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Construction of a Flashlamp-Pumped Dye Laser and an Acousto-Optic Modulator for Mode-Locking

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D. A. Jennings and D. L. Baldwin

In this paper is presented the design of a flashlamp-pumped dye laser capable of emitting light pulses 500 ns wide (FWHM) with a risetime of 300 ns. The energy output in the visible region of light is 1 to 10 mJ with an energy conversion efficiency of about 0.01% at a repetition rate of 30 pps. The design of an acousto-optic modulator used to mode-lock the dye laser by intracavity loss modulation is presented. The laser output for a given cavity length depends on the frequency and voltage applied to the modulator; a 10% - 100% modulated output can be obtained with 1 V rms - 20 V rms, whereas a train of light pulses narrower than 0.8 ns (FWHM) can be obtained with 80 V rms.

Key Words: Acousto-optic modulator; flashlamp-pumped dye laser; mode-locking; sub-nanosecond pulses.

1. Introduction

Flashlamp-pumped dye lasers were first reported in 1967,[1] and improvements too numerous to mention have been reported since that date.[2] With the use of a grating or a few prisms and proper choice of dyes, a tuning range from 400 nm to 650 nm is accessible.

An excellent review article[3] on mode-locking of lasers is available. Mode-locking of a flashlamp-pumped dye laser at 460 nm has been reported.[4] The theory of mode-locking has been discussed by Di Domenico[5] and Harris.[6]

2. Dye Laser Construction

Several articles have described the construction of flashlamp-pumped dye lasers.[7], [8] However, these designs are for coaxial systems which do not lend themselves to fast repetition rates due to the inability for flashlamp cooling to be designed into the system. Heating of the dye solution will cause thermally induced index of refraction gradients which lower the quality of the optical cavity and hence inhibit the performance of the laser. What is needed is a system in which the flashlamp and dye solutions may be cooled separately. The use of elliptical pumping geometry is adaptable to this cooling requirement. In this part of the note we describe a flashlamp-pumped dye laser with elliptical pumping and repetition rates of up to 30 pps.

Several papers have discussed the use of elliptical geometries for laser pumping cavities.[9], [10], [11] A block diagram of the dye laser is shown in figure 1 complete with the ultrasonic modulator. The detailed construction drawings are shown in the foldouts 1-5.

The laser pumping cavity was an aluminum cylinder of elliptical cross section with a major axis of 5.4 cm and eccentricity of 0.45. The flashlamp and dye cell were placed at the foci of the ellipise. The interior surfaces of the pump cavity were highly polished. The output

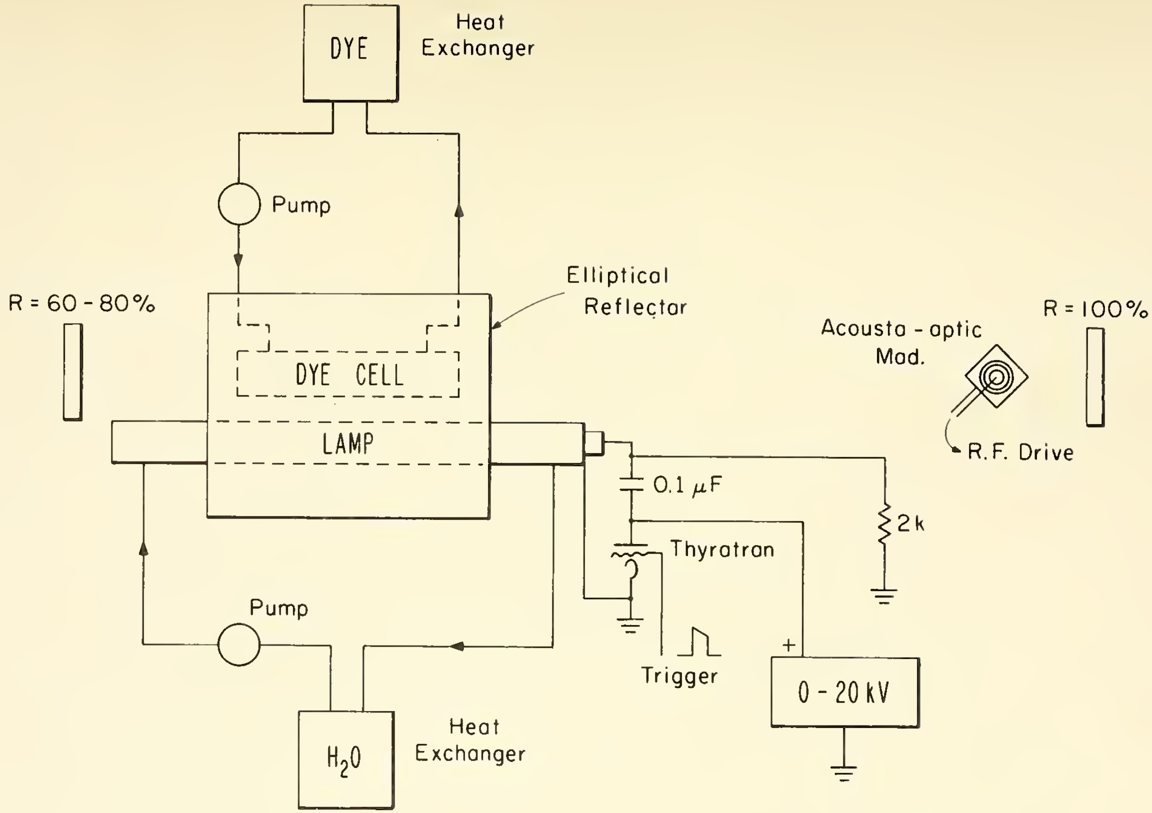


Figure 1. A block diagram of the dye laser with acousto-optic modulator in the cavity.

mirror was flat with a multilayer dielectric coating of 60 - 95% reflectivity. The other mirror was either a 2100 line/mm grating blazed at 500 nm in the first order with a reflectivity of 73% at 633 nm, or a 100% reflecting mirror. The mirror separation was 60 - 100 cm.

The dye laser uses 10^{-3} - 10^{-4} mole solution of Rhodamine 6G in ethanol. The dye solution was circulated at a flow rate of about 10 liters per minute. The flashlamp has a 9 cm arc length and a 3 mm bore and is water cooled. It is powered by a 0.1 μf, 20 KV, thyratron dumped capacitor. The flashlamp-pumping system is capable of 10 J per pulse and 30 pps.

Some operating characteristics of this dye laser without the modulator are as follows: the threshold using a 95% and 100% reflectivity mirror is 1 - 2 J, depending on the dye concentration. With an 80% reflectivity mirror and the grating, the threshold is around 5 J.

The peak emission of Rhodamine 6G is near 580 nm. However, by using methanol as a solvent for shorter wavelengths and high dye concentration in ethanol for longer wavelengths, we have been able to tune the laser from 560 to 630 nm. The line width of the emission using the grating is ~ 0.1 nm.

The flashlamp has a risetime (10 - 90% power points) of 300 ns and fall time of about the same with a 15% overshoot in the current pulse. The current pulse width is 700 ns full width at half maximum (FWHM). The laser output when pumped at 10 J is 200 - 500 ns (FWHM) in duration and 1 - 10 mJ, depending on mirror reflectivity, dye concentration, and wavelength.

3. Mode-Locking of the Dye Laser

3.1 Mode-Locking by Modulation Internal to the Cavity.

One can mode-lock a laser by modulating the losses of the cavity at a frequency near c/2L,[(12)] where c is the speed of light in a vacuum and L is the optical distance between the mirrors of the cavity. Modulation depths of a few percent to 50% internal to the cavity can give rise to 100% modulation of the laser output. In fact one can produce a train of pulses with subnanosecond widths separated by the cavity round trip transit time, in this case 10 ns. In this part of the note we describe the theory of modulation of light by acoustic waves, the construction of an acousto-optic modulator, and the results from mode-locking a dye laser.

3.2. Simplified Theory of Acousto-Optic Modulation.

In the acousto-optic method of mode-locking, the modulator is a fused quartz block excited at a longitudinal acoustic resonance. In our system the laser beam is incident parallel to the wave front of the standing acoustic wave; the laser beam diameter is much greater than the acoustic wavelength; the transit time of light through the block is short compared to the period of the acoustic wave; and the frequency of the acoustic wave is near one-half the frequency of the fundamental longitudinal mode of the laser cavity.

We use the Raman-Nath theory[13] to describe the diffraction of light by a sound wave. For a given width of the sound beam measured along the path traversed by the light, the maximum change in index of refraction, Δn, has an upper limit for the Raman-Nath theory to be applicable. Willard[14] gives an expression for the value of Δn above which the Raman-Nath theory yields the wrong quantitative results for the intensity of light in the various diffraction orders. Even so, from experiments we know that one may increase Δn past the limit given by Willard to produce additional modulation depths in the zero order diffracted beam of light. Thus, even for Δn so great that the Raman-Nath theory breaks down quantitatively it still yields the correct qualitative intensity for the undeviated beam of light.

A sound wave propagating through a material in the x-direction causes variation in the index of refraction:

$$n(x, t) = n_o + \Delta n \sin (k^* x - \omega^* t)$$

where $n(x, t)$ is the index of refraction with the confinement of the sound beam,

n_o is the index of refraction of the modulator material with no sound beam,

Δn is the maximum change in index of refraction,

k^* is the propagation constant of the sound wave, and

ω^* is the angular frequency of the sound wave.

In our case, the sound wave is a standing acoustic wave where:

$$n(x, t) = n_o + \Delta n (\cos k^* x)(\sin \omega^* t) \ .$$

The block then appears as a phase grating to light incident perpendicular to the x-axis. The analysis of light passing through a phase grating is very similar to the analysis of an ordinary diffraction grating, but one replaces the sum over the apertures of a diffraction grating with an integral over x. From the Raman-Nath theory we get for the intensity I of the undeviated beam passing through a traveling sound wave:

$$I = I_o \quad J_o^2 (\nu)$$

$$\nu = \frac{2\pi \Delta n W}{\lambda}$$

where ν is the Raman-Nath parameter,

λ is the wavelength of incident light,

W = the width of sound beam measured along the path traversed by the light,

I_o is the intensity of incident light, and

$J_o(\nu)$ is the zero order Bessel function.

Under the conditions listed above, this intensity is independent of time. In our modulator the light passes through a standing sound wave so one cannot neglect the time dependence of the index of refraction. In this case we have for the intensity of the undeviated beam:

$$I(t) = I_o J_o^2 (\nu \sin \omega^* t) \quad .$$

A fourier analysis[15] of I(t) will show that the fundamental frequency of modulation of the light is $f_m = 2 \frac{\omega^*}{2\pi} = \frac{\omega^*}{\pi}$. Modulation at this frequency dominates up to modulation depths on the order of 30% where the second harmonic begins to give appreciable distortion. Second harmonic distortion as produced here might even improve mode-locking.

3.3. Acousto-Optic Modulator and Other Apparatus for Mode-Locking a Dye Laser

The apparatus we used to mode-lock the dye laser consisted of a transducer bonded to a fused quartz block and a RF voltage source with variable frequency and voltage. The fused quartz block was a cube 1.4 cm on a side with two pair of opposite sides optically polished. It is desired that the two sides be parallel to within $\lambda^*/100$ (λ^* = wavelength of sound used) and flat to within $\lambda^*/100$. The two Brewster angle faces through which the light passes should be parallel to 10 min. of arc and flat to 1/5 of the optical wavelength.

