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PUBLICATION



# NBS TECHNICAL NOTE 395

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National  
Bureau  
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## Design for a Variable-Output-Coupling Far-Infrared Michelson Laser

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## TECHNICAL NOTE 395

ISSUED JANUARY 1971

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CODEN: NBTNA

### **Design for a Variable-Output-Coupling Far-Infrared Michelson Laser**

J. S. Wells, K. M. Evenson, L. M. Matarrese,  
D. A. Jennings, and G. L. Wichman

Quantum Electronics Division  
Institute for Basic Standards  
National Bureau of Standards  
Boulder, Colorado 80302



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# DESIGN FOR A VARIABLE-OUTPUT-COUPLING FAR-INFRARED MICHELSON LASER

J. S. Wells, K. M. Evenson, L. M. Matarrese,  
D. A. Jennings, and G. L. Wichman

A technique for varying the coupling of power from far-infrared gas lasers and the design and construction of these lasers are described. The coupling method is based on Michelson's interferometric principle and permits a continuously variable coupling of the available power from the laser. The present laser design is the result of evolution over the last year and a half.

Key words: HCN lasers; H<sub>2</sub>O lasers; infrared lasers; variable coupling lasers.

The first section of this note describes a method for extracting energy from far infrared gas lasers that has none of the disadvantages of the usual hole-coupling schemes. The second section includes detailed drawings of the laser and some construction explanations.

The energy extraction method employs a Michelson interferometer configuration with a polyethylene or polypropylene beam splitter. A simple film beam splitter had been previously used by the group at NPL<sup>(1)</sup>. The configuration is similar to the Smith<sup>(2)</sup> mode selector with the beam splitter perpendicular to that in the Smith design, and the use of identical mirrors at the beam splitter end. Some of the

advantages are: (1) Diffraction losses are kept to a minimum because the full internal beam diameter is utilized. (2) Mode distortion is minimized. (3) The coupling may be continuously adjusted from zero to four times that of a simple beam splitter. (4) The output coupling is easily varied. (5) Line identification is simplified, as will be explained in a later part of the note. (6) The output beam is linearly polarized, a useful feature in some applications, such as in coupling to the whisker diodes used in frequency measurements.<sup>(3)</sup> (7) Finally, the device is relatively easy and inexpensive to build.

Figure 1 shows the design we have successfully employed for H<sub>2</sub>O and HCN lasers operating from 28 to 373 $\mu$ m. The flat mirrors A and B can be translated by micrometer heads with a resolution of about 0.2 $\mu$ m. Mirror B serves to tune the resonator B-C. Mirror A varies the power coupled out of the polyethylene lens (the lens may be replaced by a flat window if a focused beam is not desired, ) by varying the relative phase of the waves returning to the beam splitter from mirrors A and B. Since resonator AC has such a low Q, frequency pulling by AC is negligible. The dielectric beam splitter, which is set at an angle of 45<sup>o</sup> to the laser tube axis, is a taut polyethylene or polypropylene membrane of such a thickness that provides constructive interference of the beams reflected from each of its surfaces. This thickness is an odd multiple of

$$t = 1/4 \lambda_0 (n^2 - 1/2)^{-1/2}, \quad (1)$$

where  $\lambda_0$  is the vacuum wavelength of the laser radiation, and  $n$  is the refractive index of the beam splitter material (about 1.5). For example, our HCN laser ( $\lambda_0 = 337 \mu\text{m} = 13.3 \text{ mil}$ ) has a membrane 2.5 mil thick. The  $\text{H}_2\text{O}$  laser ( $\lambda_0 = 28 \mu\text{m} = 1.1 \text{ mil}$ ) uses a membrane approximately 0.6 mil thick, which is about 3 times the value given by Eq. (1), since we were unable to obtain thinner polyethylene or polypropylene film of suitable quality.

As an example of the operation of the coupling control, we show in figure 2 recorder traces of the power coupled out of an HCN laser (337 $\mu\text{m}$ ) as function of displacement of mirror A, with laser tube current as parameter. When the two waves recombining on the beam splitter are 180<sup>o</sup> out of phase, there is practically complete cancellation of the output at current setting. Halfway between, where constructive interference is at a maximum, the laser is actually overcoupled, a desirable condition since one is then sure of obtaining maximum laser output at some intermediate setting of mirror A. If the laser gain is not high enough, there will be no oscillation in the overcoupled region. This is seen in figure 2 at laser currents of less than 0.2A, and is the normal situation with the 78- and 118- $\mu\text{m}$  lines of the  $\text{H}_2\text{O}$  laser. (The water vapor laser only lases on the 28 $\mu\text{m}$  line unless the three

mirrors are all precisely aligned.) The table shows the powers we have been able to obtain from various lasers using this coupling method.

The side mirror has also proved useful in simplifying line identification. With mirror B fixed, one need only measure the translation of mirror A from one  $180^\circ$  phase point to the next as on figure 2.

The power relectivity of the film at these wavelengths is about 4% so that the maximum fraction of power coupled out of the laser is about 16%. This can be increased even more, if the laser gain permits, by using a compound beam splitter, - that is two parallel membranes with the appropriate interspace between them.

A disadvantage of this scheme which we have noticed is the tendency for drumhead resonances to appear in the membrane if the plasma current is modulated. These can be eliminated, but at a sacrifice of output power, by using a much thicker membrane.

Construction notes and detailed drawings comprise the remainder of this note.

The vacuum seals involve O-rings which have been lightly greased. The laser tube has O-rings clamped between a flat surface and a  $45^\circ$  chamfered surface which causes a seal between the O-ring and the glass and at the same time allows the glass to slide as it heats



and expands in length. A similar detail allows the micrometer rods to pass thru on O-ring seal. The cathode and anode seals contact O-rings which rest on a 30 mm flared section of glass with differential pressure performing the previous function of the clamp. Other O-ring seals are in conventional grooves.

Epoxy is used to provide a seal at the interface of a ground glass donut and the curved mirror, C. Epoxy (or type W black wax of the low pressure variety) is also used to fasten the mirrors A and B to aluminum mounting disks which are attached to coupling rods to the micrometers.

Pairs of ball bushings (supporting the rods to which hold the mirrors) were quite effective in insuring proper translation of the mirrors. Two ball bushings were needed to overcome the changing torque and resulting mirror tipping as the relatively massive mirror was moved axially.

The beam splitter polyethylene is kitchen variety wrapping material. Typically this material will have dents and imperfections when taken from the container. Our technique is to stretch this tightly and attach it to a frame with two-sided adhesive tape, then heat it slightly with a hot air gun until the dents and imperfections disappear. It is then attached to the beam splitter frame with rubber cement.

The laser is aligned by tightening screws which compress the O-rings separating the laser proper from supports for the mirrors. Once the laser is aligned optically, three reference screws are tightened and used as stops for automatic alignment after subsequent laser disassembly and reassembly.

The water cooled cathodes are constructed almost entirely from standard copper plumbing items; the lone exception is the item into which the 1/4" water lines feed. A standard quick connect makes the water seal at the upper end. This permits one to change the insert (consisting of the inner pipe with the reducer hard soldered to it) by merely changing one soft solder joint and redoing it. Under certain discharge conditions, an electron beam from the cathode has melted a hole in the glass. This possibility has been eliminated by placing a semicircular stainless steel insert about 3cm. long below the cathode.

We have found the following alignment procedure to be very useful:

1. Align the end mirrors B and C with a  $6328 \overset{\circ}{\text{A}}$  laser or sighting down the bore and use the reference screws to precisely reposition the first mirror aligned. If mirror C is aligned first, mirror A may be aligned at the same time as mirror B by causing reflected laser light from mirror A to be superposed on that from B

and the beam splitter at some distance from the laser. Mirror C is then accurately repositioned by the reference screws.

