300 RPM chopper motor
O. Chopper motor mount 1/16"-3/32" aluminum sheet stock
P. Melles-Griot HeNe laser
Q. Stainless steel 1/2" 4-40 screw
R. Laser tube end cap gasket 1/16" neoprene rubber

(b)

Fig. C16 — FSM laser assembly; unless otherwise specified, tolerances are ±.002: (a) sectional side view and (b) parts list




(a)



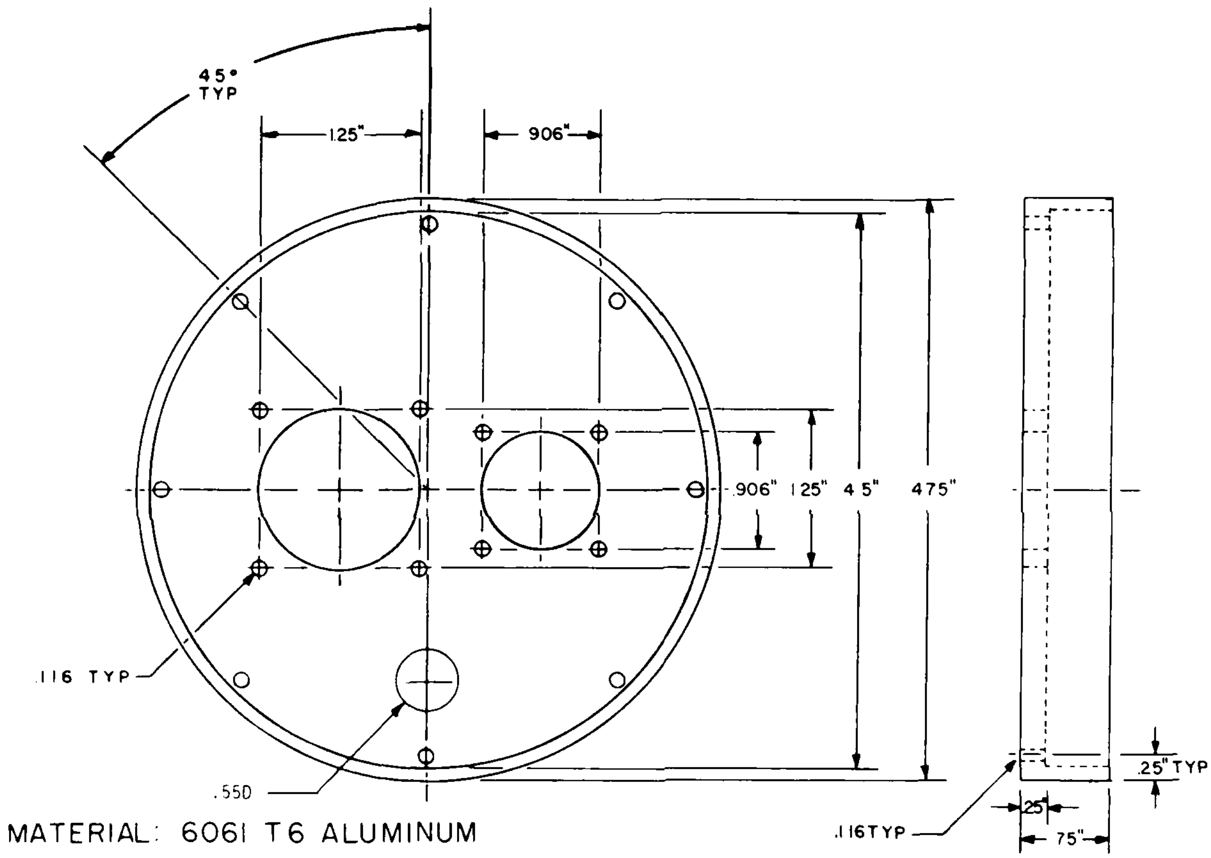

(b)

Fig. C17 — FSM laser tube; unless otherwise specified, tolerances are ± .002:
(a) side view, (b) rear view, and (c) notes

1. Cut and machine to specified dimensions and tolerances from 4-1/2" O.D. 4-1/8" I.D. aluminum tubing
2. Piece should be free from burrs and sharp edges.
3. Piece should have fine finish and overall good appearance.
4. All dimensions are after finish.
5. Black anodize after cutting and machining.
6. An aluminum hinge should be used to attach the two halves after being cut.
7. The hinge should be black anodized.

(c)

Fig. C17 (Continued) — FSM laser tube; unless otherwise specified, tolerances are ± .002
(a) side view, (b) rear view, and (c) notes

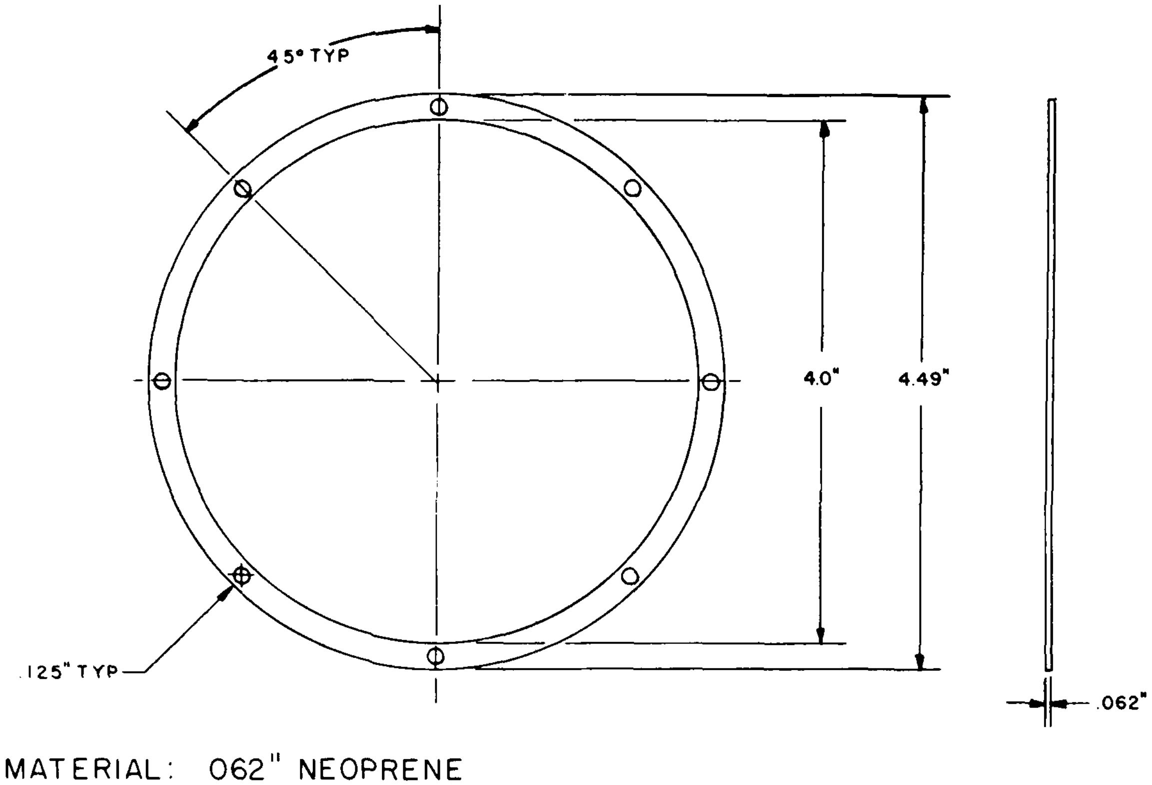



(a)

1. Machine to specified dimensions and tolerances from 5" aluminum bar stock.
2. Inner diameter of laser tube end cap should be sliding fit with outer diameter of detector tube.
3. Piece should be free from burrs and sharp edges.
4. All dimensions are after finish.
5. Black anodize after machining.

(b)

Fig. C18 — FSM laser tube, unless otherwise specified, tolerances are ± .002
(a) end cap and (b) notes




(a)

1. Cut to dimensions and tolerances specified from 1/16" neoprene rubber sheet.
2. Outer diameter of gasket must fit in laser tube cap.
3. Glue to inside of laser tube cap.

(b)

Fig. C19 — FSM laser tube; unless otherwise specified, tolerances are ±.002
(a) cap gasket and (b) notes