The x-cut quartz transducer had a fundamental frequency of

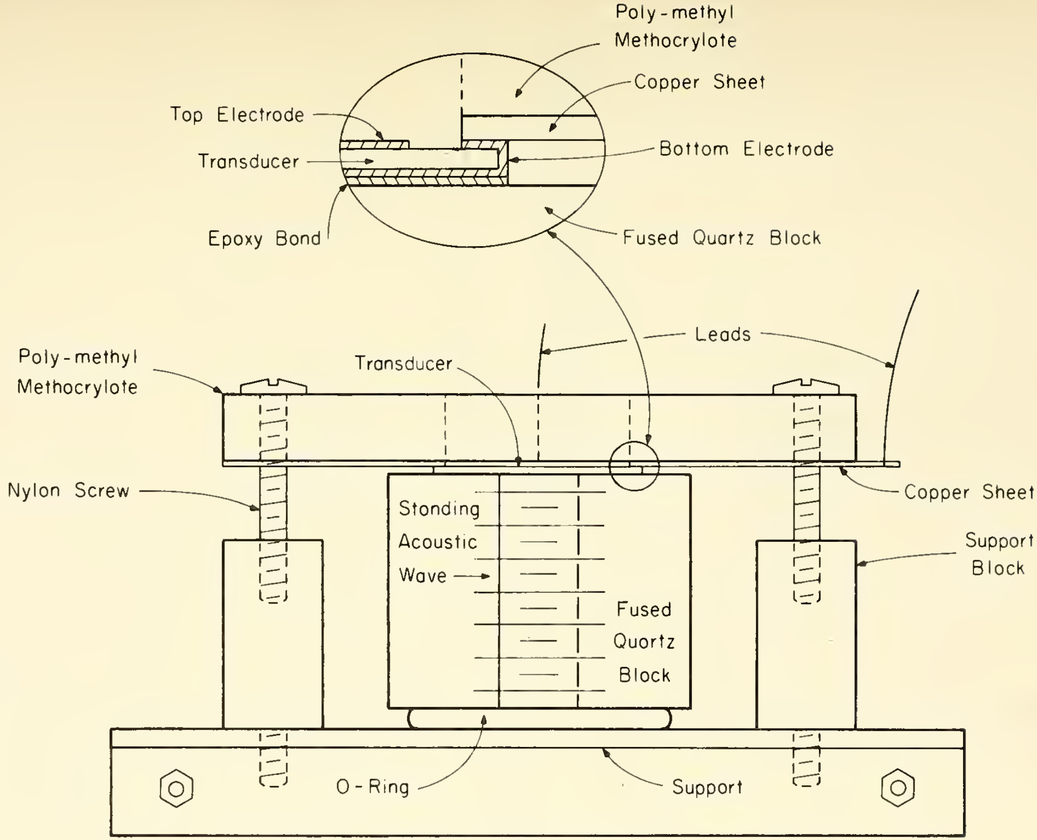


Figure 2. An end view of the acousto-optic modulator showing construction details.

20 MHz and was driven at its third harmonic. It was circular in shape, 1.3 cm in diameter, and it had evaporated gold electrodes. The top electrode was 1 cm in diameter. The bottom electrode covered the whole bottom of the transducer and wrapped around the edge of the transducer for electrical connection from the top. The transducer was bonded to the block with a clear epoxy spread thin with a razor blade. It is desired that the bond thickness be less than $\lambda^{*}/100$ and be uniform. A copper sheet with a 1.1 cm diameter hole was used to make contact to the lower electrode as shown in figure 2, since the thin gold plating wrapped around the transducer was troublesome when soldered to a small wire lead. It seems probable that the trouble could also have been avoided by evaporating gold right onto the fused quartz block for the lower electrode.

A signal generator providing up to 1.74 V rms into 50 Ω was used as the RF voltage source. It had an output bandwidth of less than 1 KHz and was easily tuned from 58 - 62 MHz with nearly constant output. The voltage was amplified to 20 - 150 V rms by a tuned push-pull tube amplifier. The quartz transducer with a 20 MHz fundamental frequency and a 1 cm diameter top electrode had a capacitance of 22.5 pf. The effective shunt resistance of the acousto-optic modulator was more than 50 KΩ when the drive frequency was a resonant frequency of the transducer and the fused quartz block.

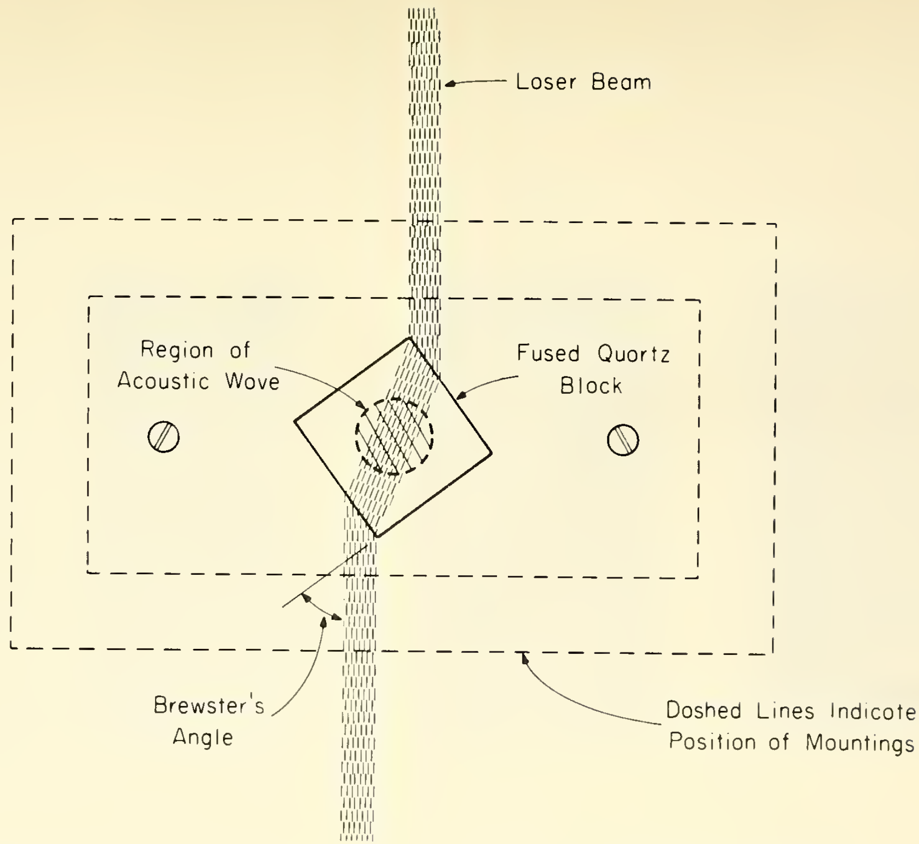
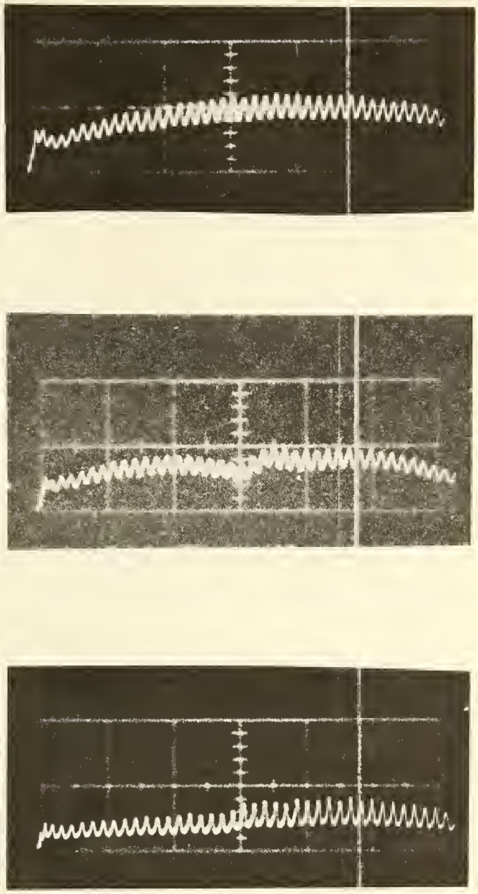


Figure 3. Top view of the acousto-optic modulator showing position of the laser beam.

Thus, undesirable operation would result from putting the modulator at the end of a coaxial cable. The best results were obtained by including the transducer as part of the resonant circuit of a tuned amplifier and mounting the modulator near this amplifier using tinned copper wires less than two inches long. Since one must match three frequencies, it is desirable that the applied frequency be easily adjustable at least over ± 2 MHz.

A cavity of optical length of 1.25 m was used with a modulator drive frequency of 60 MHz. To minimize reflection losses and to avoid resonances in sub-cavities of the system, the modulator was placed at Brewster's angle as shown in figure 3. For the same reason, the AR coated windows of the dye cavity were tilted a few degrees from normal incidence. The modulator was as close to the totally reflecting mirror as possible. The multi-layer, dielectric coated rear mirror reflected 99.9% of light at 580 nm wavelength and had a 2.15 m radius of curvature. Dielectric coated flat mirrors which transmitted for 5% - 20% of the light at 580 nm were used for the output mirror.

The detection equipment consisted of a vacuum biplaner photodiode driving an oscilloscope. The risetime (10% - 90% max. signal) of the photodiode depends on the DC voltage and is calculated to be 0.4 ns with 1000 V DC applied. The oscilloscope has a risetime of 0.28 ns giving a risetime of the system[16] as $\sqrt{0.4^2 + 0.28^2} = 0.48$ ns.

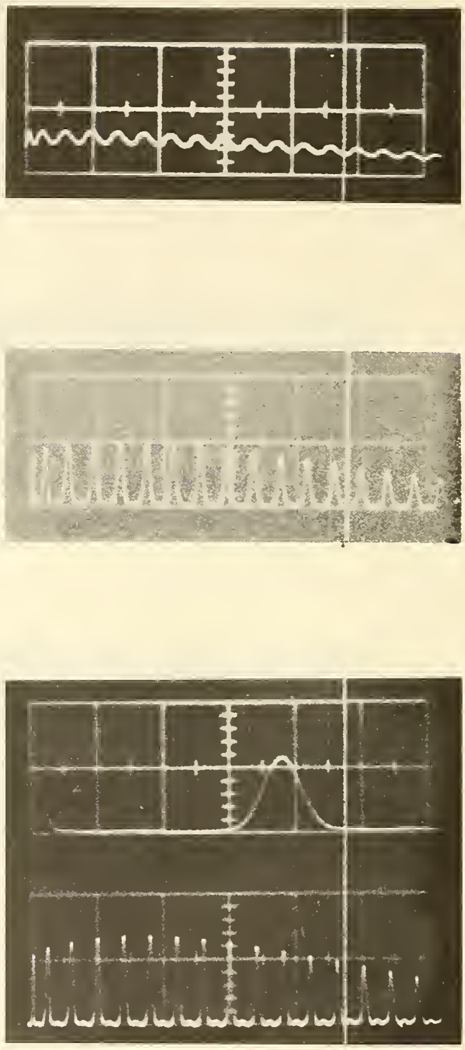


(a)

(b)

(c)

Figure 4. Oscilloscope traces of the dye laser output modulated by two passes through the acousto-optic modulator placed outside the cavity for various voltages applied to the modulator. (50 ns/cm sweep speed)
(a) 60 V rms; (b) 100 V rms; (c) 134 V rms



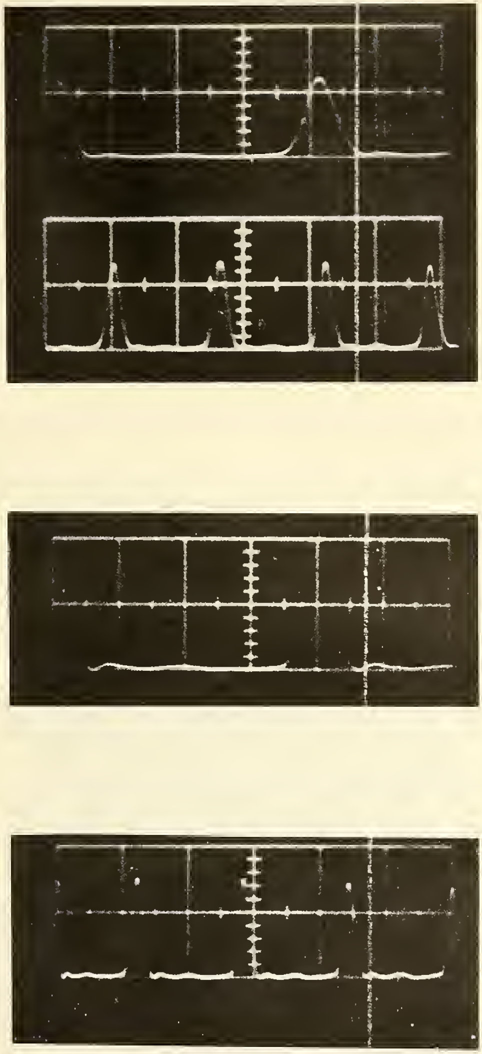
(a)