2. With the laser oscillating on the  $337\mu\text{m}$  line for HCN or  $28\mu\text{m}$  line for the  $\text{H}_2\text{O}$  laser, mirrors B and C are alternately slightly readjusted until the output power is maximized.

3. Liquid crystal is positioned at the focal point of the polyethylene lens for the final adjustment. Mirror A is adjusted until beams from mirrors A and B are superposed as evidenced by a single spot rather than two on the liquid crystal. Another manifestation of this alignment is the absence of interference fringes on the liquid crystal when it is held next to the polyethylene lens rather than at its focal point. After this step is completed, a detector is placed at the focal point and mirror A is very finely aligned to give the maximum fluctuation in the output signal as mirror A is translated. The laser then should be properly aligned.

We would like to thank V. Lecinski for the fine draftsmanship and K. Gebert for his contributions regarding the cathode construction.

Table: Powers available from H<sub>2</sub>O and HCN Michelson Lasers. The lasers were 8 meters long and of folded confocal geometry. The power was measured with an "aquadag" blackened copper cone calorimeter.

Laser	$\lambda$	Inside Diameter	Power	Gas Mixtures
HCN	337 $\mu\text{m}$	133 mm	150 mW*	Ammonia and methane
HCN	311 $\mu\text{m}$	133 mm	50 mW*	"
H <sub>2</sub> O	118 $\mu\text{m}$	75 mm	20 mW	H <sub>2</sub> O vapor and hydrogen
H <sub>2</sub> O	79 $\mu\text{m}$	75 mm	15 mW	"
H <sub>2</sub> O	78 $\mu\text{m}$	75 mm	40 mW	"
H <sub>2</sub> O	28 $\mu\text{m}$	37 mm	450 mW (Multimode)	"

\* The HCN laser discharge was adjusted for maximum spectral purity and not maximum gain. Good spectral purity is evidenced by stationary striations in the methane and ammonia discharge.

## REFERENCES

1. J. E. Chamberlain, et. al. *Infrared Physics* 6, 195 (1966)
2. P. W. Smith, *IEEE J. Quantum Electronics*, QE1, 343 (1965)
3. K. M. Evenson, J. S. Wells and L. M. Matarrese, *Appl. Phys. Letters*, 16, 251 (1970).
4. Born and Wolf, Principles of Optics, Permagon Press (1959)  
p. 281

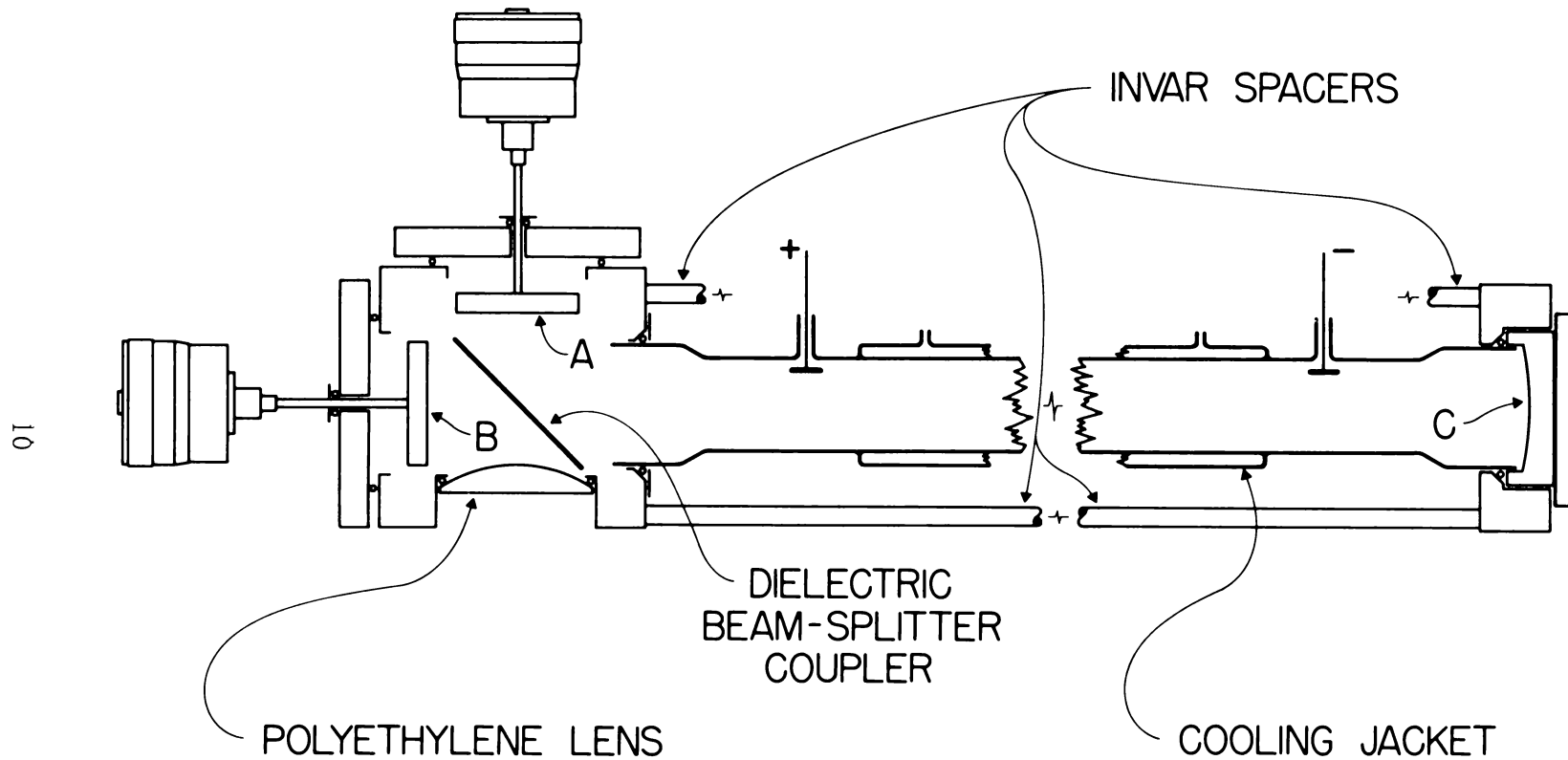


Figure 1. Schematic drawing of HCN and H<sub>2</sub>O variable coupling far infrared laser. The HCN Laser does not have a cooling jacket.