1. Machine from 6061 T6 aluminum bar stock.
2. Two laser collar mounts are needed.
3. Black anodize.

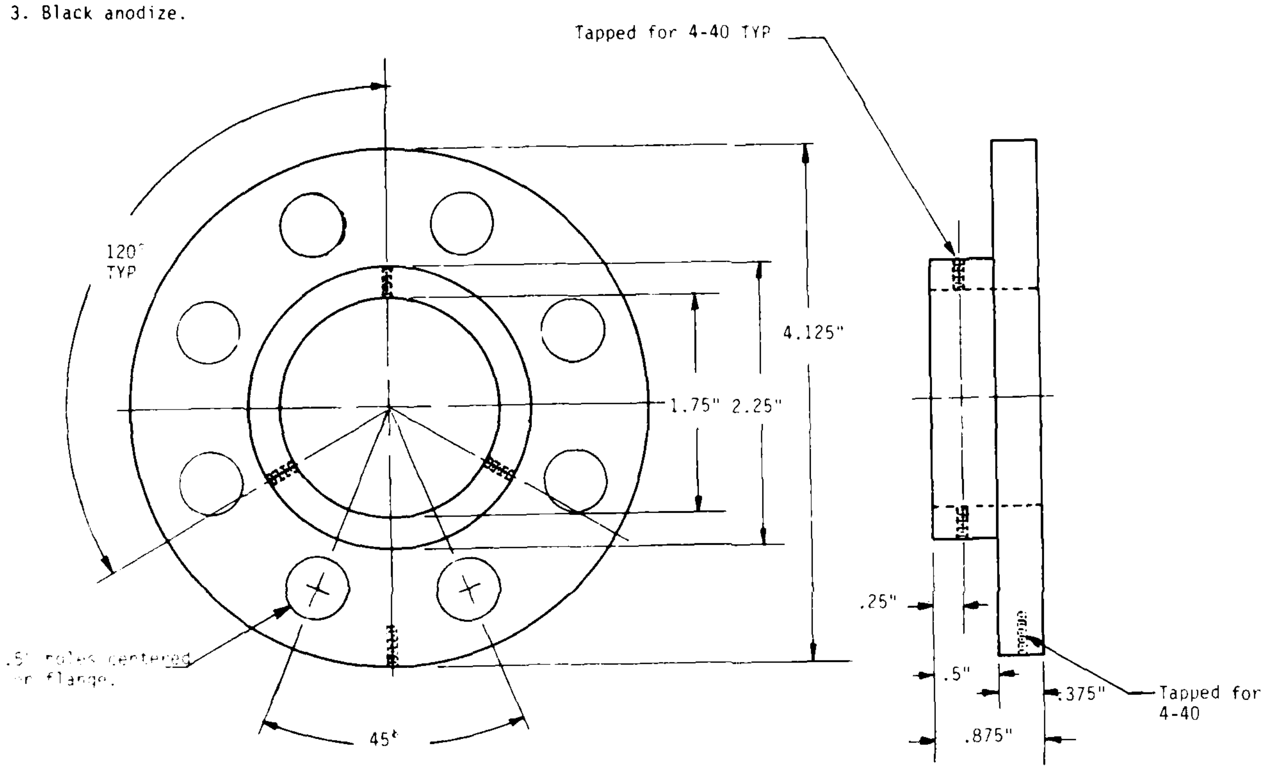



Fig. C20 — Laser collar mount; unless otherwise specified, tolerances are ± .002

1. Machine from 4 1/4" aluminum bar stock.
2. Black anodize.

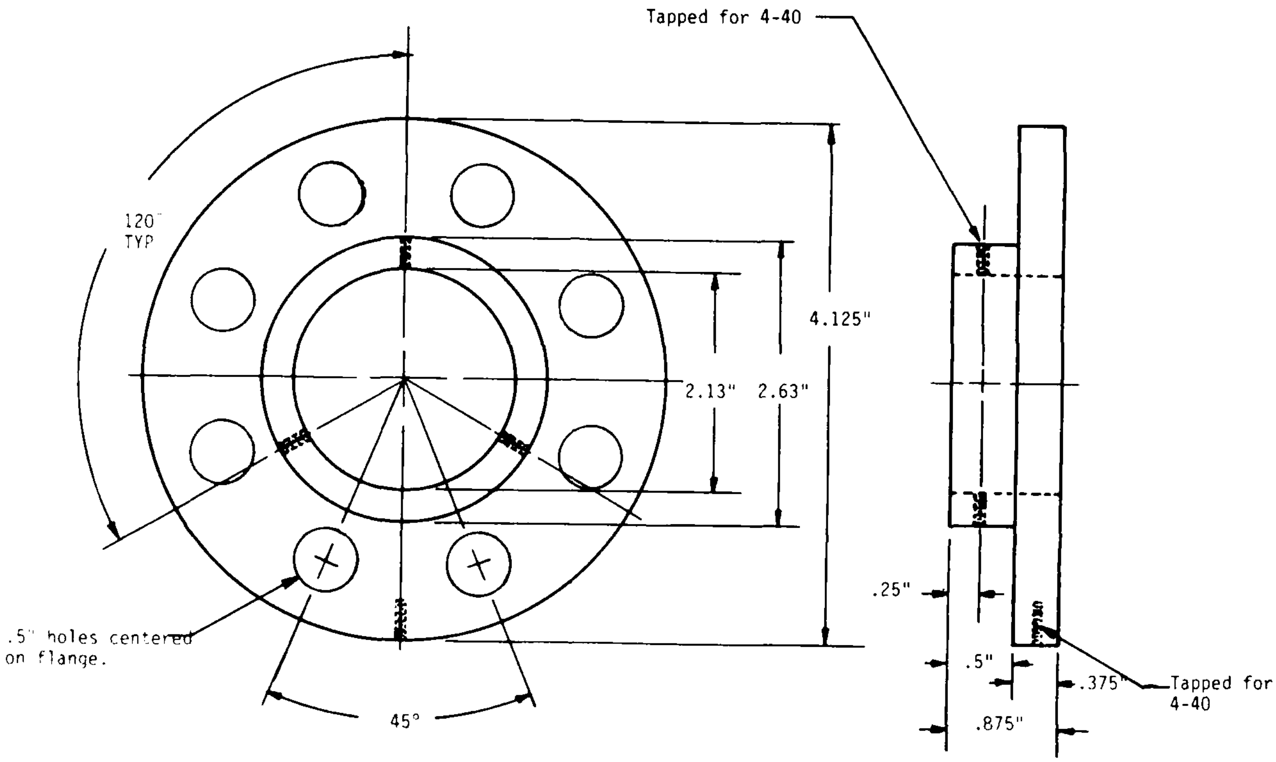



Fig. C21 — Collimator collar mount; unless otherwise specified, tolerances are ± .002