(b)

(c)

(d)

Figure 5. Oscilloscope traces of the dye laser output with the acousto-optic modulator inside the laser cavity for various voltages applied to the modulator.
(a) 10 V rms, 20 ns/cm; (b) 15 V rms, 20 ns/cm; (c) 30 V rms, 2 ns/cm; (d) 30 V rms, 20 ns/cm



(a)

(b)

(c)

(d)

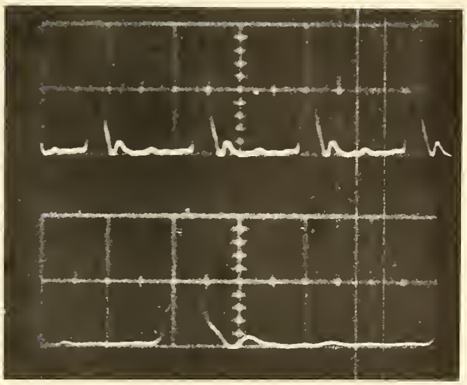
Figure 6. Oscilloscope traces of the dye laser output with the acousto-optic modulator inside the laser cavity for various voltages applied to the modulator.
(a) 80 V rms, 2 ns/cm; (b) 80 V rms, 5 ns/ cm
(c) 120 V rms, 2 ns/cm; (d) 120 V rms, 5 ns/cm

The photodiode is mounted in a housing with a 50 Ω output impedance. An impedance matching transformer was used to step up the impedance to the 125 Ω impedance of the oscilloscope.

3.4. Results of Using the Acousto-Optic Modulator to Mode-Lock the Dye Laser

The width of the pulses observed on the oscilloscope depended on the frequency of modulation and on the voltage applied to the modulator. Pulse widths of around 1.5 ns (FWHM) were independent of a frequency change of 200 KHz or 0.3%. The depth of modulation of light passing through the modulator increases with the RF voltage applied to the modulator as shown in figure 4. A modulation depth of a few percent per pass through the modulator is sufficient to produce a 50% modulation depth of the light leaving the laser. Modulation depths of 5% per pass produced pulses with widths less than 2 ns (FWHM). Modulation depths of 20% per pass produced pulses with widths less than 0.8 ns (FWHM). Results of the laser output with the modulator inside the cavity are shown in figures 5 and 6.

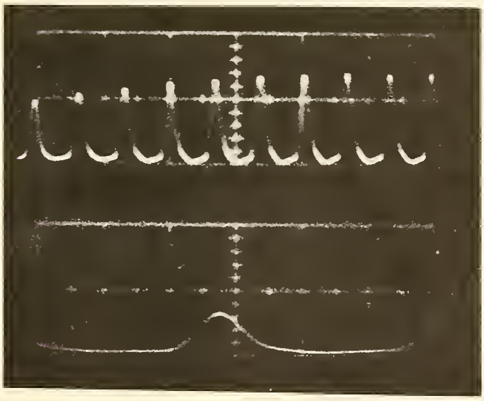
Pulses as narrow as 0.75 ns (FWHM) have been observed on the oscilloscope as shown in figure 7. The pulse shown has a risetime (10% - 90% max. signal) of 0.54 ns. Since the detection system has a risetime of about 0.5 ns, we believe that the actual light pulses are even narrower than indicated by the oscilloscope. Note that in figure 7



(a)

(b)

Figure 7. Oscilloscope traces of the dye laser output with the acousto-optic modulator inside the laser cavity after critical adjustment of frequency. 100 V rms is applied to the modulator.
(a) sweep speed of 5 ns/cm; (b) sweep speed of 2 ns/cm



(a)

(b)

Figure 8. Oscilloscope traces of the dye laser output with electro-optic modulator inside the laser cavity one meter long. Approximately 600 V rms on the modulator.
(a) 10 ns/cm; (b) 2 ns/cm

there is a second pulse whose amplitude is about 10% the maximum amplitude of the first pulse. This second pulse is about 1.8 ns after the main pulse. Independent measurements verify that the second pulse is a reflection of the first pulse from an impedance mismatch between the detector housing and the step up transformer.

The optical bandwidth of the dye laser depends on pump energy, dye concentration and mirror reflectivity. Measurements with a spectrometer indicate that the bandwidth for a given pump energy near threshold was about 5 nm with the modulator turned off and also with the modulator turned on producing a train of 1.5 ns pulses.

3.5. Other Methods of Mode-Locking

We have also tried to mode-lock the dye laser with an electro-optic modulator.(17)

Pulses as narrow as 1.8 ns (FWHM) as shown in figure 8 were obtained using this modulator with about 600 V rms applied at 75 MHz with a 1 meter cavity. The half wave voltage for the KD*P crystal we used was about 6 KV.

Pulses less than 1 ns wide were also obtained by placing a bleachable dye inside the cavity near one mirror,(18) but to get these pulses the concentration of the dyes had to be just right. This was very difficult to accomplish. A photograph of the shortest pulses obtained by this technique is shown in figure 9.

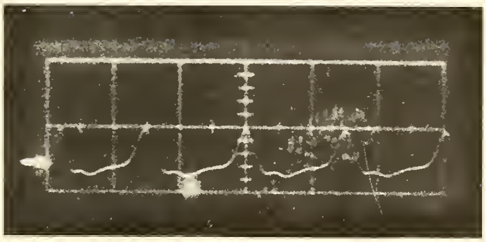


Figure 9. The dye laser output using saturable dye mode-locking, the sweep speed is 2 ns/cm.

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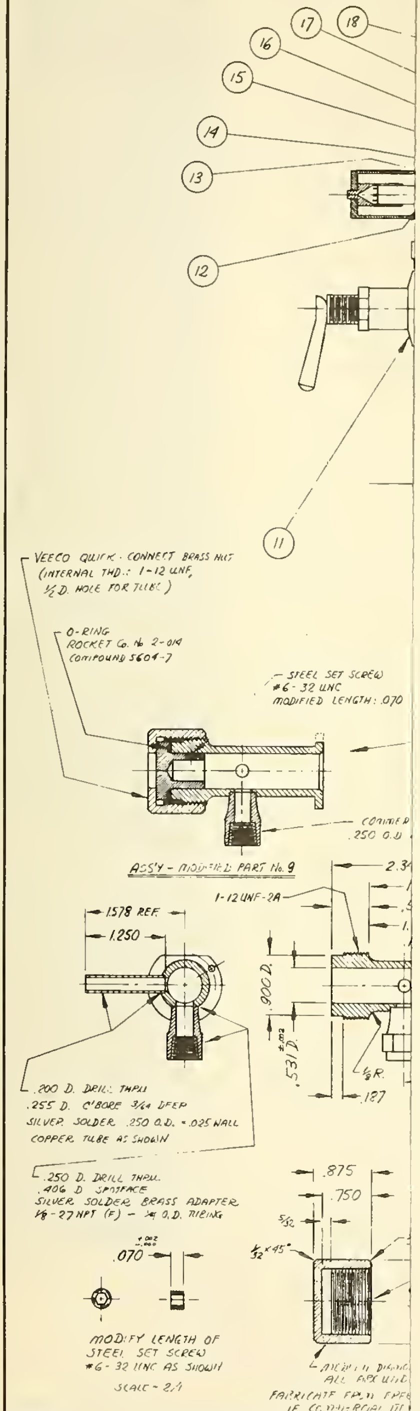

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LIST OF PARTS

*) STOCK PARTS

PIECE NO	NOMENCLATURE	No. REQ'D	PIECE NO	NOMENCLATURE	NO REQ'D
			30	INSULATOR MAT'L ~ "TEFLON"	1
			*29	XENON CORP WATER COOLING ADAPTER FOR LAMP 701 AR	1
			28	CONDUCTOR CLAMP MAT'L ~ FREE CUTTING BRASS	2
			*27	STEEL SCREW, # 4-40 UNC HEX. SOCKET HEAD ¼" LONG	4
*56	BRASS SCREW, # 4-40 UNC ROUND HD., ¼ LG	12	*26	STEEL SCREW # 4-40 UNC HEX SOCKET HEAD, 5/8" LONG	1
55	CONTACT SPRING MAT'L ~ BERYLLIUM COPPER	1	25	CLAMP ELECT. RETURN MAT'L ~ FREE CUTTING BRASS	1
54	NUT, CONTACT SPRING MAT'L ~ FREE CUTTING BRASS	1	24	MIRROR HOLDER MAT'L ~ FREE CUTTING BRASS	1
*53	RUBBER GROMMET (FOR ½" D. HOLE)	1	*23	ALIGNMENT PIN MAT'L ~ STEEL, .1250 D × ½" LG.	2
52	INSULATOR MAT'L ~ "PYREX" GLASS	1	22	LAMP FILTER JACKET MAT'L ~ QUARTZ	1
*51	H THYRATRON EG & G 7322/1802	1	*21	O-RING (COMPOUND 5604-7) ROCKET COMP. No. 2-018	2
50	CONNECTOR CAP TO THYRATRON MAT'L ~ STAINLESS STEEL 304	1	20	DYE CELL TUBE MAT'L ~ QUARTZ	1
*49	BRASS HEX. NUT # 10-32 UNF	2	*19	O-RING (COMPOUND 5604-7) ROCKET COMP. No. 2-010	2
*48	BRASS HEADLESS CONTACT SCREW # 10-32 UNF, 3½" LG.	1	*18	O-RING (COMPOUND 5604-7) ROCKET COMP. No. 2-008	2
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*46	STEEL SCREW, # 10-32 UNF HEX SOCKET HD., ½ LG	1	16	MIRROR HOLDER MAT'L ~ FREE CUTTING BRASS	1
45	MOUNTING CLAMP MAT'L ~ FREE CUTTING BRASS	1	*15	BRASS SCREW, # 3-56 UNF FILLISTER HEAD, 3/8" LONG	6
*44	CAP 0.2 μf CONDENSER PROD. # EB 204-20 MP	1	*14	O-RING (COMPOUND 5604-7) ROCKET COMP. No. 2-014	3
43	INSULATOR MAT'L ~ "TEFLON"	1	13	LAMP WATER JACKET MAT'L ~ QUARTZ	1
42	TOP COVER MAT'L ~ FREE CUTTING BRASS	1	*12	FLASH LAMP XENON CORP. # 701 AR	1
41	SHIELD CAP & THYRATRON MAT'L ~ FREE CUTTING BRASS	1	*11	PET COCK VALVE ⅛-27 NPT (USE OPTIONAL)	1
40	CONDUCTOR CLAMP MAT'L ~ FREE CUTTING BRASS	2	*10	BRASS SCREW, # 4-40 UNC FILLISTER HEAD, ¼" LONG	3
*39	STEEL SCREW, # 4-40 UNC HEX. SOCKET HEAD, ¼ LONG	4	9	LAMP SHIELD & ELEC. RETURN MAT'L ~ FREE CUTTING BRASS	1
*38	STEEL SCREW, # 4-40 UNC HEX. SOCKET HEAD, ⅛ LONG	1	8	CAVITY END PLATE (LEFT H.) MAT'L ~ ALUMINUM	1
*37	BRASS HEX. NUT 3/8 - 16 UNC	1	*7	BRASS SCREW # 8-32 UNC FILLISTER HEAD, 2" LONG	2
*36	STEEL ROLL PIN ⅛" DIA. × ½ LONG	1	6	CAVITY REMOVABLE HALF-SECT. MAT'L ~ ALUMINUM	1
35	BUSBAR CONDUCTOR MAT'L ~ COPPER	1	5	CAVITY, NON-REMOVABLE HALF-SECT. MAT'L ~ ALUMINUM	1
*34	BRASS SCREW # 4-40 UNC BINDING HEAD, ¼" LONG	2	4	CAVITY END PLATE (RIGHT H.) MAT'L ~ ALUMINUM	1
33	INSULATOR MAT'L ~ "TEFLON"	1	*3	BRASS SCREW, # 6-32 UNC FILLISTER HEAD, ½" LONG	4
32	BUSBAR CONDUCTOR MAT'L ~ COPPER	1	*2	BRASS SCREW, # 4-40 UNC FILLISTER HEAD, ¼" LONG	3
31	BUSBAR CONDUCTOR MAT'L ~ COPPER	1	1	LAMP SHIELD & ELEC. RETURN MAT'L ~ FREE CUTTING BRASS	1