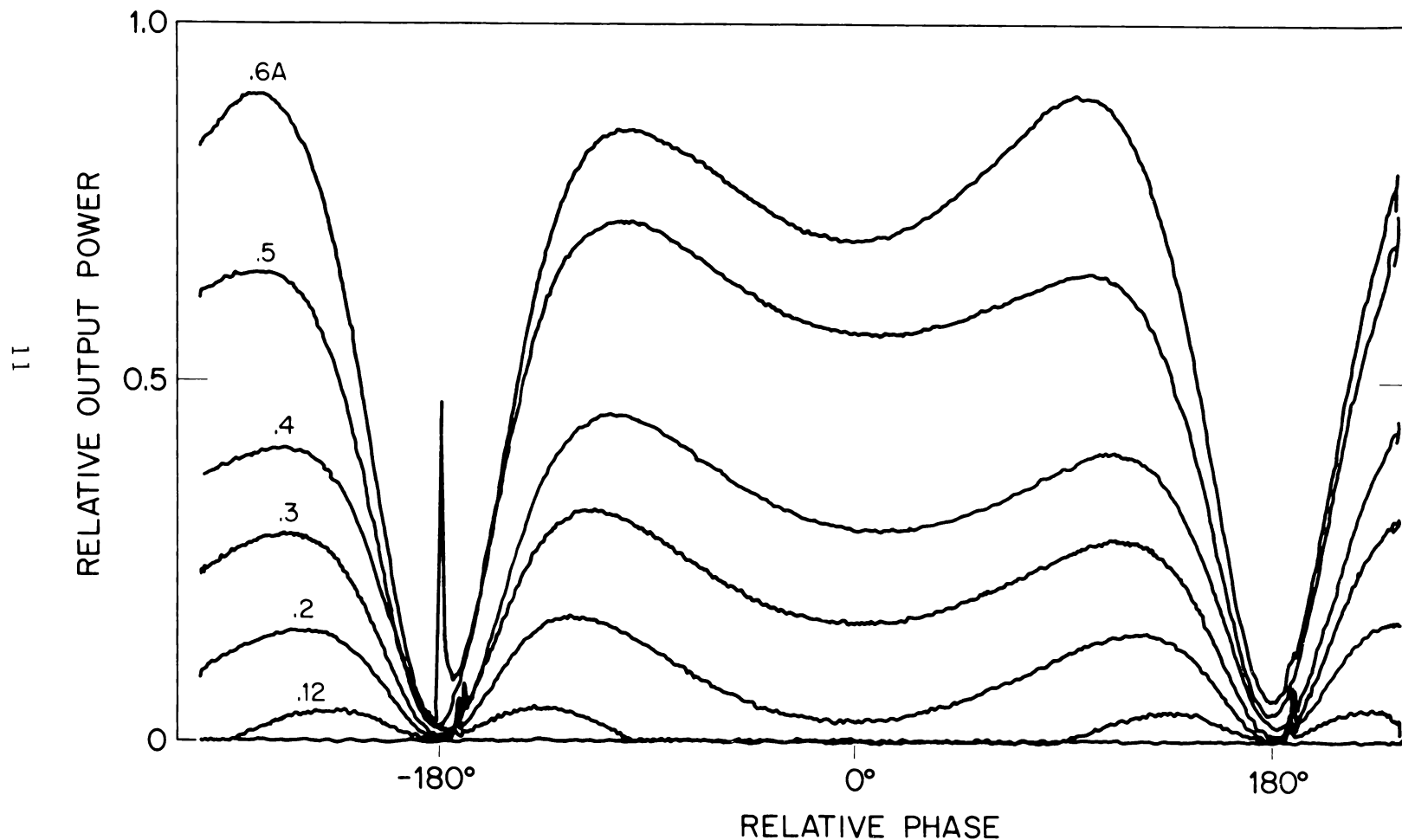


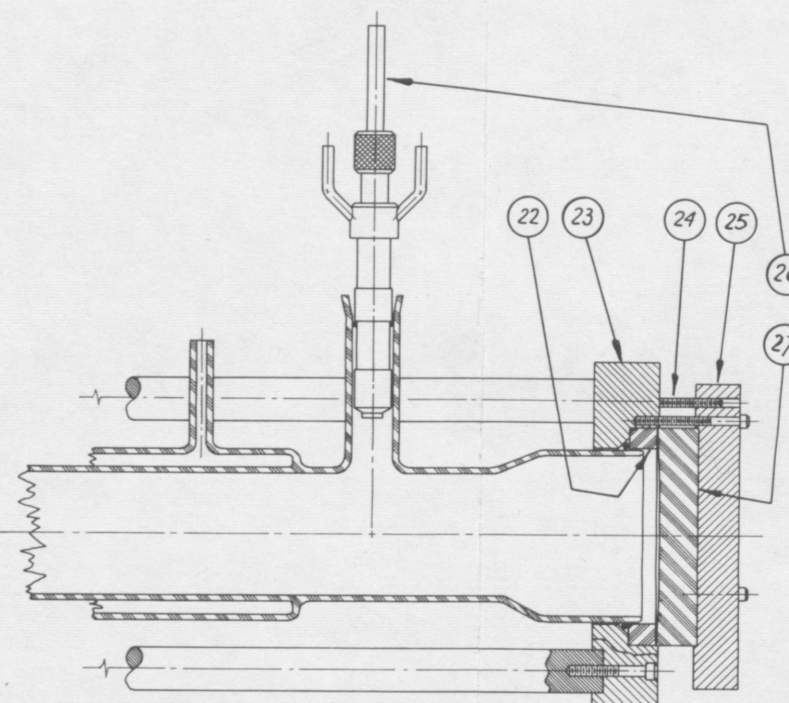
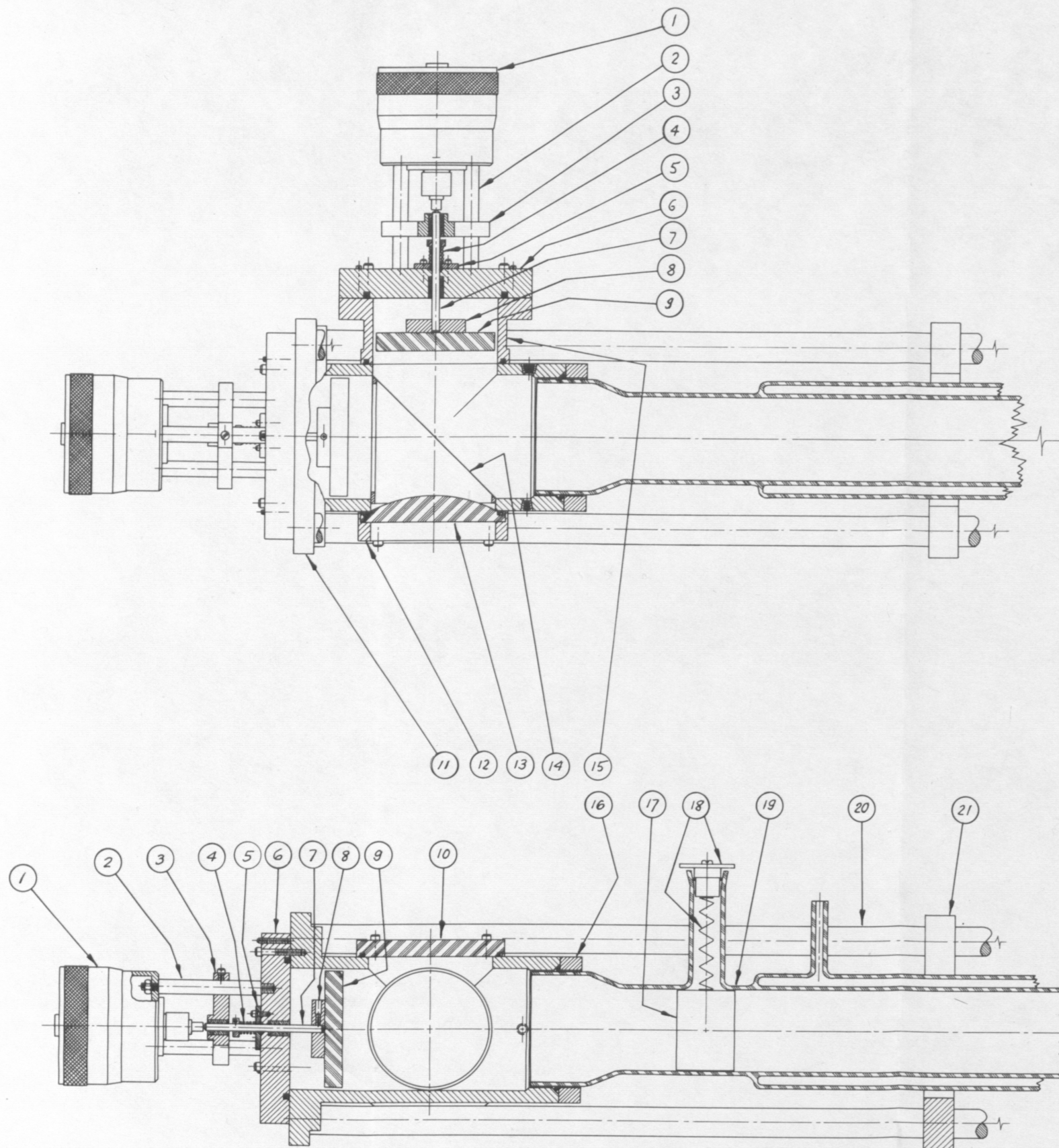
Figure 2. Recorder traces of power coupled out of an HCN laser ( $337\mu\text{m}$ ) by the device of figure 1 as a function of the relative phase of the waves reflected from mirrors A and B. The parameter is laser tube current. A power meter was connected to the Y-axis of the recorder, and a transducer giving a signal proportional to the displacement of mirror A, to the X-axis. The transient spikes appearing at the  $180^\circ$  positions are caused by mode jumping in the laser.