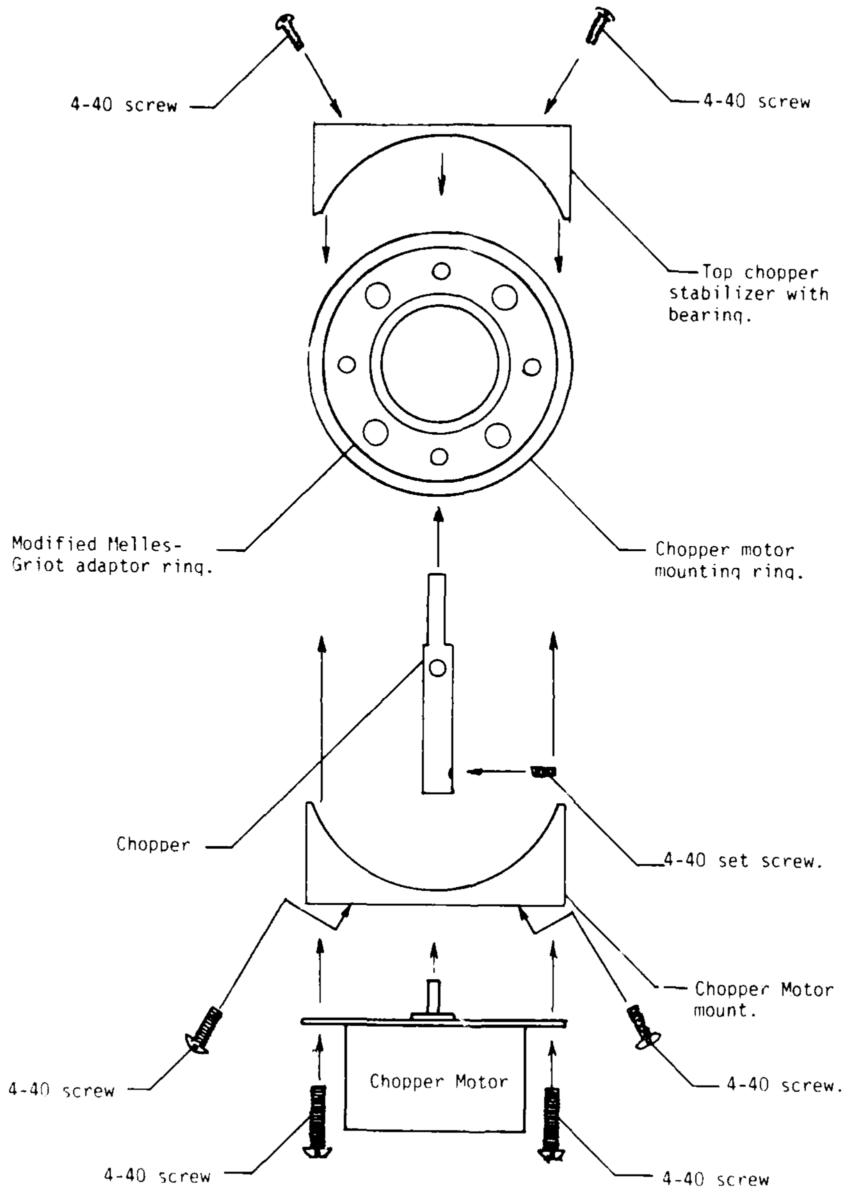



Fig. C22 — Assembly of chopper mount

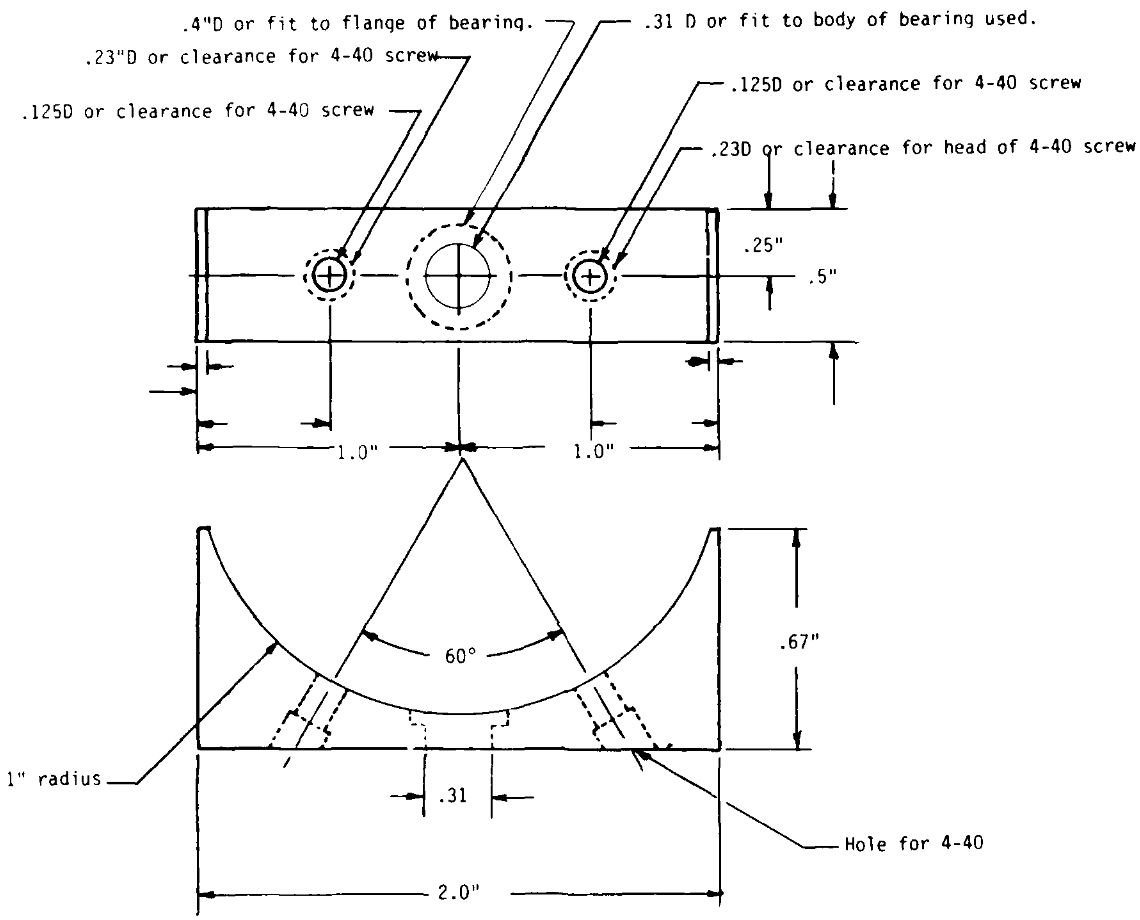



Fig. C23 — Chopper stabilizer; unless otherwise specified, tolerances are ± .002

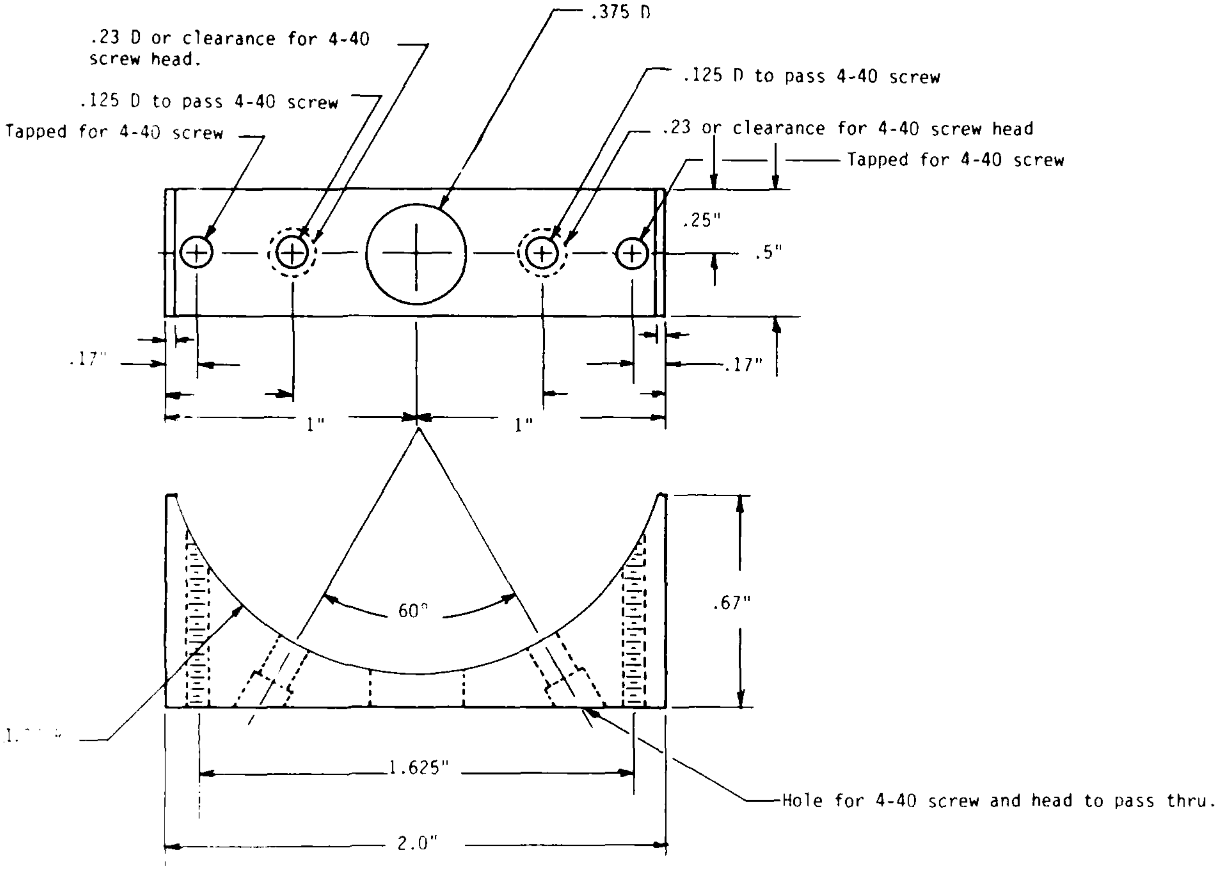



Fig. C24 — Chopper motor mount; unless otherwise specified, tolerances are ± .002

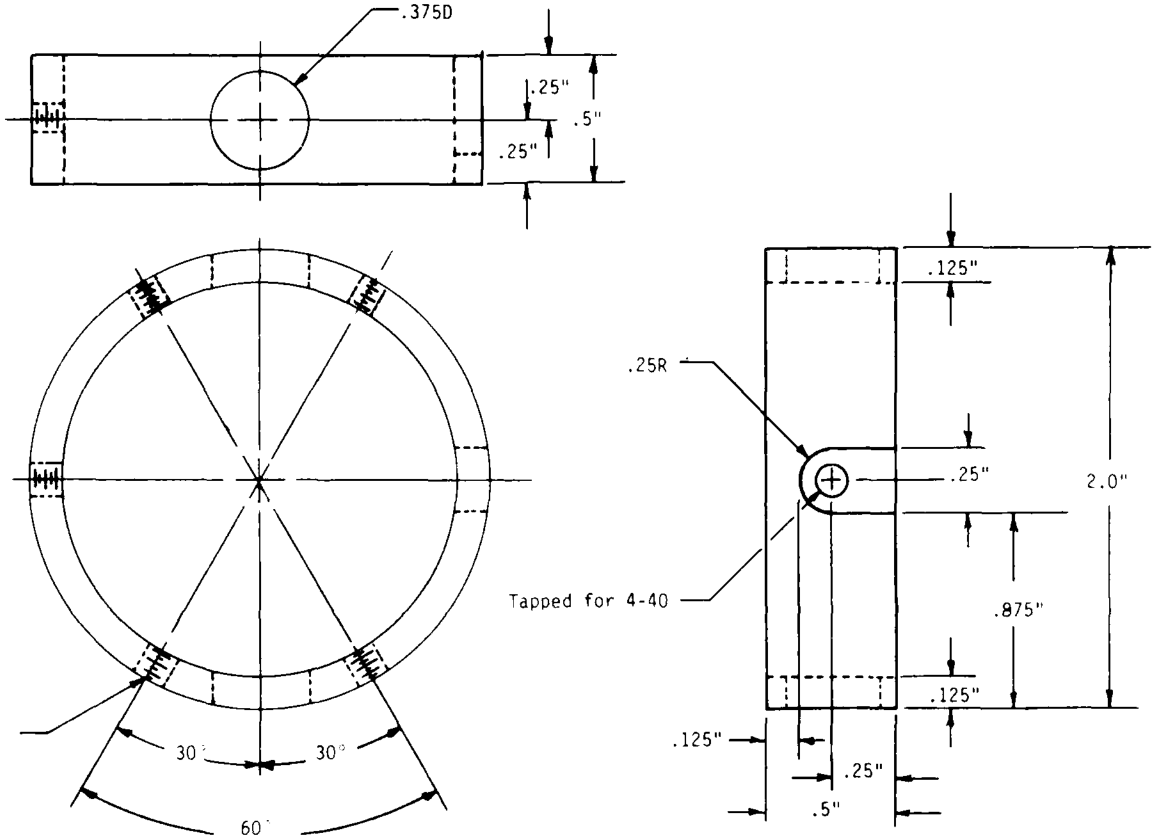



Fig. C25 — Chopper motor mounting ring; unless otherwise specified, tolerances are ±.002

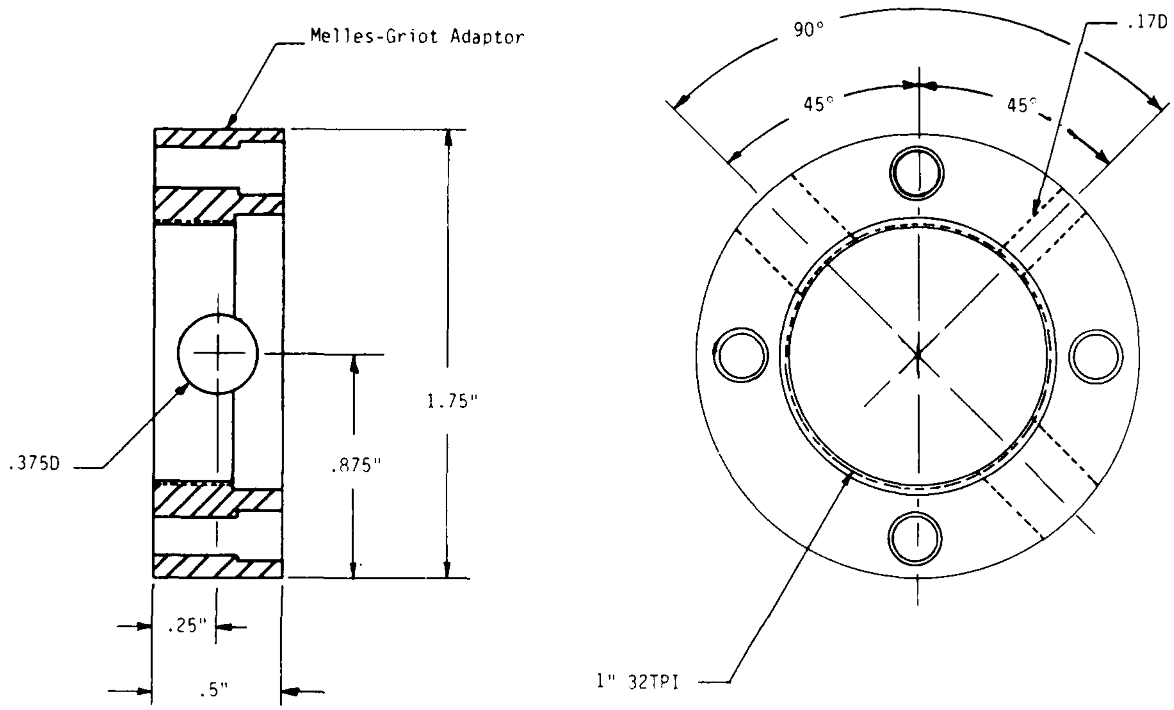



Fig. C26 — Modifications to the Melles-Griot adaptor; unless otherwise specified, tolerances are ± .005