NATIONAL BUREAU OF STANDARDS

RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302

ASSEMBLY DYE LASER SYSTEM

FOR RESEARCH

MODEL I	TYPE	SCALE 1/1
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN Victor Lecinski	CHECKED
TOLERANCES (Unless otherwise specified)	PROJECT ENGR Dr. D.A. Jennings	PROJECT ENGR
DECIMALS ± .005 FRACTIONS ± .010 ANGLES ± ½°	SUBMITTED BY	CHIEF SEC
DO NOT SCALE THIS PRINT	EXAMINED BY	CHIEF ENGINEER
DIV. SEC. 271, 05 — THIS PRINT ISSUED	APPROVED BY	CHIEF DIV

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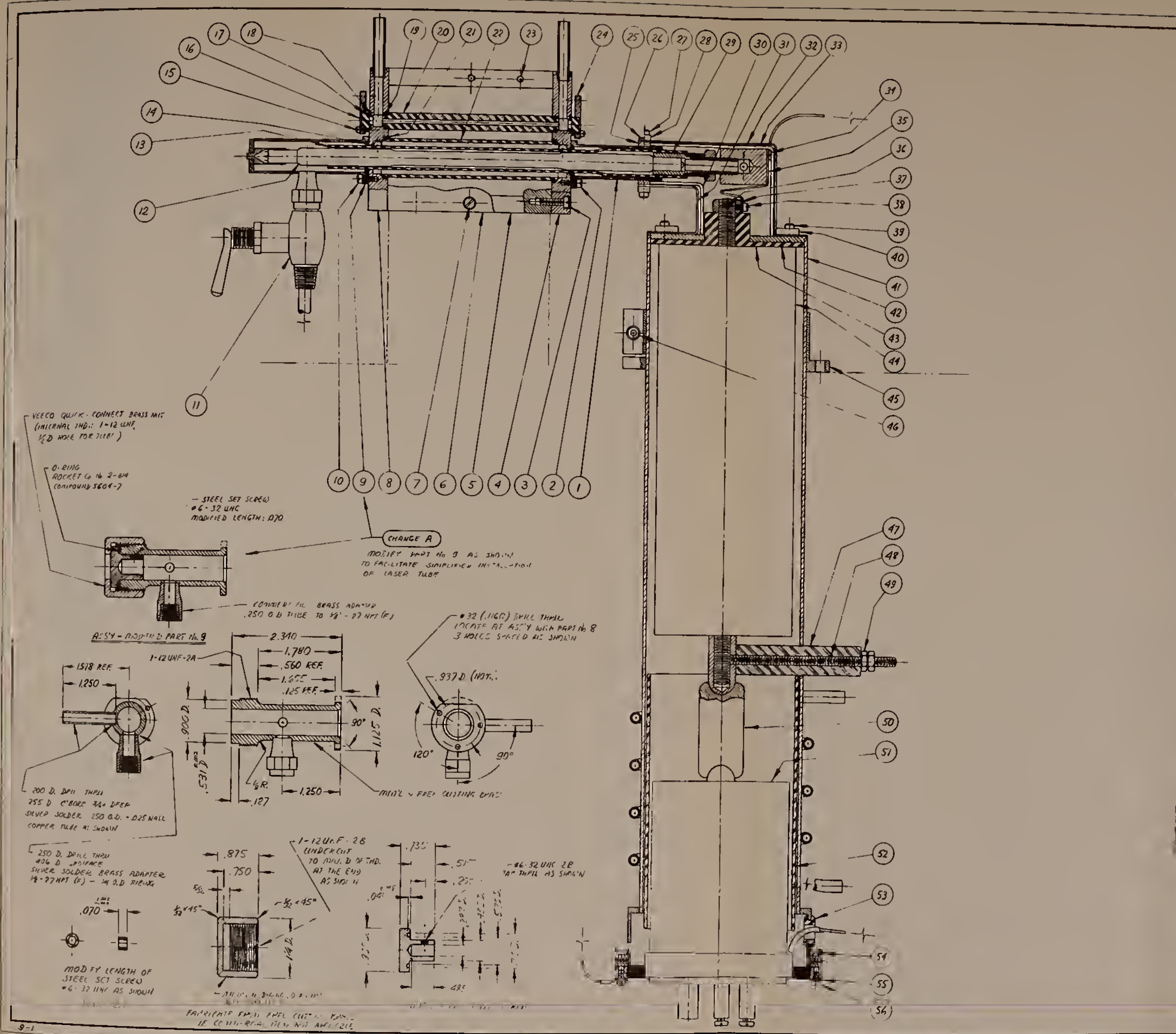
SHEET 1 OF 5



LIST OF PARTS

*) STOCK PARTS

PART NO.	NOMENCLATURE	NO. REQ'D
*56	BRASS SCREW, #4-40 UNC ROUND HD. 1/4 LG	12
55	CONTACT SPRING MAT'L - BERYLLIUM COPPER	1
54	NUT, CONTACT SPRING MAT'L - FREE CUTTING BRASS	1
*53	RUBBER GROMMET (FOR 1/2" D HOLE)	1
52	INSULATOR MAT'L - "PYREX" GLASS	1
*51	H THYRATRON EG & G 7322 / 1802	1
50	CONNECTOR CAP TO THYRATRON MAT'L - STAINLESS STEEL 304	1
*49	BRASS HEX NUT #10-32 UNF	2
*48	BRASS HEADLESS CONTACT SCREW #10-32 UNF, 3 1/2" LG	1
47	INSULATOR MAT'L - "TEFLON"	1
*46	STEEL SCREW, #10-32 UNF HEX SOCKET HD., 1/2 LG	1
45	MOUNTING CLAMP MAT'L - FREE CUTTING BRASS	1
*44	CAP 0.2 μf CONDENSER MOD # EB 204 - 20 MP	1
43	INSULATOR MAT'L - "TEFLON"	1
42	TOP COVER MAT'L - FREE CUTTING BRASS	1
41	SHIELD CAP & THYRATRON MAT'L - FREE CUTTING BRASS	1
40	CONDUCTOR CLAMP MAT'L - FREE CUTTING BRASS	2
*39	STEEL SCREW, #4-40 UNC HEX SOCKET HEAD, 1/4 LONG	4
*38	STEEL SCREW, #4-40 UNC HEX SOCKET HEAD, 1/2 LONG	1
*37	BRASS HEX. NUT 3/8 - 16 UNC	1
*36	STEEL ROLL PIN 1/8" DIA. x 1/2 LONG	1
35	BUSBAR, CONDUCTOR MAT'L - COPPER	1
*34	BRASS SCREW #4-40 UNC BINDING HEAD, 1/4" LONG	2
33	INSULATOR MAT'L - "TEFLON"	1
32	BUSBAR CONDUCTOR MAT'L - COPPER	1
31	BUSBAR CONDUCTOR MAT'L - COPPER	1
30	INSULATOR MAT'L - "TEFLON"	1
*29	XENON CORP WATER COOLING ADAPTER FOR LAMP 701 AR	1
28	CONDUCTOR CLAMP MAT'L - FREE CUTTING BRASS	2
*27	STEEL SCREW, #4-40 UNC HEX SOCKET HEAD 1/4" LONG	4
*26	STEEL SCREW #4-40 UNC HEX SOCKET HEAD 5/8" LONG	1
25	CLAMP ELECT. RETURN MAT'L - FREE CUTTING BRASS	1
24	MIRROR HOLDER MAT'L - FREE CUTTING BRASS	1
*23	ALIGNMENT PIN MAT'L - STEEL, .050 D x 1/4" LG	2
22	LAMP FILTER JACKET MAT'L - QUARTZ	1
*21	O-RING (COMPOUND 5604-7) ROCKET COMP No 2-018	2
20	DYE CELL TUBE MAT'L - QUARTZ	1
*19	O-RING (COMPOUND 5604-7) ROCKET COMP. No 2-010	2
*18	O-RING (COMPOUND 5604-7) ROCKET COMP. No 2-008	2
17	OUTPUT MIRROR MAT'L - OPTICAL QUARTZ	2
16	MIRROR HOLDER MAT'L - FREE CUTTING BRASS	1
*15	BRASS SCREW, #3-56 UNF FILLISTER HEAD 3/4" LONG	6
*14	O-RING (COMPOUND 5604-7) ROCKET COMP. No. 2-014	3
13	LAMP WATER JACKET MAT'L - QUARTZ	1
*12	FLASH LAMP XENON CORP. # 701 AR	1
*11	PET COCK VALVE 1/8 - 27 NPT	1
*10	BRASS SCREW #4-40 UNC FILLISTER HEAD 1/4" LONG	3
9	LAMP SHIELD & ELEC. RETURN MAT'L - FREE CUTTING BRASS	1
8	CAVITY END PLATE (LEFT H.) MAT'L - ALUMINUM	1
*7	BRASS SCREW #8-32 UNF FILLISTER HEAD 2" LONG	2
6	CAVITY REMOVABLE HALF SECT. MAT'L - ALUMINUM	1
5	CAVITY, NON-REMOVABLE HALF SECT. MAT'L - ALUMINUM	1
4	CAVITY END PLATE (RIGHT H.) MAT'L - ALUMINUM	1
*3	BRASS SCREW #6-32 UNC FILLISTER HEAD, 1/2" LONG	4
*2	BRASS SCREW #4-40 UNC FILLISTER HEAD 1/4" LONG	3
1	LAMP SHIELD & ELEC. RETURN MAT'L - FREE CUTTING BRASS	1