ORIGINAL DATE OF DRAWING			
REVISIONS			
NO.	E. C. N.	CHANGE	DATE
1			
2			
3			
4			

NOTE: DETAILS OF NUMBERED ITEMS ARE SHOWN ON SHEETS 2-6 OF THIS DWG.



LIST OF STOCK PARTS

O-RING PARKER No. 2-118	2
O-RING PARKER No. 2-349	2
O-RING PARKER No. 2-344	2
O-RING PARKER No. 2-246	1
O-RING PARKER No. 2-245	1
O-RING PARKER No. 2-10	2
STEEL SET SCREW, #8-32 UNC 1 1/2" LONG (SPECIAL), FLAT POINT	3
STEEL SCREW, #10-32 UNF HEX. SOCKET HEAD, 2 1/4" LONG	3
BRASS SCREW, #10-32 UNF ROUND HEAD, 1/2" LONG (FOR ANODE)	1
STEEL SET SCREW, #6-32 UNC 3/8" LONG, FLAT POINT	2
STEEL SCREW, #10-32 UNF HEX. SOCKET HEAD, 1" LONG	8
STEEL STD SCREW, #20 UNC 1 3/8" LONG	4
STEEL SCREW, 1/4-20 UNC HEX. SOCKET HEAD, 1 1/2" LONG	8
STEEL SET SCREW, #8-32 UNC 1" LONG, FLAT POINT	6
STEEL SCREW, #10-32 UNF HEX. SOCKET HEAD, 1 3/8" LONG	10
BRASS SCREW, #6-32 UNC FILLISTER HEAD, 3/8" LONG	6
STEEL SPLIT SHAFT CLAMP (.250 I.D.)	2
NYLON SCREW, #6-32 UNC FILLISTER HEAD, 3/4" LONG	6
BALL BUSHING (.250 I.D.) CAT. No. A-4812 (THOMSON)	4
MICROMETER, L.S. STARRETT #469 MH (METRIC) RANGE: 0-25mm	2
BRASS OR STEEL HEX. NUT 1/4-28 UNF	6

NOMENCLATURE NO. REQ'D

NATIONAL BUREAU OF STANDARDS  
QUANTUM ELECTRONICS DIV., BOULDER, COLO. 80302

ASSEMBLY

FOR MICHELSON LASER CAVITY

MODEL J	TYPE	SCALE
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN VICTOR LECHEWIKI	CHECKER
TOLERANCES (Unless otherwise specified)	PROJECT ENGR PAUL M. EVENSON	PROJECT ENGR DR. J. S. WELLS
DECIMALS .005	SUBMITTED BY	
FRACTIONS .018	CHIEF SEC.	
ANGLES .1/2°	EXAMINED BY	
DO NOT SCALE THIS PRINT	CHIEF ENGINEER	
DIV. SEC.	APPROVED BY	CHIEF DIV.
THIS PRINT ISSUED		

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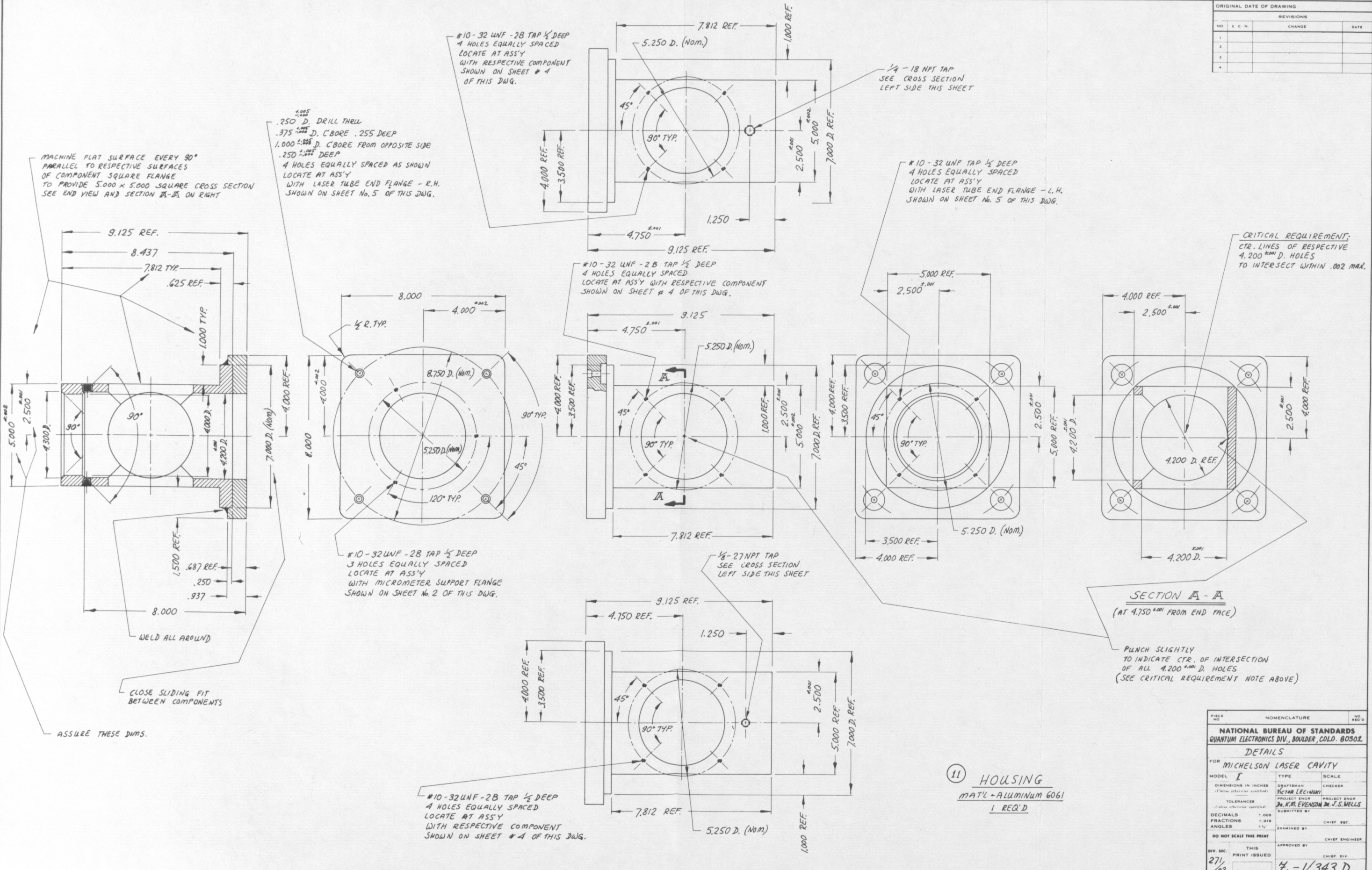
SHEET 1 OF 6







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REVISIONS			
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1			
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CRITICAL REQUIREMENT:  
CTR. LINES OF RESPECTIVE  
4.200 D. HOLES  
TO INTERSECT WITHIN .002 MAX.