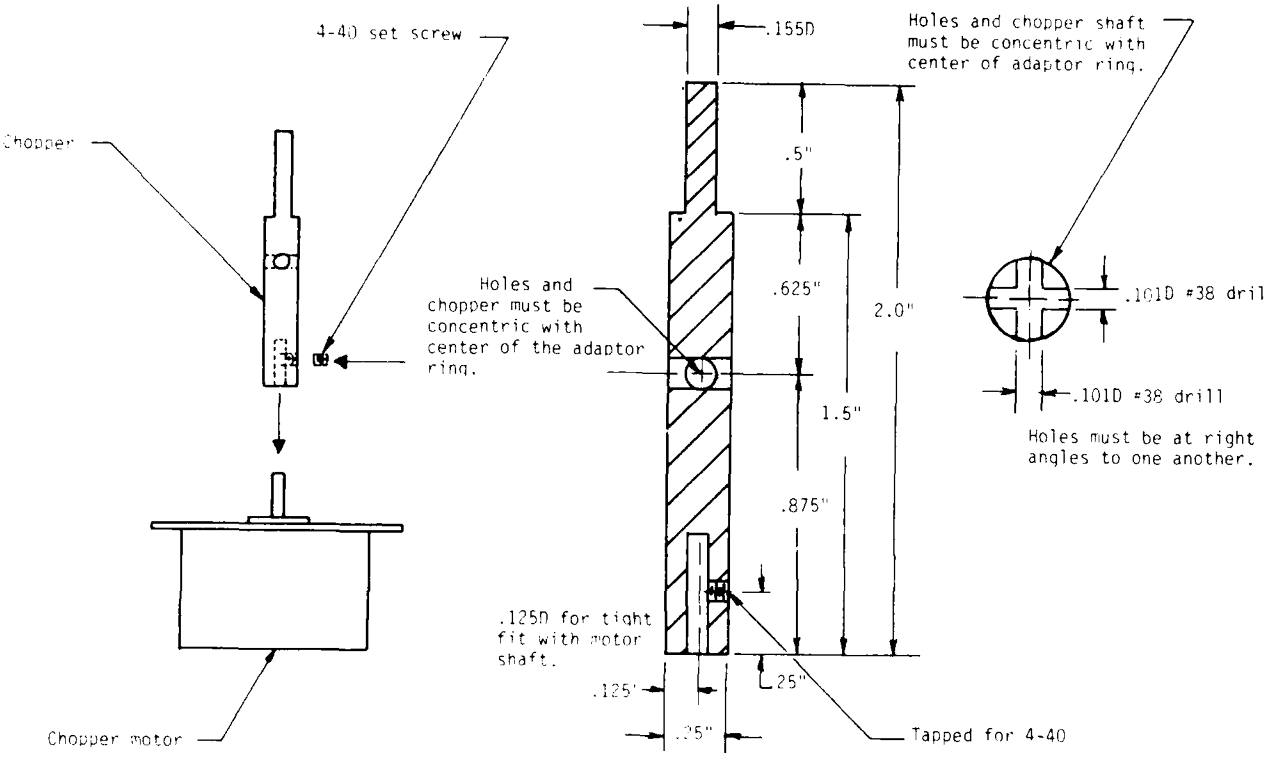
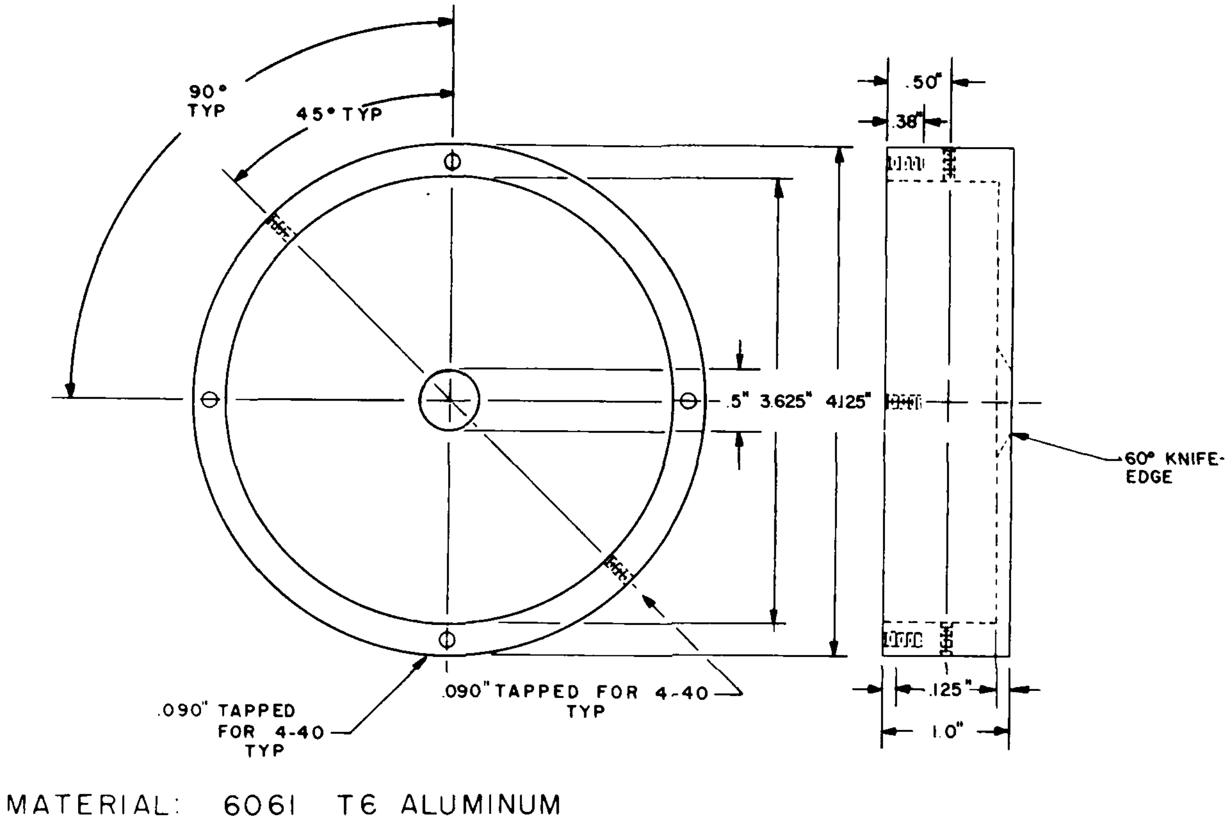



Fig. C27 — Chopper, unless otherwise specified, tolerances are ± .002




(a)

1. Machine 4.25" aluminum bar stock to specified dimensions and tolerances.
2. Outer diameter must be tight sliding fit with inner diameter of laser tube.
3. All dimensions specified are after finish.
4. Free all holes and edges from burrs and sharp areas.
5. Piece should have fine finish and overall good appearance.
6. Black anodize after machining.

(b)

Fig. C28 — Laser cylinder, unless otherwise specified, tolerances are ± .002
(a) baffle A and (b) notes

1. Machine or cut from 1/16" aluminum sheet
2. Black anodize.

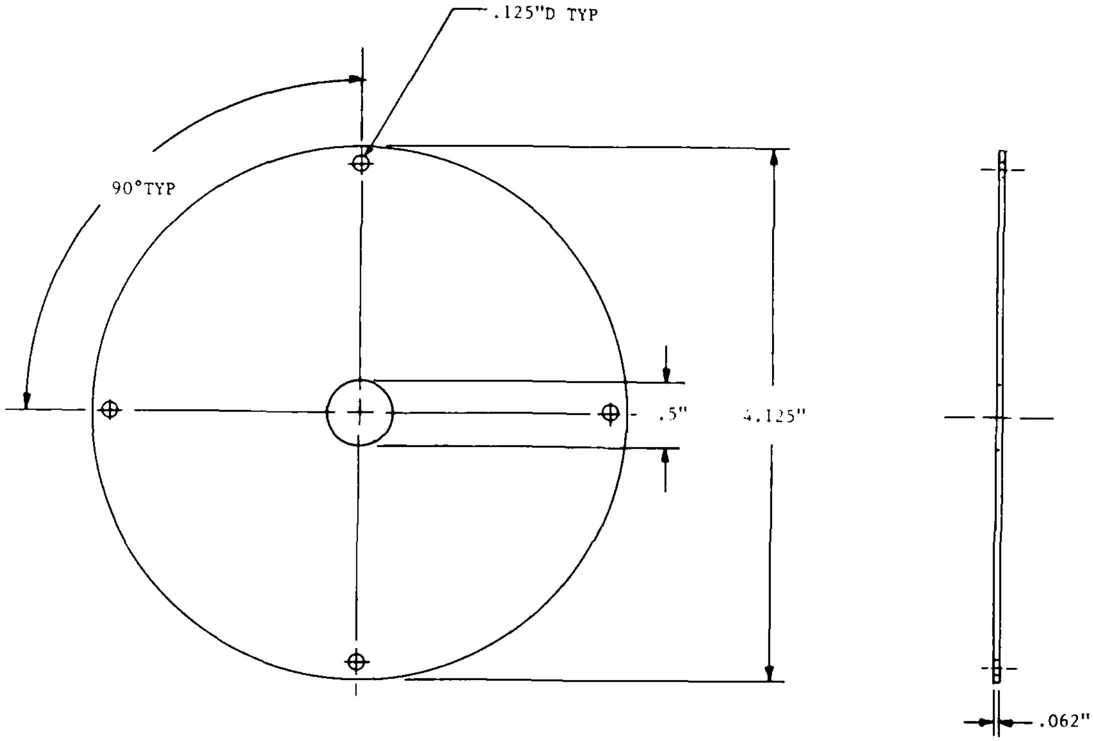



Fig. C29 — Laser tube baffle plate; unless otherwise specified, tolerances are ±.002