ORIGINAL DATE OF DRAWING FEB 4 1972

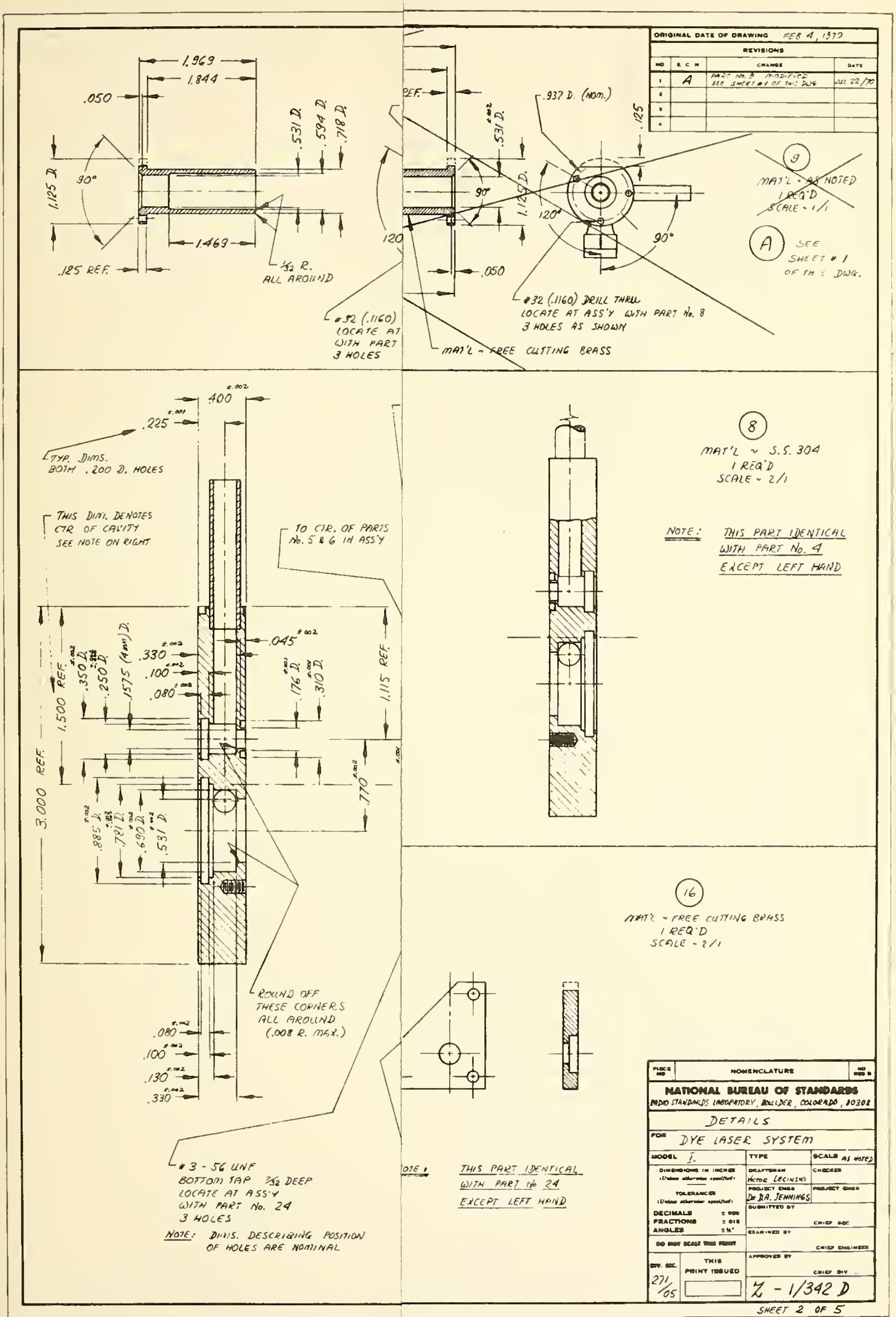
NATIONAL BUREAU OF STANDARDS

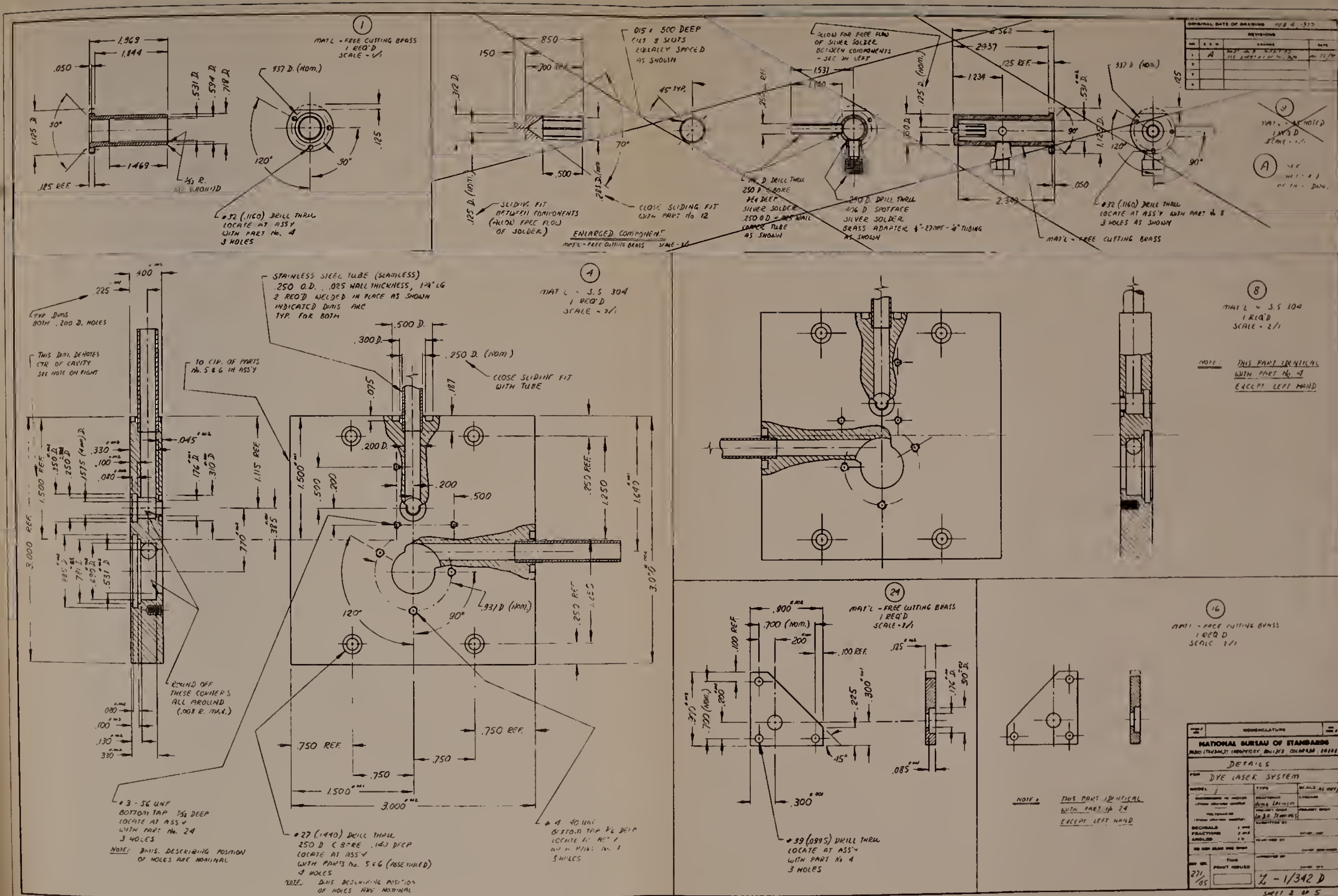
ASSEMBLY / DYE LASER SYSTEM

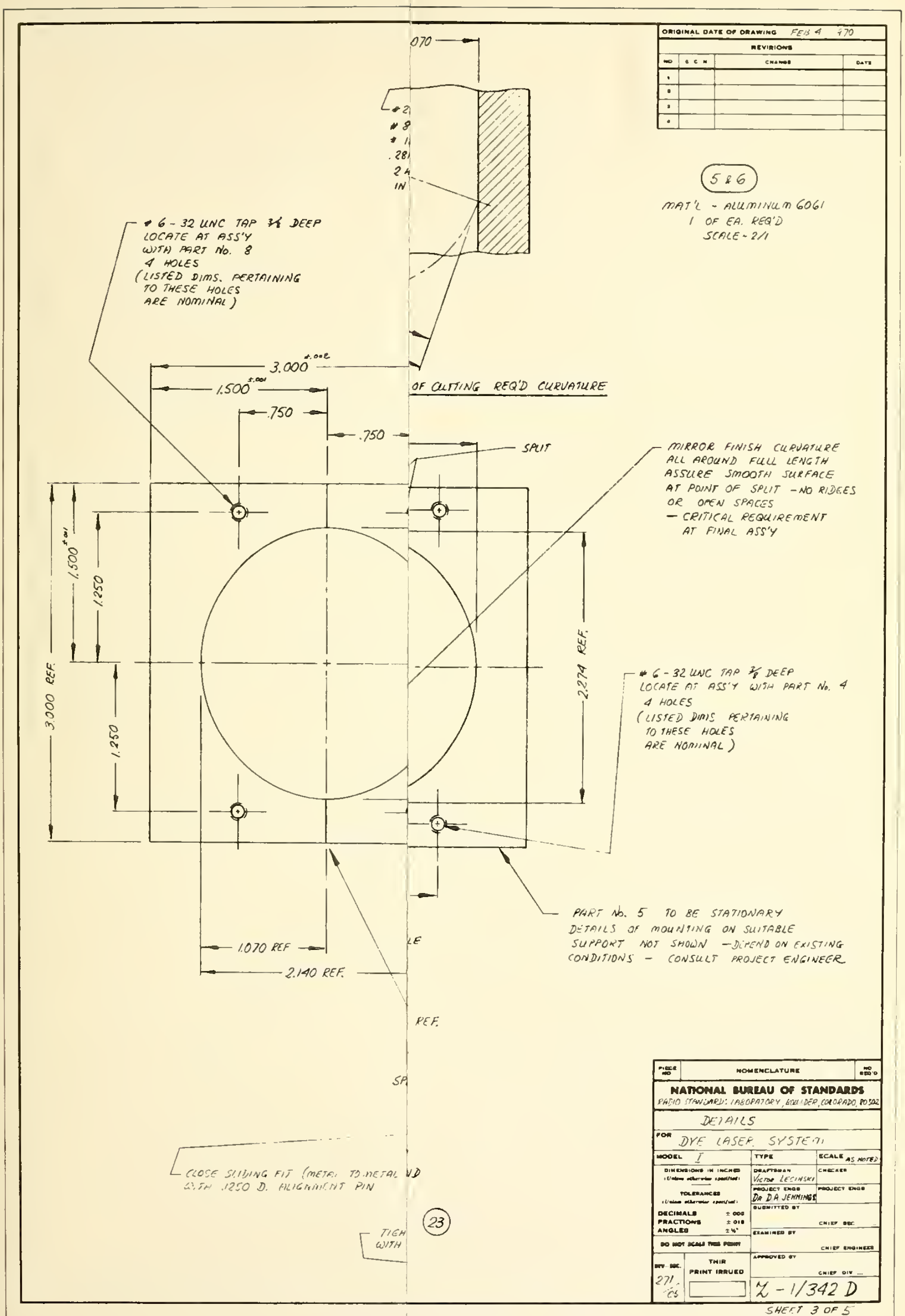
RESEARCH

Z - 1/342 D

SHEET 1 OF 5


ORIGINAL DATE OF DRAWING FEB 4, 1970
REVISIONS
NO | E C N | CHANGE | DATE
1 | A | PART No. 9 MODIFIED SEE SHEET #1 OF THIS DWG | JUL 22/70
1.969
1.844
.050
.531 D.
.594 D.
.718 D.
1.125 D.
90°
1.469
.125 REF.
1/32 R. ALL AROUND
.937 D. (nom.)
.125
120°
90°
.050
#32 (.1160) DRILL THRU LOCATE AT ASS'Y WITH PART No. 8 3 HOLES AS SHOWN
#32 (.1160) LOCATE AT WITH PART 3 HOLES
MAT'L ~ FREE CUTTING BRASS
9
MAT'L ~ AS NOTED 1 REQ'D SCALE ~ 1/1
A SEE SHEET #1 OF THIS DWG.
.400
.225
TYP. DIMS. BOTH .200 D. HOLES
THIS DIM. DENOTES CTR OF CAVITY SEE NOTE ON RIGHT
TO CTR. OF PARTS No. 5 & 6 IN ASS'Y
.045
.330
.100
.080
1.500 REF.
.350 D.
.250 D.
.1575 (4mm) D.
.176 D.
.310 D.
1.115 REF.
3.000 REF.
.885 D.
.781 D.
.690 D.
.531 D.
.770
ROUND OFF THESE CORNERS ALL AROUND (.008 R. MAX.)
.080
.100
.130
.330
#3-56 UNF BOTTOM TAP 5/32 DEEP LOCATE AT ASS'Y WITH PART No. 24 3 HOLES
NOTE: DIMS. DESCRIBING POSITION OF HOLES ARE NOMINAL
8
MAT'L ~ S.S. 304 1 REQ'D SCALE ~ 2/1
NOTE: THIS PART IDENTICAL WITH PART No. 4 EXCEPT LEFT HAND
16
MAT'L ~ FREE CUTTING BRASS 1 REQ'D SCALE ~ 2/1
NOTE: THIS PART IDENTICAL WITH PART No 24 EXCEPT LEFT HAND
NOMENCLATURE
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
DETAILS
FOR DYE LASER SYSTEM
MODEL I.
SCALE AS NOTED
DRAFTSMAN Victor Lecinski
PROJECT ENGR Dr D.A. JENNINGS
DO NOT SCALE THIS PRINT
271/05
Z - 1/342 D
SHEET 2 OF 5