SECTION A-A  
(AT 4.750 FROM END FACE)

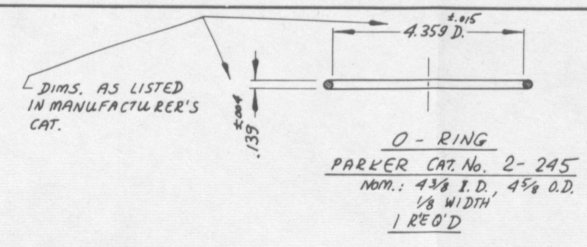
PUNCH SLIGHTLY  
TO INDICATE CTR. OF INTERSECTION  
OF ALL 4.200 D. HOLES  
(SEE CRITICAL REQUIREMENT NOTE ABOVE)

11 HOUSING  
MAT'L - ALUMINUM 6061  
1 REQ'D

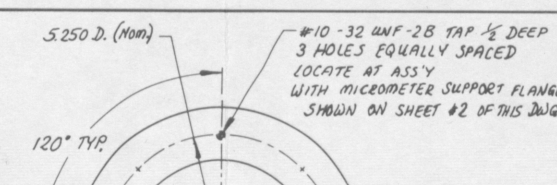
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FOR MICHELSON LASER CAVITY		
MODEL I	TYPE	SCALE
DIMENSIONS IN INCHES (Unless otherwise specified)		DRAFTSMAN VICTOR LECINSKY
TOLERANCES (Unless otherwise specified)		CHECKER DR. K.M. EVANSON DR. J.S. WELLS
DECIMALS .005	FRACTIONS 1/16	PROJECT ENGR
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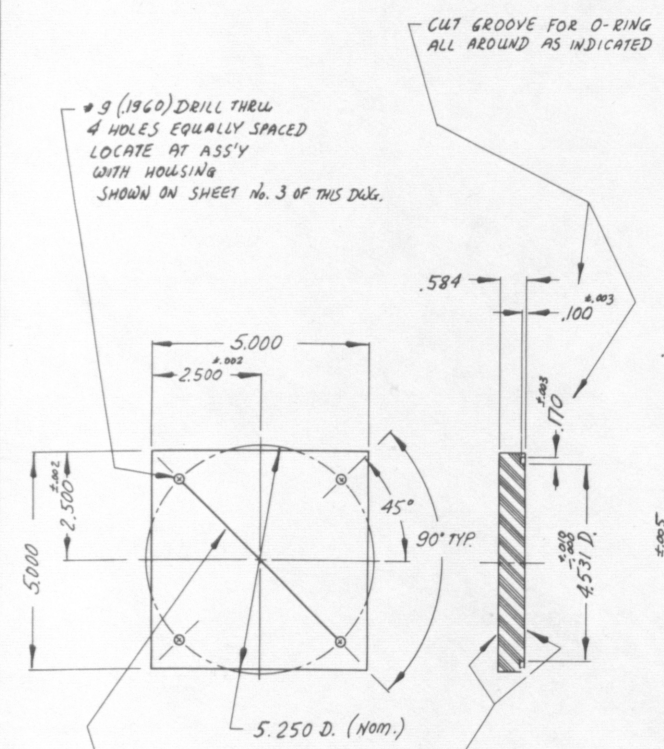
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NO.	E. C. N.	CHANGE	DATE
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2			
3			
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PARKER CAT. No. 2-245  
Nom.: 4 3/8 I.D., 4 5/8 O.D.  
1/8 WIDTH  
1 REQ'D



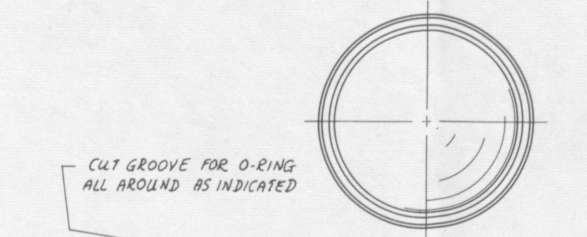
#10 - 32 UNF-2B TAP 1/2 DEEP  
3 HOLES EQUALLY SPACED  
LOCATE AT ASS'Y  
WITH MICROMETER SUPPORT FLANGE  
SHOWN ON SHEET #2 OF THIS DWG.



CUT GROOVE FOR O-RING  
ALL AROUND AS INDICATED

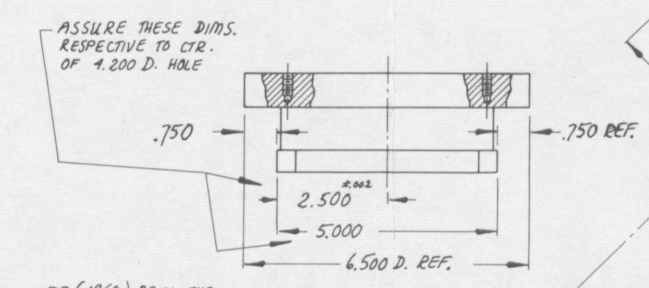
#9 (1960) DRILL THRU  
4 HOLES EQUALLY SPACED  
LOCATE AT ASS'Y  
WITH HOUSING  
SHOWN ON SHEET No. 3 OF THIS DWG.

DIMS. AS LISTED  
IN MANUFACTURER'S  
CAT.



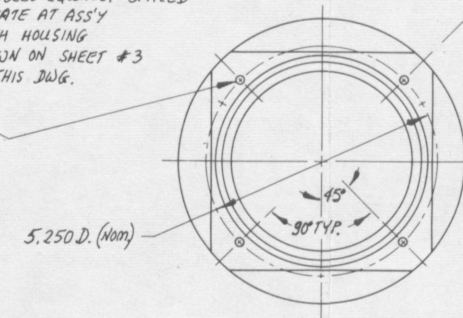
CUT GROOVE FOR O-RING  
ALL AROUND AS INDICATED

**LENS 13**  
MAT'L - HIGH DENSITY POLYETHYLENE  
1 REQ'D

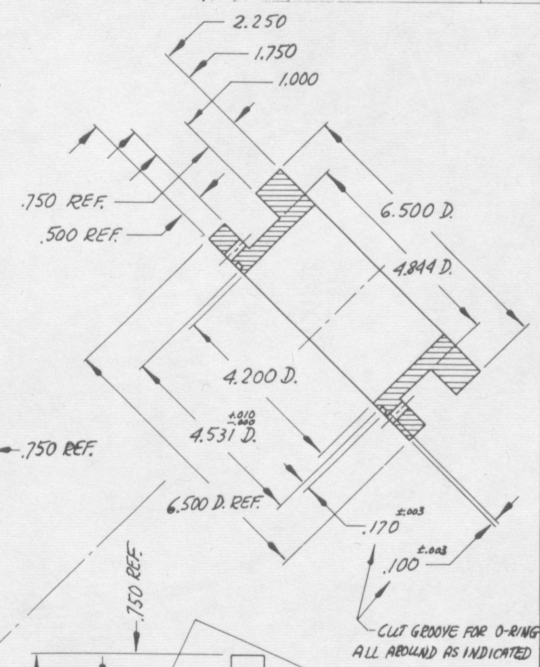


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OF 4.200 D. HOLE

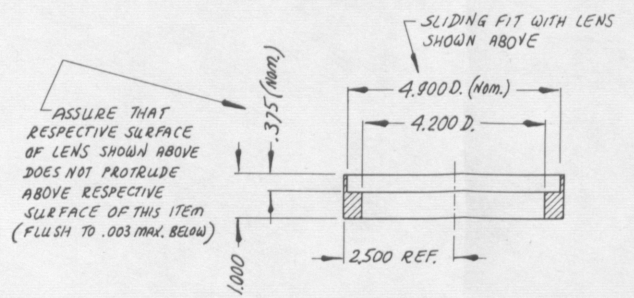
#9 (1960) DRILL THRU  
4 HOLES EQUALLY SPACED  
LOCATE AT ASS'Y  
WITH HOUSING  
SHOWN ON SHEET #3  
OF THIS DWG.