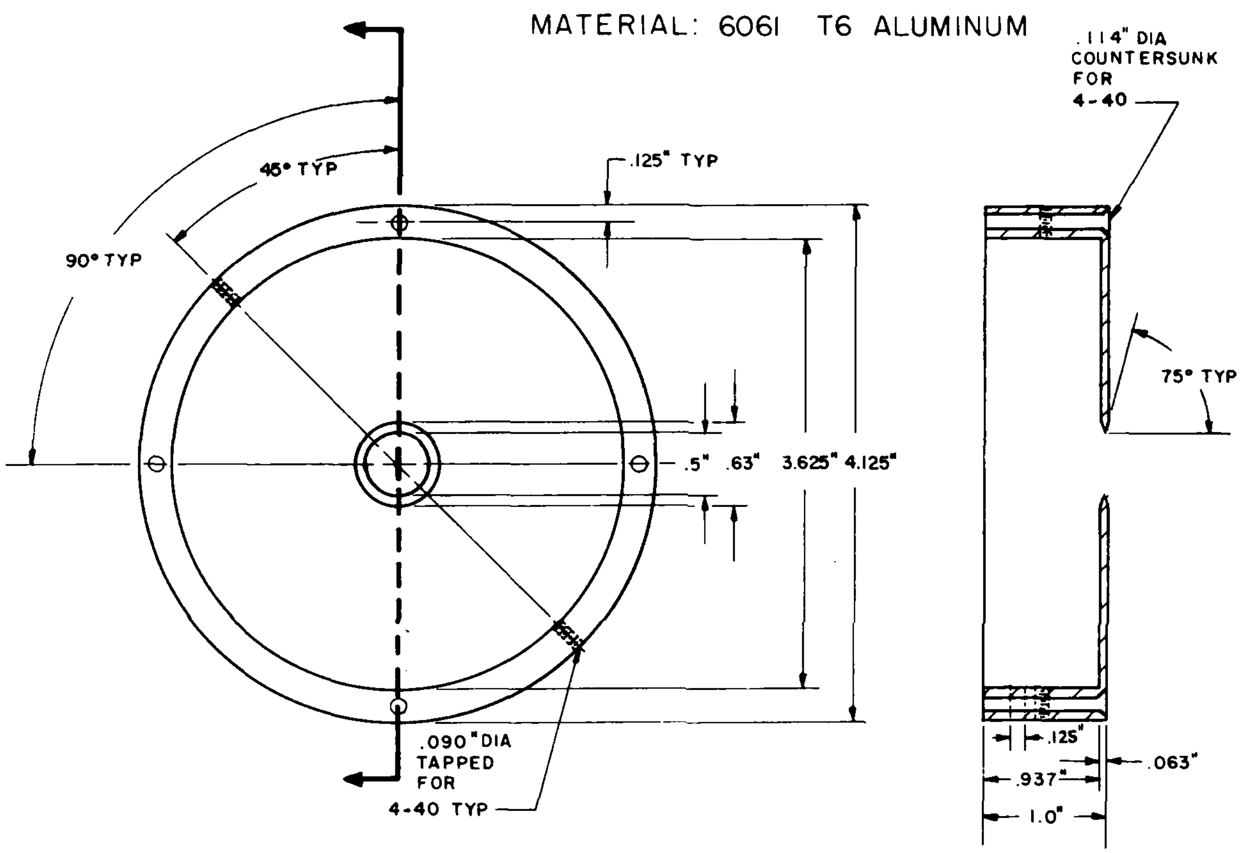



Fig. C30 — FSM laser baffle B; unless otherwise specified, tolerances are ± .002

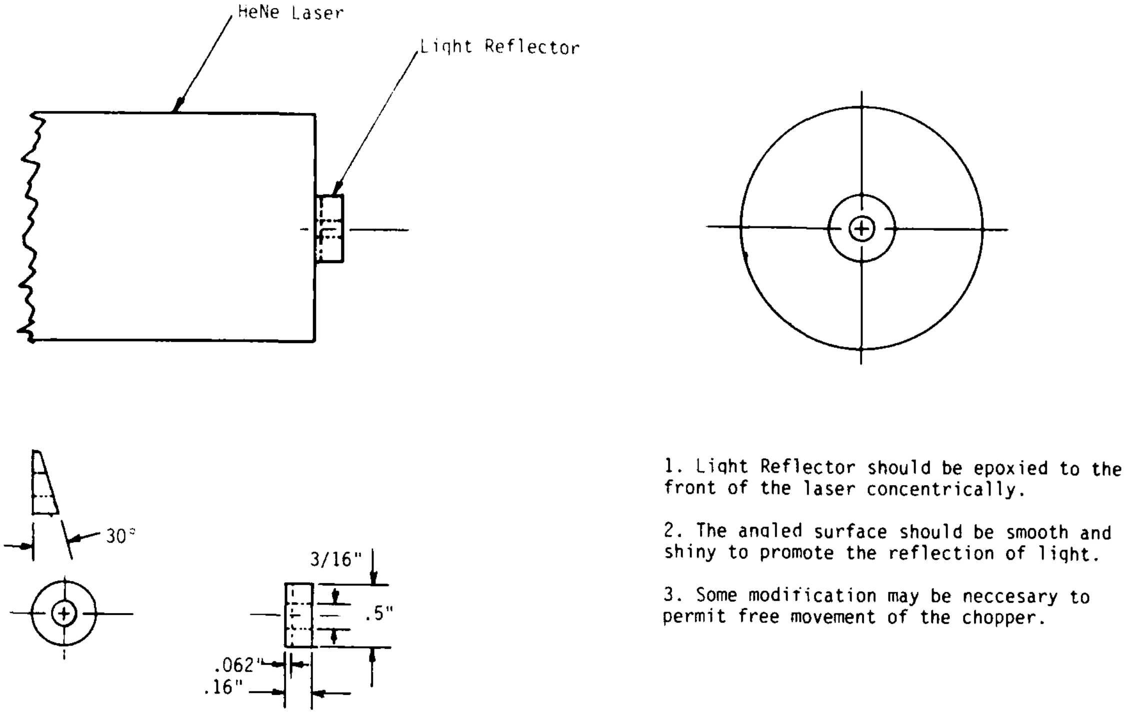



Fig. C31 — Light reflector; unless otherwise specified, tolerances are ±.002

1. Machine from aluminum bar stock.
2. Black anodize after finish.
3. All dimensions are after finish.

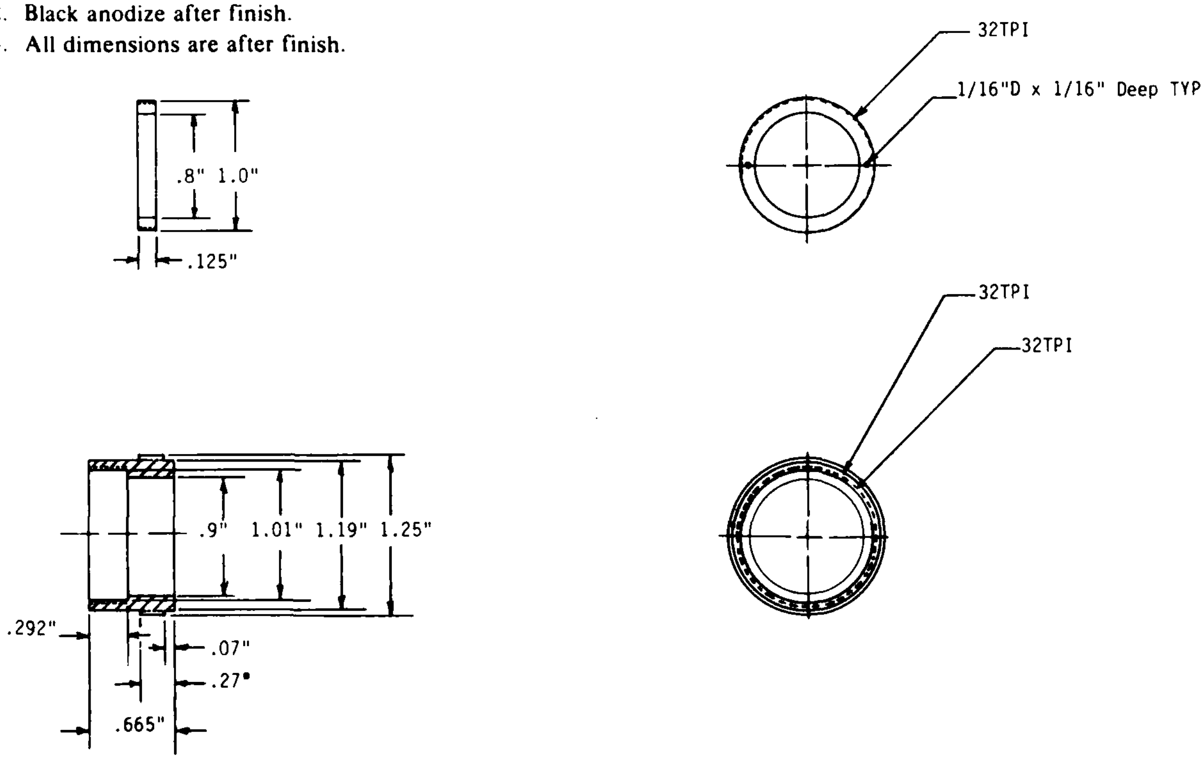



Fig. C32 — Collimator lens adaptor

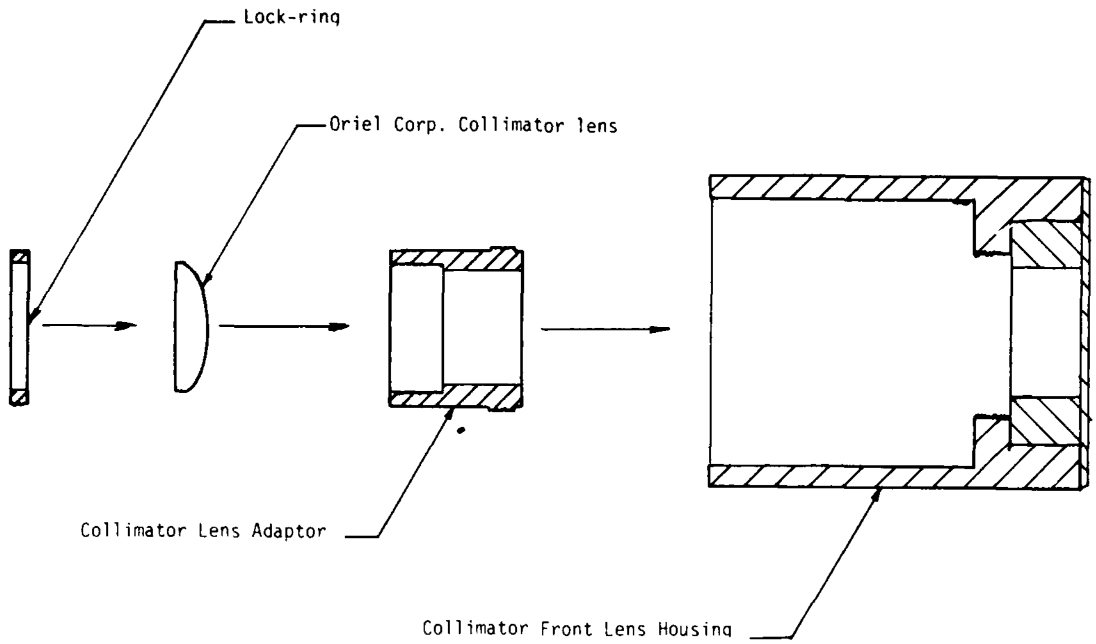
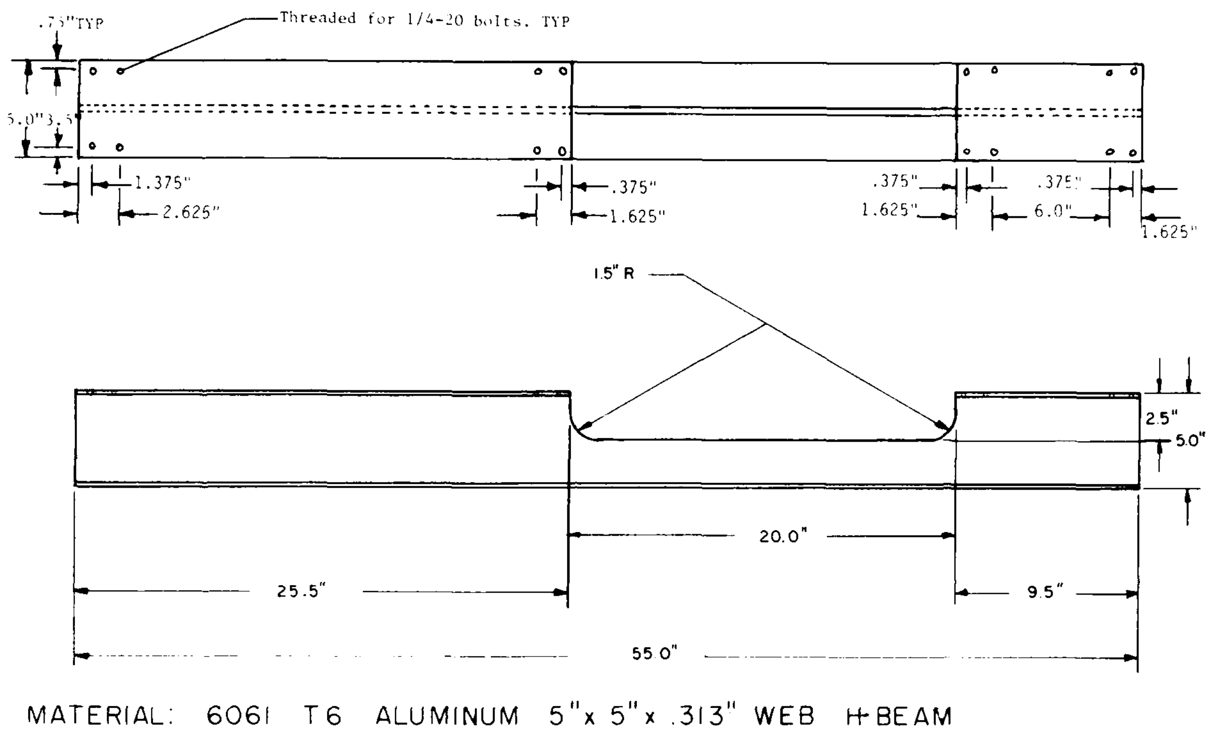



Fig. C33 — Assembly of collimator

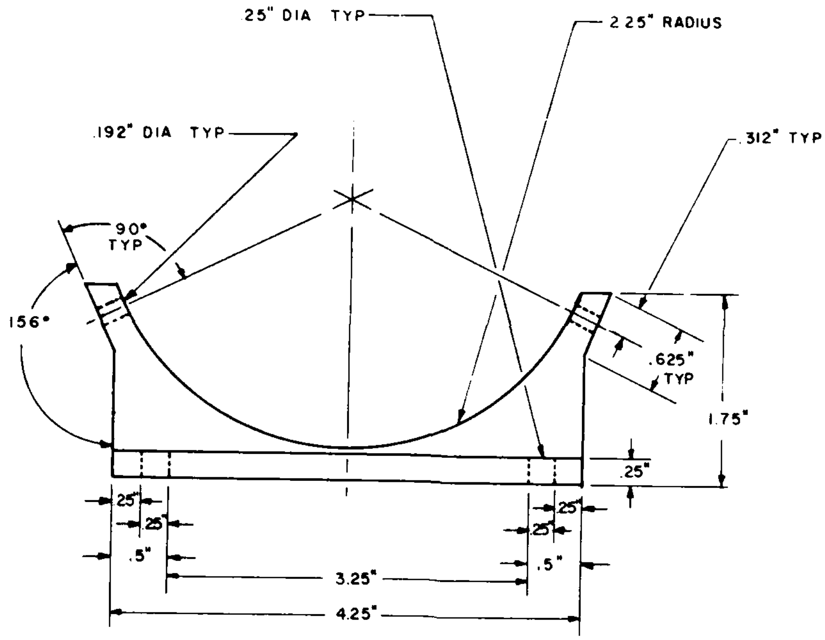



(a)