MAT'L - FREE CUTTING BRASS
1 REQ'D
.937 D. (Nom.)
.125 REF.
#32 (.1160) DRILL THRU
LOCATE AT ASS'Y
WITH PART No. 4
3 HOLES
.015 x .500 DEEP
CUT 8 SLOTS
EQUALLY SPACED
AS SHOWN
SLIDING FIT
BETWEEN COMPONENTS
(ALLOW FREE FLOW
OF SOLDER)
CLOSE SLIDING FIT
WITH PART No. 12
ENLARGED COMPONENT
SILVER SOLDER
COPPER TUBE
AS SHOWN
SILVER SOLDER
BRASS ADAPTER
MAT'L - FREE CUTTING BRASS
STAINLESS STEEL TUBE (SEAMLESS)
.250 O.D., .025 WALL THICKNESS, 1/4" LG
2 REQ'D WELDED IN PLACE AS SHOWN
INDICATED DIMS ARE
TYP. FOR BOTH
MAT'L - S.S 304
1 REQ'D
SCALE - 2/1
.250 D. (Nom)
CLOSE SLIDING FIT
WITH TUBE
TO C.P. OF PARTS
No. 5 & 6 IN ASS'Y
THIS DIM. DENOTES
CTR OF CAVITY
SEE NOTE ON RIGHT
.937 D (Nom.)
ROUND OFF
THESE CORNERS
ALL AROUND
#3 - 56 UNF
BOTTOM TAP
LOCATE AT ASS'Y
WITH PART No. 24
3 HOLES
NOTE: DIMS. DESCRIBING POSITION
OF HOLES ARE NOMINAL
#27 (.1440) DRILL THRU
LOCATE AT ASS'Y
WITH PARTS No. 5 & 6 (ASSEMBLED)
4 HOLES
NOTE. DIMS DESCRIBING POSITION
OF HOLES ARE NOMINAL
MAT'L - S.S 304
1 REQ'D
SCALE - 2/1
NOTE: THIS PART IDENTICAL
WITH PART No. 4
EXCEPT LEFT HAND
MAT'L - FREE CUTTING BRASS
1 REQ'D
SCALE - 2/1
#39 (.0995) DRILL THRU
LOCATE AT ASS'Y
WITH PART No. 4
3 HOLES
NOTE: THIS PART IDENTICAL
WITH PART No. 24
EXCEPT LEFT HAND
NATIONAL BUREAU OF STANDARDS
DETAILS
DYE LASER SYSTEM
SHEET 2 OF 5



ORIGINAL DATE OF DRAWING FEB 4 1970
REVISIONS
NO | E C N | CHANGE | DATE
5 & 6
MAT'L - ALUMINUM 6061
1 OF EA. REQ'D
SCALE - 2/1
6 - 32 UNC TAP 3/8 DEEP
LOCATE AT ASS'Y
WITH PART No. 8
4 HOLES
(LISTED DIMS. PERTAINING
TO THESE HOLES
ARE NOMINAL)
.070
3.000
1.500
.750
.750
OF CUTTING REQ'D CURVATURE
SPLIT
MIRROR FINISH CURVATURE
ALL AROUND FULL LENGTH
ASSURE SMOOTH SURFACE
AT POINT OF SPLIT - NO RIDGES
OR OPEN SPACES
- CRITICAL REQUIREMENT
AT FINAL ASS'Y
3.000 REF.
1.500
1.250
1.250
2.274 REF.
6 - 32 UNC TAP 3/8 DEEP
LOCATE AT ASS'Y WITH PART No. 4
4 HOLES
(LISTED DIMS PERTAINING
TO THESE HOLES
ARE NOMINAL)
PART No. 5 TO BE STATIONARY
DETAILS OF MOUNTING ON SUITABLE
SUPPORT NOT SHOWN - DEPEND ON EXISTING
CONDITIONS - CONSULT PROJECT ENGINEER
1.070 REF
2.140 REF.
REF.
CLOSE SLIDING FIT (METAL TO METAL
WITH .1250 D. ALIGNMENT PIN
NOMENCLATURE
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
DETAILS
FOR DYE LASER SYSTEM
MODEL I
SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ± .005
FRACTIONS ± .015
ANGLES ± ½°
DO NOT SCALE THIS PRINT
DRAFTSMAN Victor Lecinski
PROJECT ENGR Dr D A JENNINGS
SUBMITTED BY
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EXAMINED BY
CHIEF ENGINEER
APPROVED BY
CHIEF DIV
THIS PRINT ISSUED
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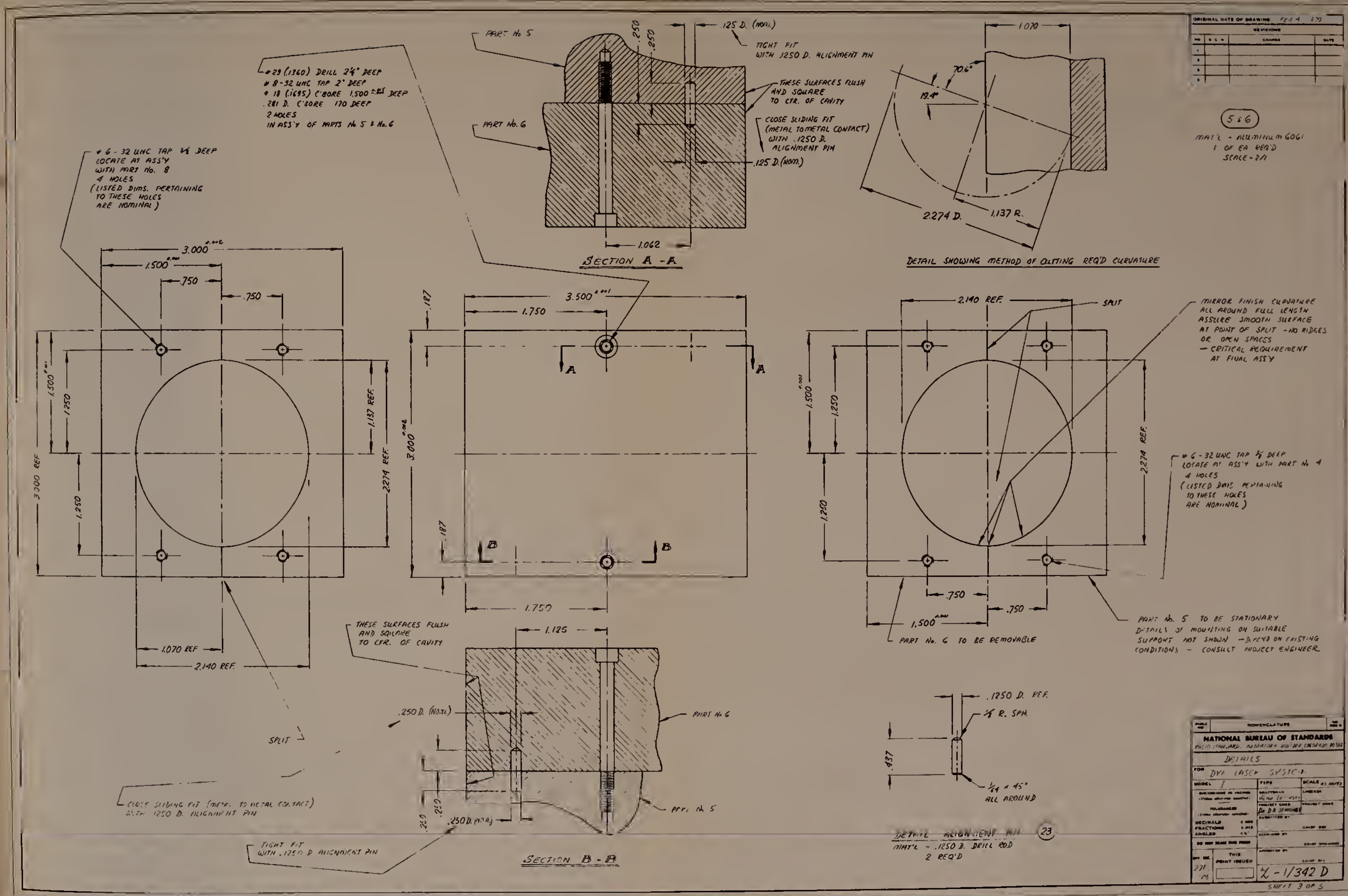
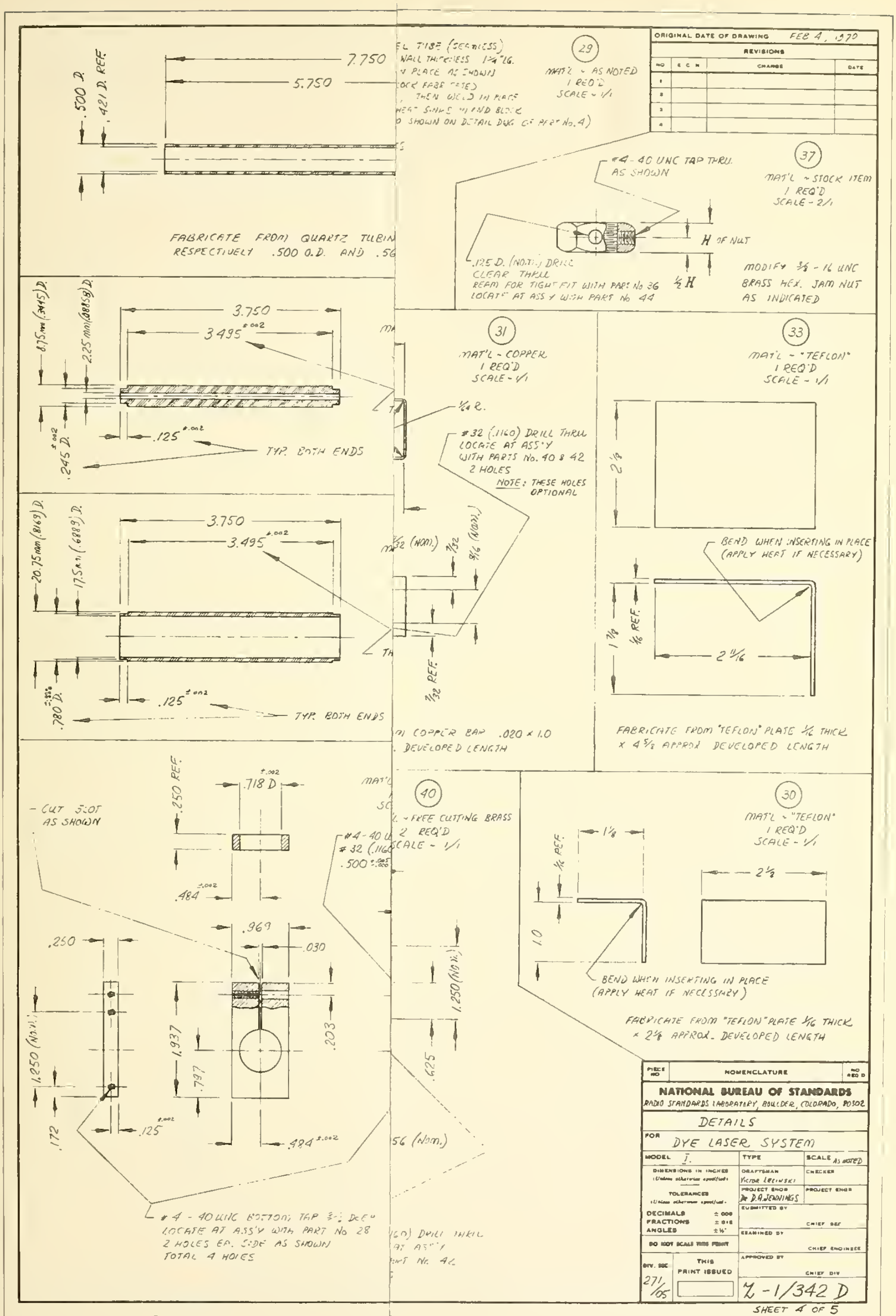
Z - 1/342 D
SHEET 3 OF 5