**15 COLLAR**  
MAT'L - ALUMINUM 6061  
1 REQ'D

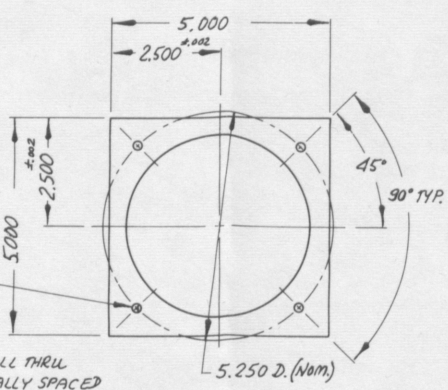


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RESPECTIVE TO CTR.  
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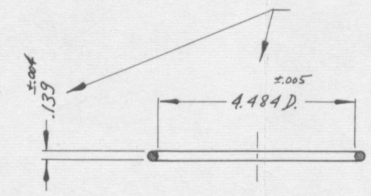
SLIDING FIT WITH LENS  
SHOWN ABOVE

ASSURE THAT  
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OF LENS SHOWN ABOVE  
DOES NOT PROTRUDE  
ABOVE RESPECTIVE  
SURFACE OF THIS ITEM  
(FLUSH TO .003 MAX. BELOW)

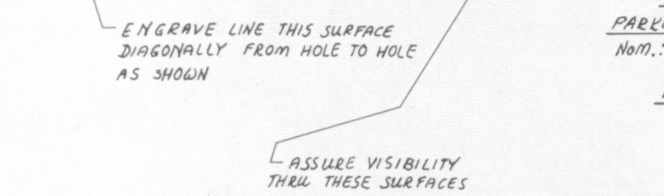


#9 (1960) DRILL THRU  
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SHOWN ON SHEET #3  
OF THIS DWG.

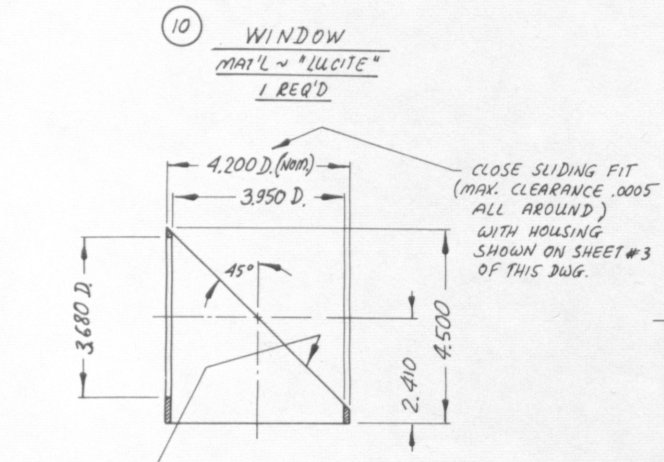
**12 LENS SUPPORT FLANGE**  
MAT'L - ALUMINUM 6061  
1 REQ'D



**O-RING**  
PARKER CAT. No. 2-246  
Nom.: 4 1/2 I.D., 4 3/4 O.D.  
1/8 WIDTH  
1 REQ'D



**O-RING**  
PARKER CAT. No. 2-246  
Nom.: 4 1/2 I.D., 4 3/4 O.D.  
1/8 WIDTH  
1 REQ'D



CLOSE SLIDING FIT  
(MAX. CLEARANCE .0005  
ALL AROUND)  
WITH HOUSING  
SHOWN ON SHEET #3  
OF THIS DWG.

LAP THIS SURFACE FLAT  
CEMENT TRANSPARENT  
POLYETHYLENE MEMBRANE .001-.002 THICK  
ASSURE FLATNESS (NO DISTORTION  
OF SEMI-REFLECTED IMAGE)