1. Cut to specified dimensions and tolerances 6061 T6 aluminum 5" × 5" × .313 web H-beam.
2. Piece should be free from burrs and sharp edges.
3. Black anodize and paint white after cutting.

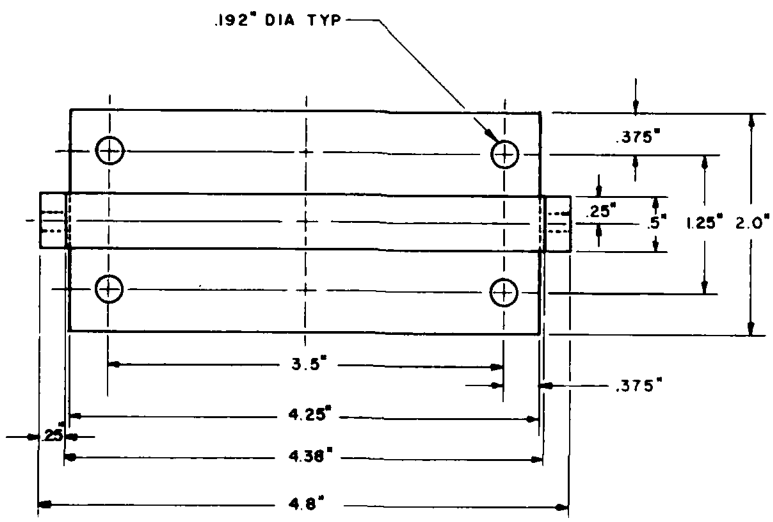
(b)

Fig. C34 — FSM sensor base, unless otherwise specified, tolerances are ± .01
(a) side and top views and (b) notes




MATERIAL: 6061 T6 ALUMINUM

(a)

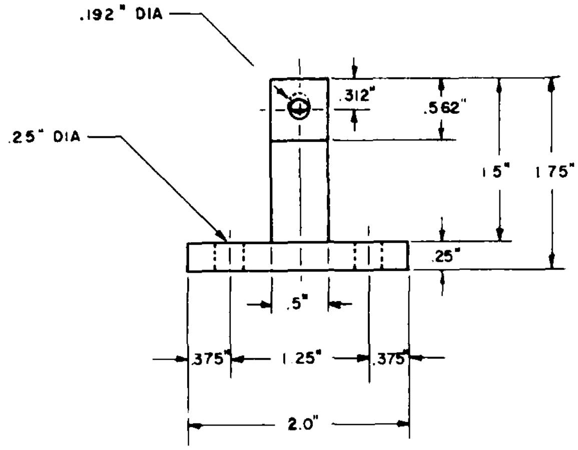



MATERIAL: 6061 T6 ALUMINUM

(b)

Fig. C35 — FSM cradle mounts; unless otherwise specified, tolerances are ± .002
(a) front view, (b) top view, (c) side view and (d) notes