PART No 5
PART No. 6
.125 D. (NOM.)
TIGHT FIT WITH .1250 D. ALIGNMENT PIN
THESE SURFACES FLUSH AND SQUARE TO CTR. OF CAVITY
CLOSE SLIDING FIT (METAL TO METAL CONTACT) WITH .1250 D. ALIGNMENT PIN
.125 D. (NOM.)
1.062
SECTION A - A
1.070
70.6°
19.4°
2.274 D.
1.137 R.
DETAIL SHOWING METHOD OF CUTTING REQ'D CURVATURE
5 & 6
MAT'L - ALUMINUM 6061
1 OF EA REQ'D
SCALE - 2/1
#29 (.1360) DRILL 2¼" DEEP
8-32 UNC TAP 2" DEEP
18 (.1695) C'BORE 1.500 DEEP
.281 D. C'BORE .170 DEEP
2 HOLES
IN ASS'Y OF PARTS No. 5 & No. 6
6 - 32 UNC TAP ¼ DEEP
LOCATE AT ASS'Y WITH PART No. 8
4 HOLES
(LISTED DIMS. PERTAINING TO THESE HOLES ARE NOMINAL)
3.000
1.500
.750
.750
3.500
1.750
2.140 REF.
SPLIT
MIRROR FINISH CURVATURE ALL AROUND FULL LENGTH
ASSURE SMOOTH SURFACE AT POINT OF SPLIT - NO RIDGES OR OPEN SPACES
- CRITICAL REQUIREMENT AT FINAL ASS'Y
1.500
1.250
1.137 REF.
2.274 REF.
3.000 REF
1.250
3.000
.187
A
B
6 - 32 UNC TAP ⅜ DEEP
LOCATE AT ASS'Y WITH PART No. 4
4 HOLES
(LISTED DIMS PERTAINING TO THESE HOLES ARE NOMINAL)
1.750
1.070 REF
2.140 REF.
.750
.750
1.500
PART No. 6 TO BE REMOVABLE
PART No. 5 TO BE STATIONARY
DETAILS OF MOUNTING ON SUITABLE SUPPORT NOT SHOWN - DEPEND ON EXISTING CONDITIONS - CONSULT PROJECT ENGINEER
THESE SURFACES FLUSH AND SQUARE TO CTR. OF CAVITY
1.125
.250 D. (NOM.)
PART No. 6
PART No. 5
CLOSE SLIDING FIT (METAL TO METAL CONTACT) WITH .1250 D. ALIGNMENT PIN
TIGHT FIT WITH .1250 D ALIGNMENT PIN
.250 D. (NOM.)
SECTION B - B
.1250 D. REF.
⅛ R. SPH.
.437
1/64 x 45° ALL AROUND
DETAIL ALIGNMENT PIN
23
MAT'L - .1250 D. DRILL ROD
2 REQ'D
NATIONAL BUREAU OF STANDARDS
DETAILS
DYE LASER SYSTEM
X - 1/342 D
SHEET 3 OF 5


ORIGINAL DATE OF DRAWING FEB 4, 1970
REVISIONS
NO. | E C N | CHANGE | DATE
29
MAT'L ~ AS NOTED
1 REQ'D
SCALE ~ 1/1
7.750
5.750
.500 D.
.421 D. REF.
FABRICATE FROM QUARTZ TUBIN
RESPECTIVELY .500 O.D. AND .56
37
#4-40 UNC TAP THRU.
AS SHOWN
MAT'L ~ STOCK ITEM
1 REQ'D
SCALE - 2/1
H OF NUT
½ H
.125 D. (NOM.) DRILL
CLEAR THRU
REAM FOR TIGHT FIT WITH PART No 36
LOCATE AT ASS'Y WITH PART No 44
MODIFY 3/8 - 16 UNC
BRASS HEX. JAM NUT
AS INDICATED
3.750
3.495 ±.002
8.75mm (.3445) D.
2.25 mm (.0885) D.
.125 ±.002
.245 D. ±.002
TYP. BOTH ENDS
31
MAT'L ~ COPPER
1 REQ'D
SCALE ~ 1/1
1/64 R.
#32 (.1160) DRILL THRU
LOCATE AT ASS'Y
WITH PARTS No. 40 & 42
2 HOLES
NOTE: THESE HOLES OPTIONAL
33
MAT'L ~ "TEFLON"
1 REQ'D
SCALE ~ 1/1
BEND WHEN INSERTING IN PLACE
(APPLY HEAT IF NECESSARY)
2 11/16
1/16 REF.
3.750
3.495 ±.002
20.75 mm (.8169) D.
17.5 mm (.6889) D.
.125 ±.002
.780 D.
TYP. BOTH ENDS
3/32 REF.
COPPER BAR .020 × 1.0
DEVELOPED LENGTH
FABRICATE FROM "TEFLON" PLATE 1/16 THICK
× 4 5/8 APPROX. DEVELOPED LENGTH
40
~ FREE CUTTING BRASS
2 REQ'D
SCALE ~ 1/1
.718 D ±.002
.250 REF.
CUT SLOT AS SHOWN
.484 ±.002
.969
.030
.250
1.937
.797
.203
1.250 (NOM.)
.125 ±.002
.172
.484 ±.002
.625
56 (Nom.)
#4-40 UNC BOTTOM TAP 3/16 DEEP
LOCATE AT ASS'Y WITH PART No 28
2 HOLES EA. SIDE AS SHOWN
TOTAL 4 HOLES
30
MAT'L ~ "TEFLON"
1 REQ'D
SCALE ~ 1/1
1 1/8
2 1/8
1/4 REF.
1.0
BEND WHEN INSERTING IN PLACE
(APPLY HEAT IF NECESSARY)
FABRICATE FROM "TEFLON" PLATE 1/16 THICK
× 2 1/8 APPROX. DEVELOPED LENGTH
PIECE NO | NOMENCLATURE | NO REQ'D
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
DETAILS
FOR DYE LASER SYSTEM
MODEL I. | TYPE | SCALE AS NOTED
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.000
FRACTIONS ±.015
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN Victor Lecinski
CHECKER
PROJECT ENGR Dr D.A. JENNINGS
SUBMITTED BY
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APPROVED BY
CHIEF DIV
THIS PRINT ISSUED
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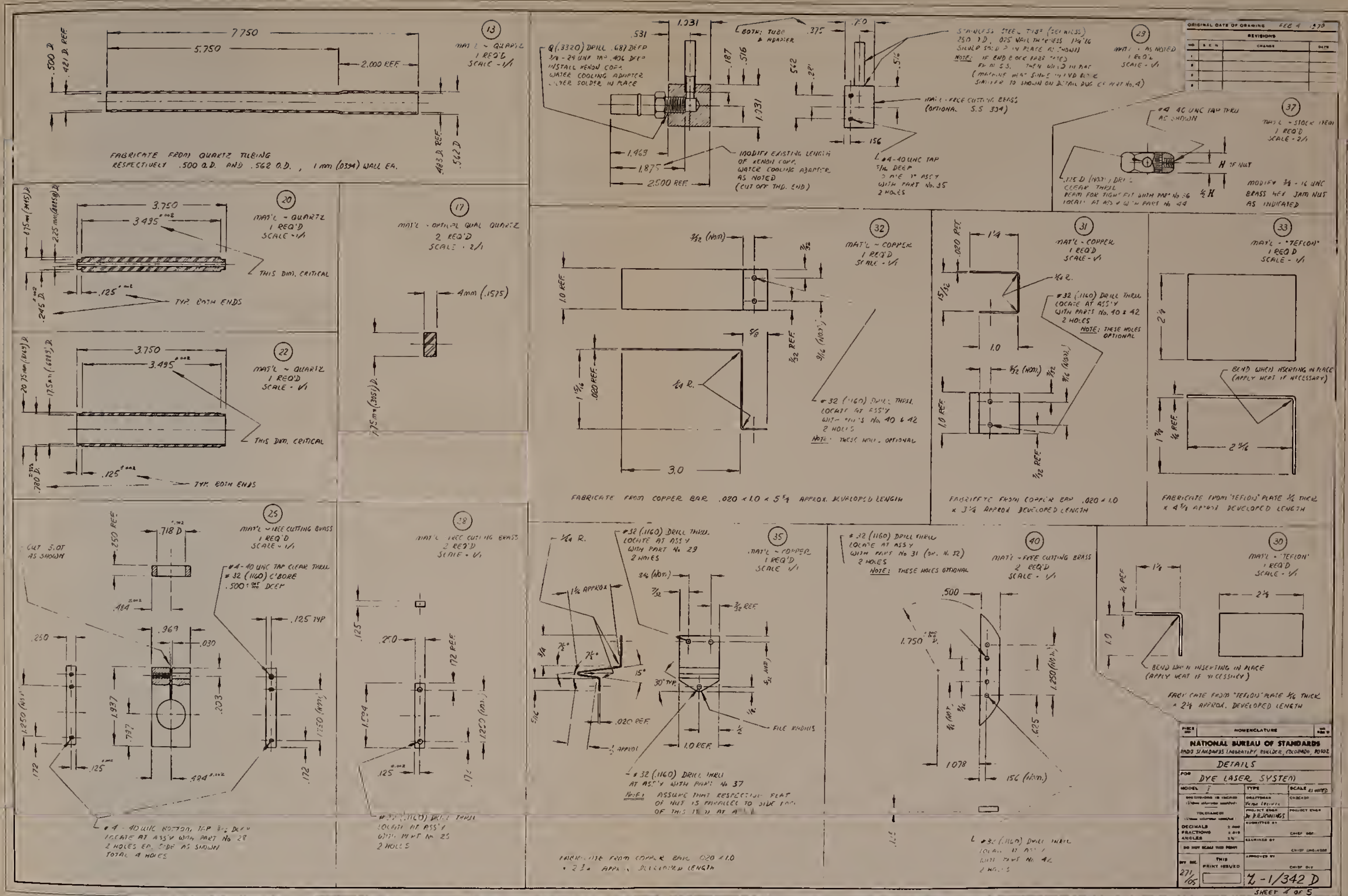
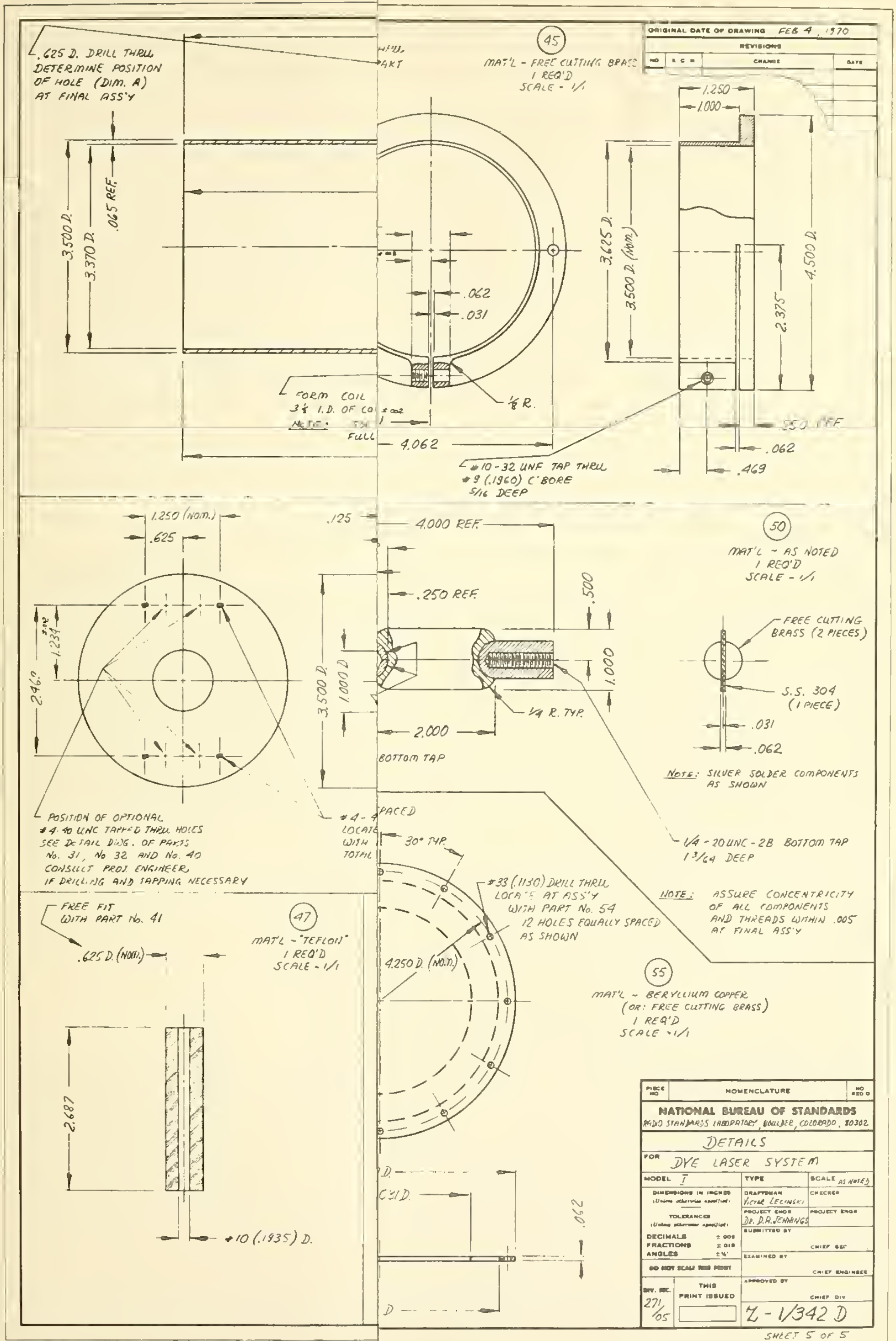
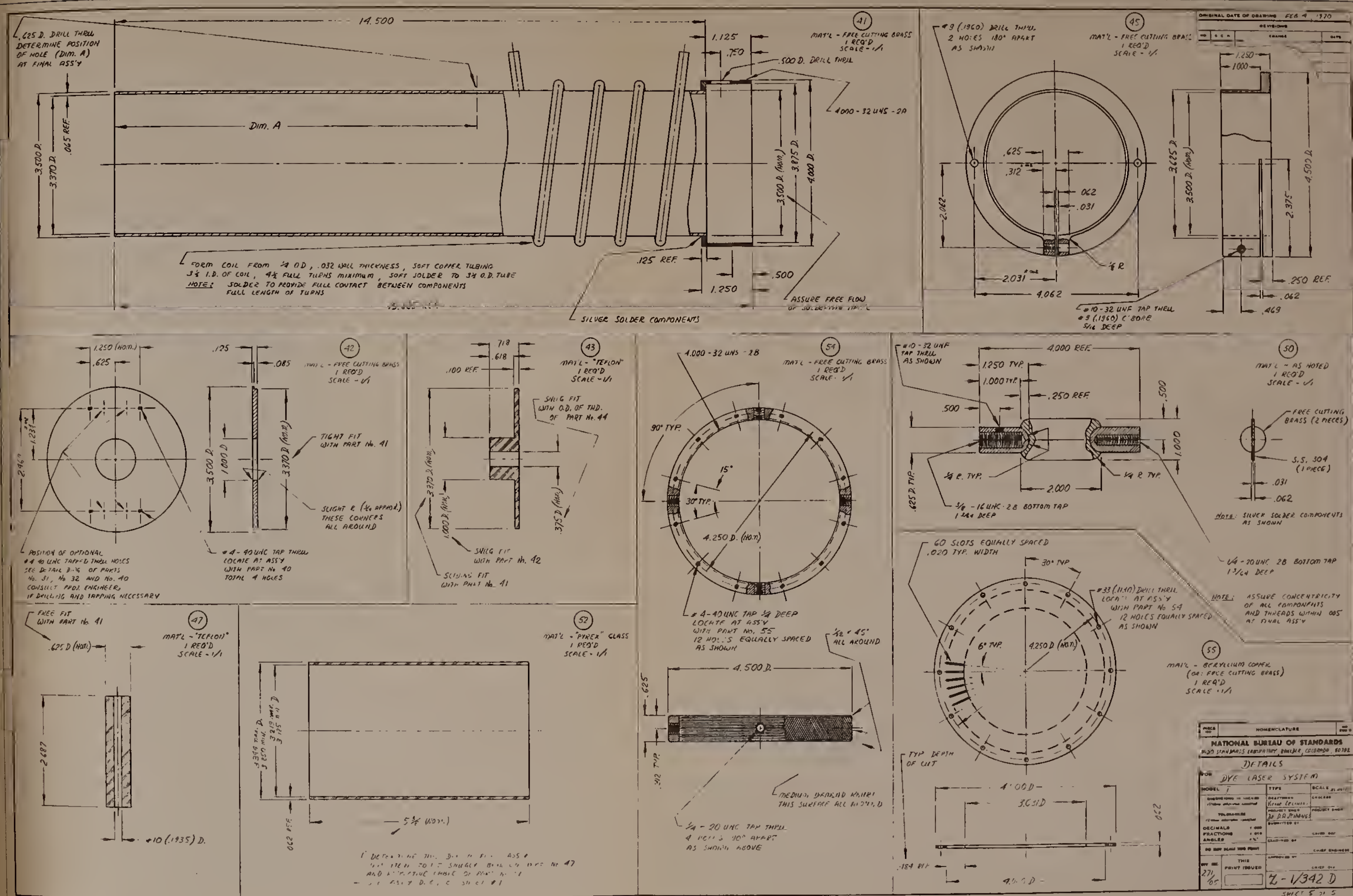
Z-1/342 D
SHEET 4 OF 5