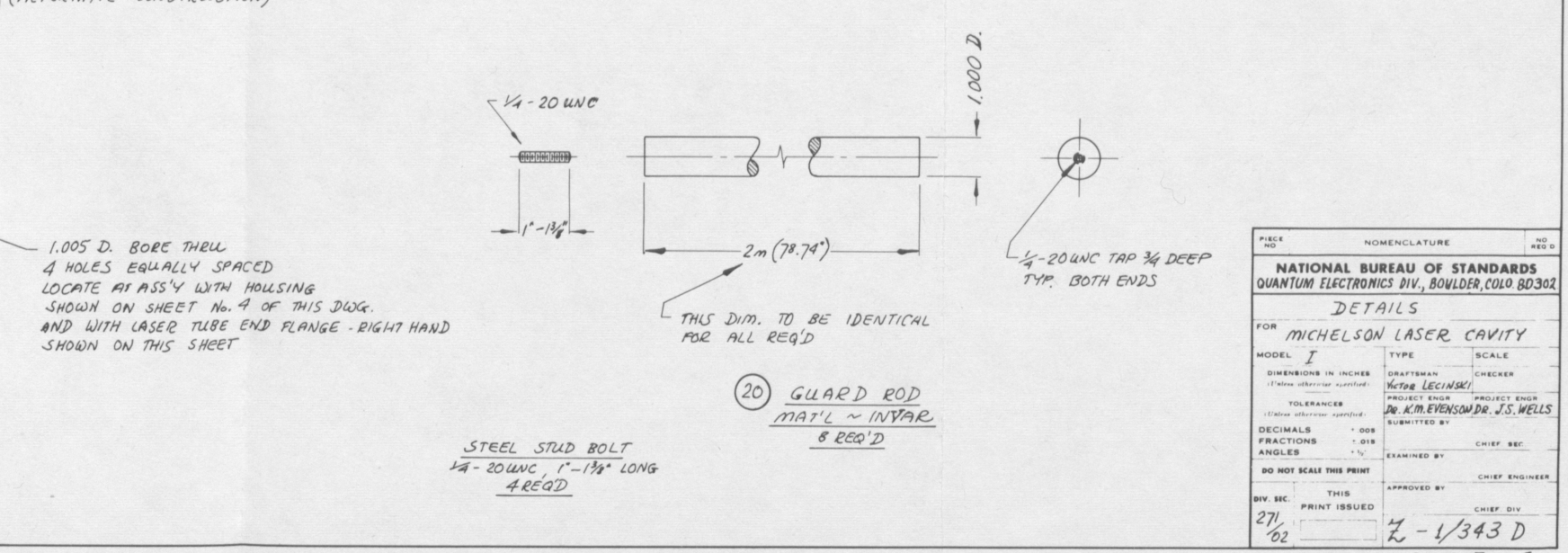
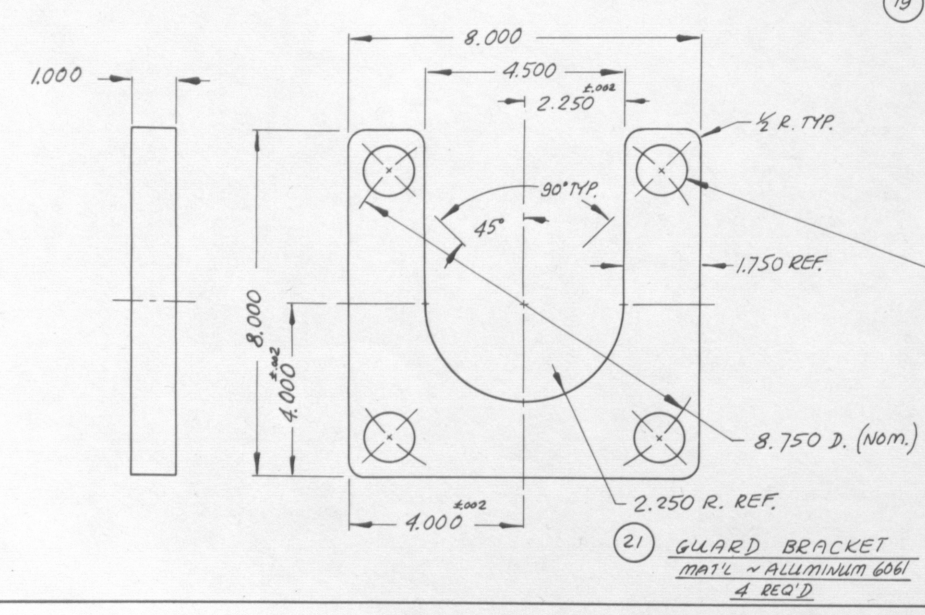
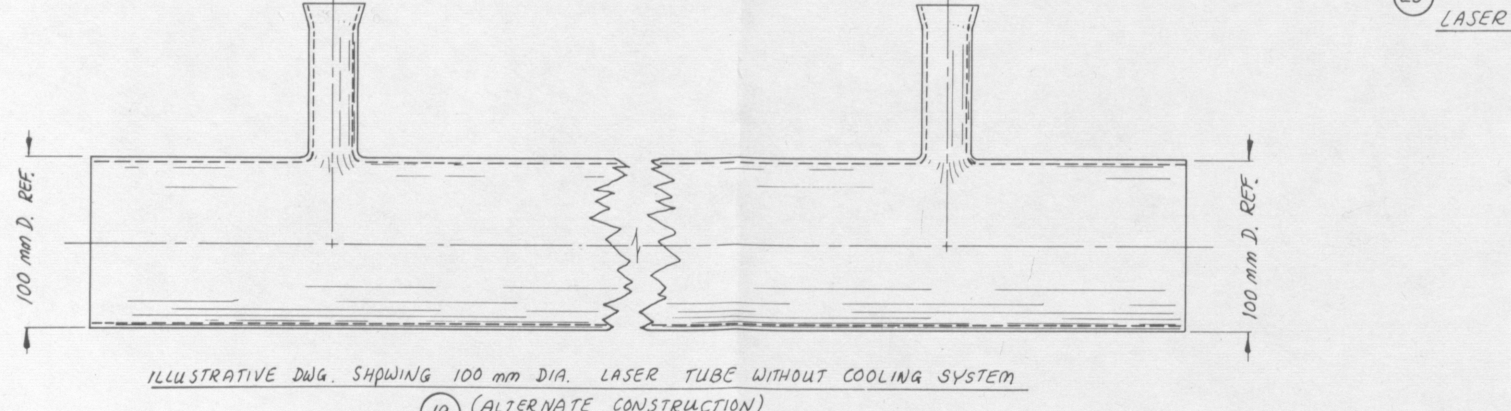
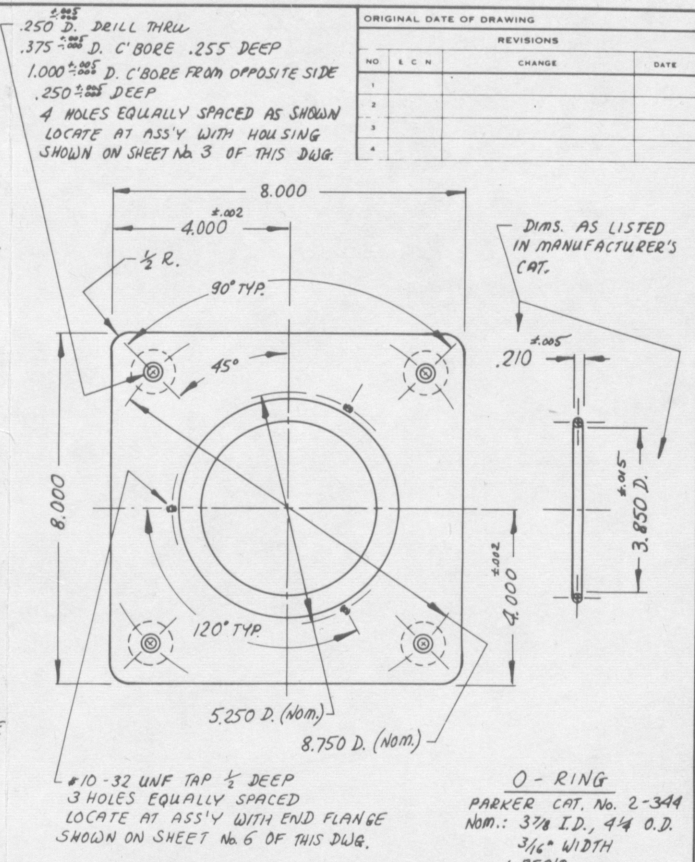
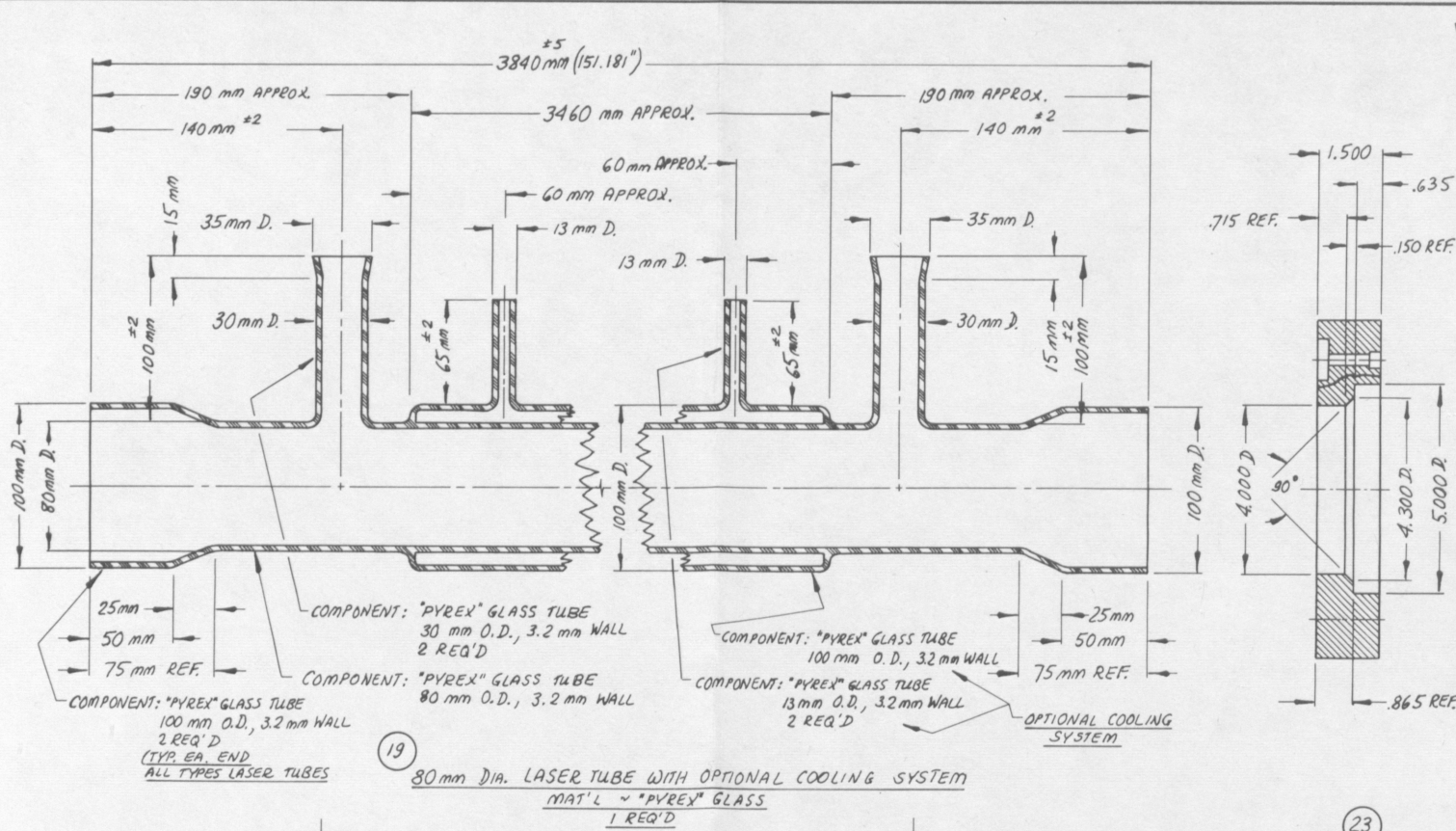
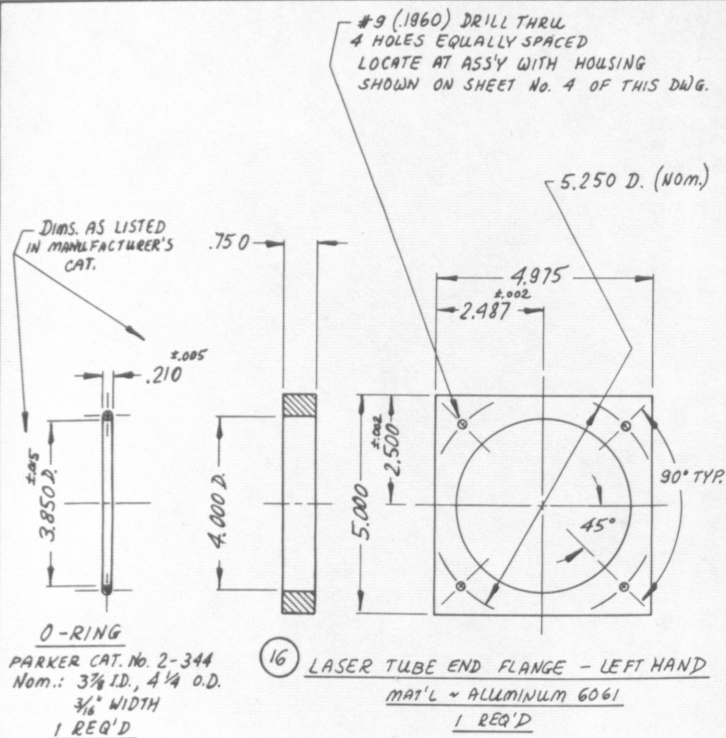
**14 TRANSPARENT MIRROR SUPPORT**  
MAT'L - ALUMINUM 6061  
1 REQ'D