MATERIAL: 6061 T6 ALUMINUM

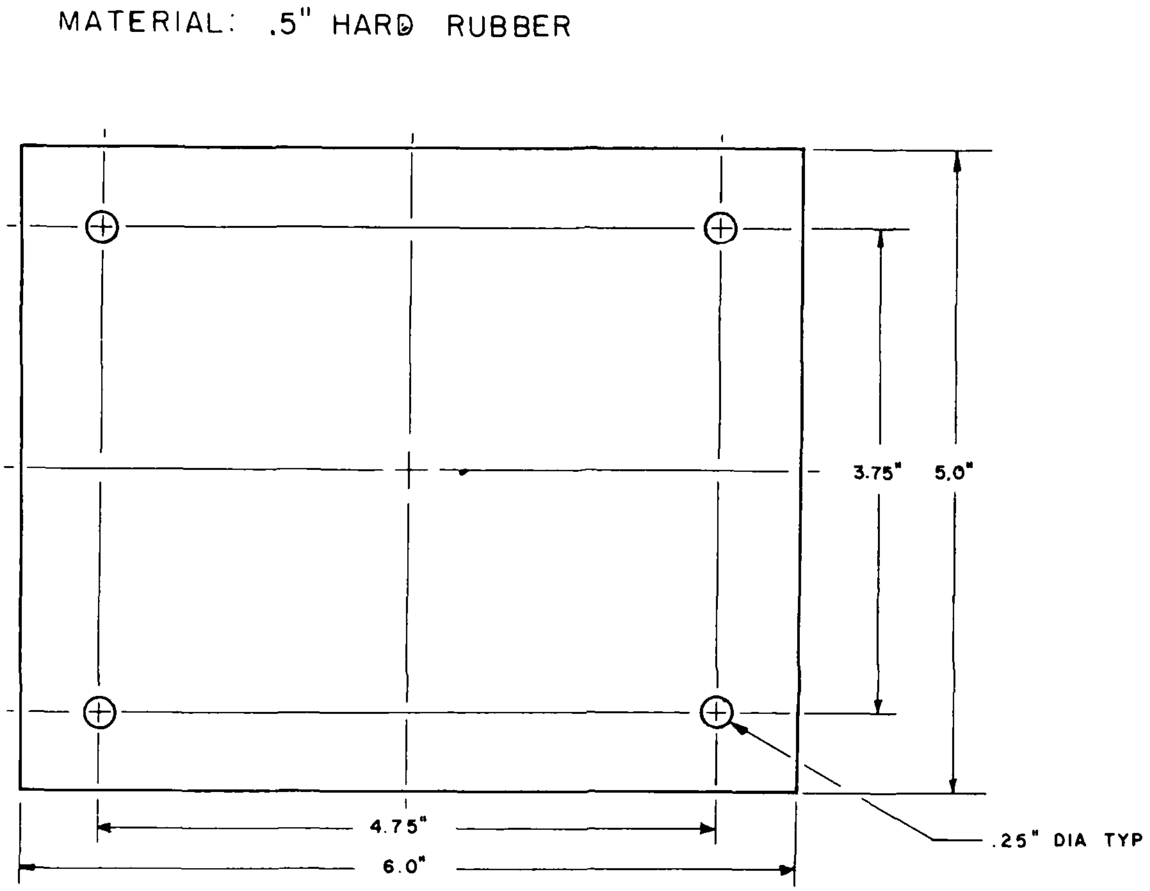



(c)

1. Machine to specified dimensions and tolerances from plate aluminum.
2. All dimensions are after finish.
3. Outer diameter of laser and detector tubes must fit in cradle of mount.
4. Black anodize and paint white after machining.
5. Four cradle mounts are needed each of which must be the same height.
6. Piece should be free from all burrs and sharp edges.
7. Piece should have fine finish and good overall appearance.

(d)

Fig. C35 (Continued) — FSM cradle mounts; unless otherwise specified, tolerances are ±.002
(a) front view, (b) top view, (c) side view and (d) notes

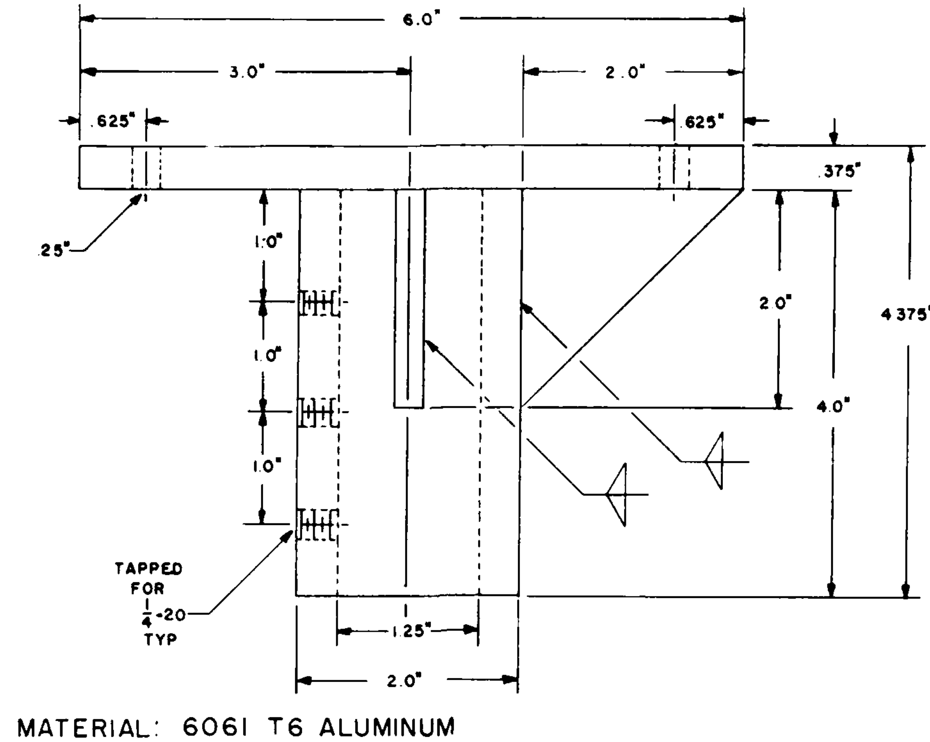



(a)

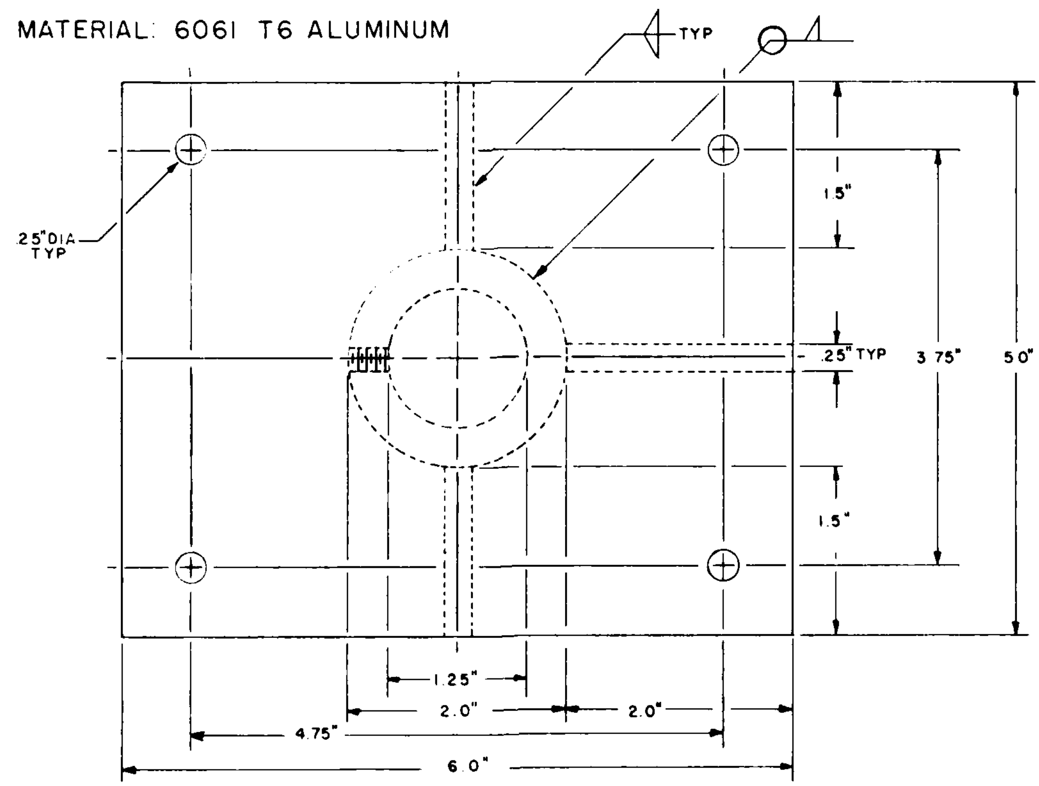
1. Cut and drill holes to specified dimensions and tolerances.
2. Use 1/2" sheet rubber.
3. Piece should have good overall appearance.

(b)

Fig. C36 — FSM shock mount: (a) top view and (b) notes




(a)




(b)

Fig. C37 — FSM mounting plate; unless otherwise specified, tolerances are ± .002
(a) side view, (b) top view and (c) notes

1. Cut top plate and drill holes to specified dimensions and tolerances from 3/8" plate aluminum.
2. Cut support fins from 1/4" plate aluminum to specified dimensions and tolerances.
3. Cut mounting plate tube from 1-1/4" I.D. 2.0" O.D. aluminum tubing or machine from bar stock.
4. Finish pieces to specified dimensions and tolerances.
5. All dimensions are after finish.
6. Pieces should be free from burrs and sharp edges.
7. Silver solder all seams.
8. Piece should have a smooth finish and overall good appearance.
9. Black anodize and paint white after constructing.

(c)

Fig. C37 (Continued) — FSM mounting plate; unless otherwise specified, tolerances are ±.002
(a) side view, (b) top view and (c) notes