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<b>DETAILS</b>		
FOR MICHELSON LASER CAVITY		
MODEL I	TYPE	SCALE
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAWN BY MICHAŁ UCIŃSKI	CHECKER
TOLERANCES (Unless otherwise specified)	PROJECT ENGR DAVID EVANSON	PROJECT ENGR DR. J.S. WELLS
DECIMALS ± .005	SUBMITTED BY	CHIEF SEC.
FRACTIONS ± .015	EXAMINED BY	CHIEF ENGINEER
ANGLES ± 1/2°	APPROVED BY	CHIEF DIV.
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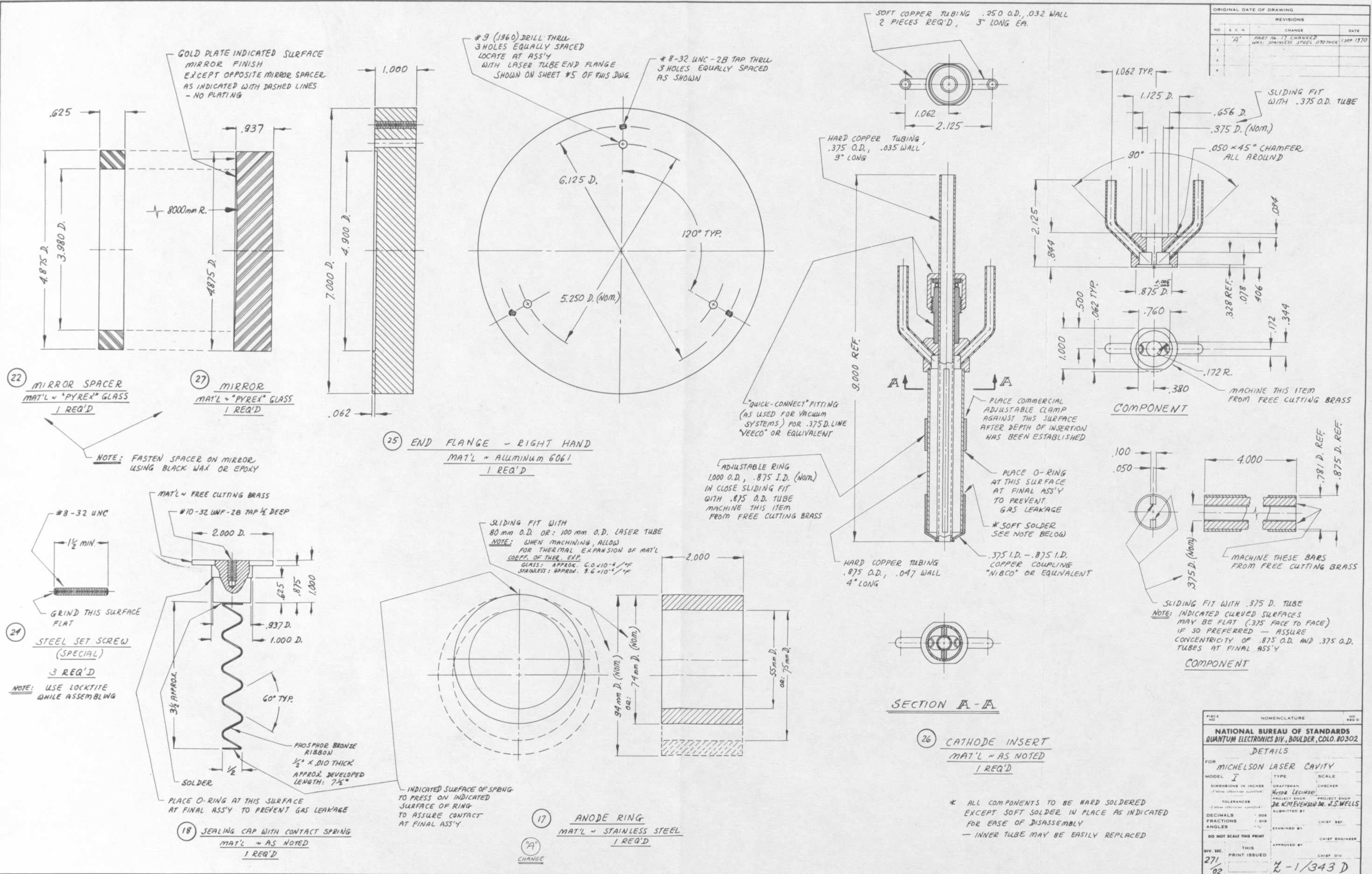
ORIGINAL DATE OF DRAWING		
REVISIONS		
NO	I.C.N.	DATE



PIECE NO.	NOMENCLATURE	NO. REQ'D
NATIONAL BUREAU OF STANDARDS QUANTUM ELECTRONICS DIV., BOULDER, COLO. 80302		
DETAILS		
FOR MICHELSON LASER CAVITY		
MODEL I	TYPE	SCALE
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN Victor LECINSKI	CHECKER
TOLERANCES (Unless otherwise specified)	PROJECT ENGINEER DR. ALM. EVENSON DR. J.S. WELLS	SUBMITTED BY
DECIMALS .008	EXAMINED BY	CHIEF SEC.
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ORIGINAL DATE OF DRAWING			
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1	"A"	PART NO. 17 CHANGED WAS: STAINLESS STEEL 0.070 THICK	1 SEP 1970
2			
3			
4			







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**WASHINGTON, D.C. 20230**

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