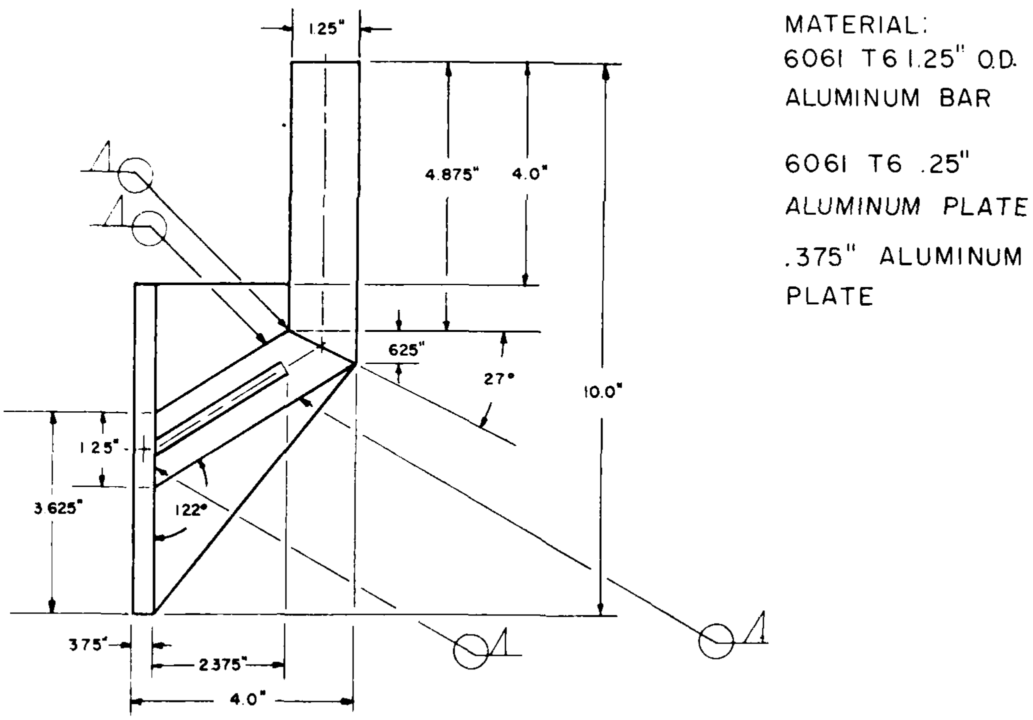
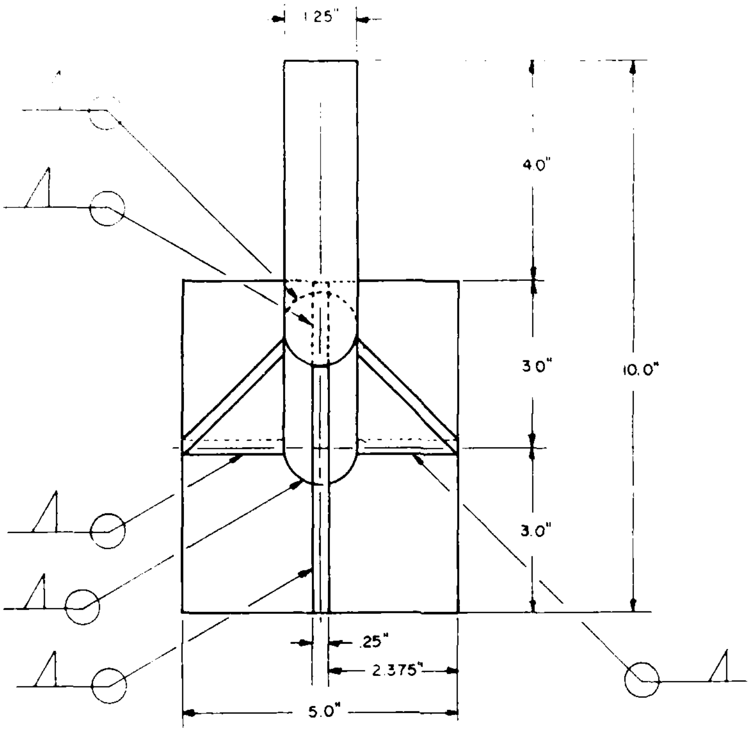
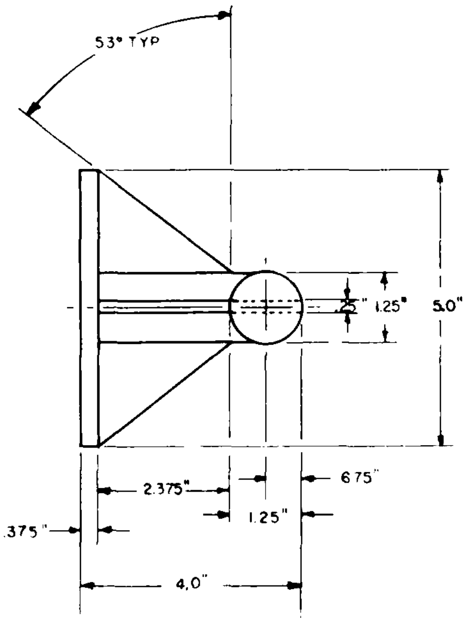



Fig. C38 — FSM pole mount; unless otherwise specified, tolerances are ±.002
(a) side view, (b) front view, (c) top view and (d) notes




(b)




1. Cut shafting from 1-1/4" aluminum bar stock.
2. Cut strengthening fins from 1/4" plate aluminum.
3. Cut mounting plate from 3/8" aluminum plate stock.
4. Silver solder all seams.
5. Piece should be free from all burrs and sharp edges.
6. Piece should have smooth finish and have overall good appearance.
7. All dimensions are after finish.
8. Black anodize and paint white after machining.

(c) (d)

Fig. C38 (Continued) — FSM pole mount; unless otherwise specified, tolerances are ± .002
(a) side view, (b) front view, (c) top view and (d) notes

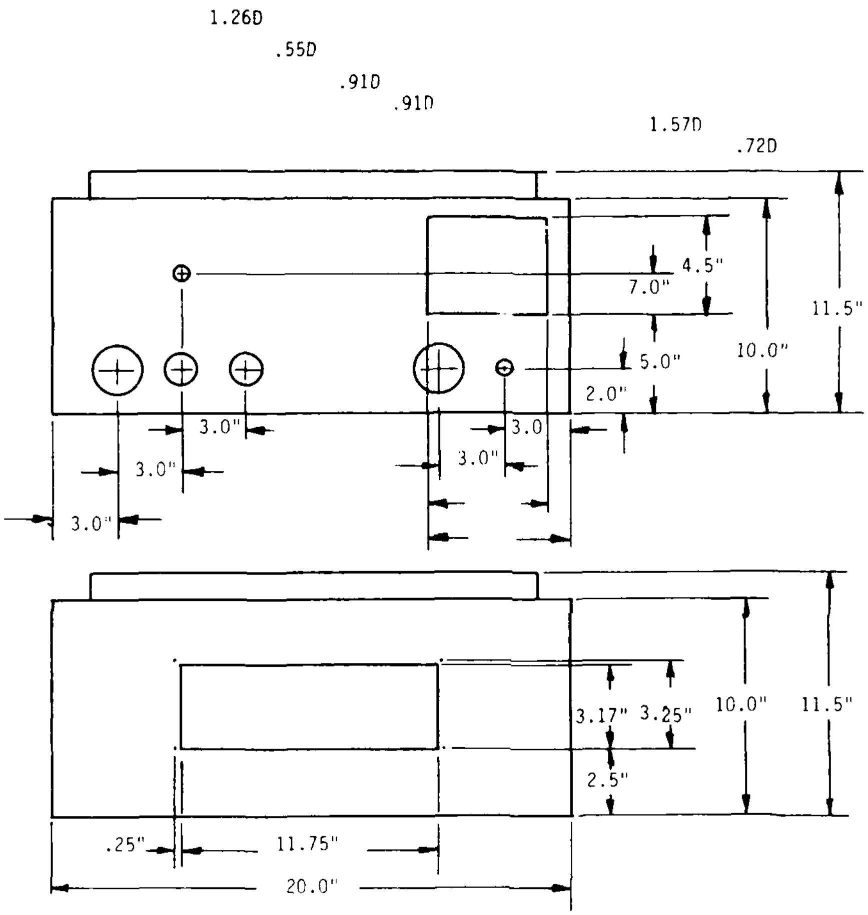



Fig. C39 — 24 × 20 × 10 steel electronics enclosure, front and back; unless otherwise specified, tolerances are ± .02

1. Cut and form from 1/16" sheet aluminum.
2. Continuous weld all seams.
3. Black anodize.

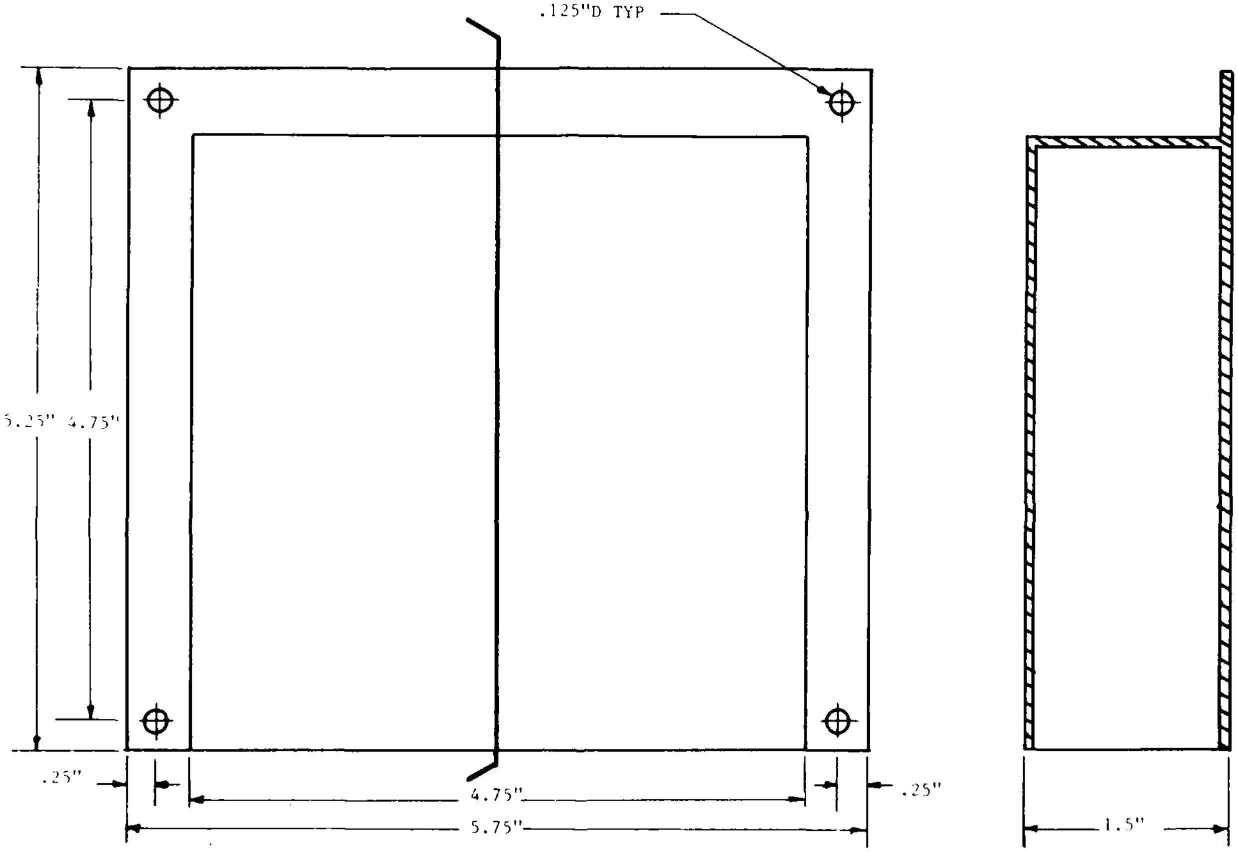



Fig. C40 — Fan cover, front and side sectional views; unless otherwise specified, tolerances are ± .02

END
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