FABRICATE FROM QUARTZ TUBING RESPECTIVELY .500 O.D. AND .562 O.D. , 1 mm (.0394) WALL EA.
MAT'L ~ QUARTZ 1 REQ'D SCALE - 1/1
THIS DIM. CRITICAL
TYP. BOTH ENDS
MAT'L - OPTICAL QUAL QUARTZ 2 REQ'D SCALE - 2/1
MODIFY EXISTING LENGTH OF XENON COOLING WATER COOLING ADAPTER AS NOTED (CUT OFF THD. END)
MAT'L - FREE CUTTING BRASS (OPTIONAL S.S 304)
#4-40 UNC TAP AS SHOWN
MODIFY 3/4 - 16 UNC BRASS HEX JAM NUT AS INDICATED
MAT'L ~ COPPER 1 REQ'D SCALE - 1/1
FABRICATE FROM COPPER BAR .020 x 1.0 x 5 3/4 APPROX. DEVELOPED LENGTH
MAT'L - COPPER 1 REQ'D SCALE - 1/1
MAT'L - "TEFLON" 1 REQ'D SCALE - 1/1
BEND WHEN INSERTING IN PLACE (APPLY HEAT IF NECESSARY)
FABRICATE FROM "TEFLON" PLATE 1/16 THICK x 4 3/4 APPROX. DEVELOPED LENGTH
MAT'L - FREE CUTTING BRASS 1 REQ'D SCALE - 1/1
MAT'L - FREE CUTTING BRASS 2 REQ'D SCALE - 1/1
MAT'L - COPPER 1 REQ'D SCALE 1/1
FILE RADIUS
MAT'L - FREE CUTTING BRASS 2 REQ'D SCALE - 1/1
MAT'L - "TEFLON" 1 REQ'D SCALE - 1/1
FABRICATE FROM "TEFLON" PLATE 1/16 THICK x 2 1/4 APPROX. DEVELOPED LENGTH
NATIONAL BUREAU OF STANDARDS
DETAILS
DYE LASER SYSTEM
Z - 1/342 D
SHEET 4 OF 5


ORIGINAL DATE OF DRAWING FEB 4, 1970
REVISIONS
NO | E C N | CHANGE | DATE
.625 D. DRILL THRU
DETERMINE POSITION
OF HOLE (DIM. A)
AT FINAL ASS'Y
45
MAT'L - FREE CUTTING BRASS
1 REQ'D
SCALE - 1/1
1.250
1.000
3.500 D.
3.370 D.
.065 REF.
.062
.031
3.625 D.
3.500 D. (Nom.)
2.375
4.500 D.
FORM COIL
3 1/2 I.D. OF CO ±.002
1/8 R.
4.062
#10-32 UNF TAP THRU
#9 (.1960) C'BORE
5/16 DEEP
.250 REF.
.062
.469
1.250 (Nom.)
.625
.125
4.000 REF.
.250 REF.
.500
1.000
2.000
1.000 D
3.500 D.
1.234
2.469
1/4 R. TYP.
BOTTOM TAP
50
MAT'L ~ AS NOTED
1 REQ'D
SCALE - 1/1
FREE CUTTING
BRASS (2 PIECES)
S.S. 304
(1 PIECE)
.031
.062
NOTE: SILVER SOLDER COMPONENTS
AS SHOWN
POSITION OF OPTIONAL
#4-40 UNC TAPPED THRU HOLES
SEE DETAIL DWG. OF PARTS
No. 31, No 32 AND No. 40
CONSULT PROJ. ENGINEER
IF DRILLING AND TAPPING NECESSARY
1/4-20 UNC-2B BOTTOM TAP
1 3/64 DEEP
30° TYP.
#33 (.1130) DRILL THRU
LOCATE AT ASS'Y
WITH PART No. 54
12 HOLES EQUALLY SPACED
AS SHOWN
NOTE: ASSURE CONCENTRICITY
OF ALL COMPONENTS
AND THREADS WITHIN .005
AT FINAL ASS'Y
FREE FIT
WITH PART No. 41
47
MAT'L ~ "TEFLON"
1 REQ'D
SCALE ~ 1/1
.625 D. (Nom.)
4.250 D. (Nom.)
55
MAT'L ~ BERYLLIUM COPPER
(OR: FREE CUTTING BRASS)
1 REQ'D
SCALE ~ 1/1
2.687
#10 (.1935) D.
.062
NATIONAL BUREAU OF STANDARDS
RADIO STANDARDS LABORATORY, BOULDER, COLORADO, 80302
DETAILS
FOR DYE LASER SYSTEM
MODEL I
SCALE AS NOTED
DRAFTSMAN Victor Lelinski
PROJECT ENGR Dr. D.A. Jennings
DECIMALS ± .005
FRACTIONS ± .010
ANGLES ± 1/2°
DO NOT SCALE THIS PRINT
271/05
Z-1/342 D
SHEET 5 OF 5


14.500
.625 D. DRILL THRU DETERMINE POSITION OF HOLE (DIM. A) AT FINAL ASS'Y
MAT'L - FREE CUTTING BRASS 1 REQ'D SCALE - 1/1
.500 D. DRILL THRU
1.000 - 32 UNS - 2A
Dim. A
FORM COIL FROM 1/4 O.D., .032 WALL THICKNESS, SOFT COPPER TUBING
NOTE: SOLDER TO PROVIDE FULL CONTACT BETWEEN COMPONENTS FULL LENGTH OF TURNS
SILVER SOLDER COMPONENTS
ASSURE FREE FLOW
MAT'L - "TEFLON" 1 REQ'D SCALE - 1/1
TIGHT FIT WITH PART No. 41
SLIGHT R THESE CORNERS ALL AROUND
POSITION OF OPTIONAL
SNUG FIT WITH PART No. 42
SLIDING FIT WITH PART No. 41
4.000 - 32 UNS - 2B
90° TYP.
30° TYP.
4.250 D. (NOM.)
MAT'L - "PYREX" GLASS 1 REQ'D SCALE - 1/1
FREE FIT WITH PART No. 41
4.500 D.
MEDIUM DIAMOND KNURL
1/4 - 20 UNC TAP THRU 4 HOLES 90° APART AS SHOWN ABOVE
4.000 REF.
MAT'L - AS NOTED 1 REQ'D SCALE - 1/1
FREE CUTTING BRASS (2 PIECES)
S.S. 304 (1 PIECE)
NOTE: SILVER SOLDER COMPONENTS AS SHOWN
60 SLOTS EQUALLY SPACED .020 TYP. WIDTH
NOTE: ASSURE CONCENTRICITY OF ALL COMPONENTS AND THREADS WITHIN .005 AT FINAL ASS'Y
MAT'L - BERYLLIUM COPPER (OR: FREE CUTTING BRASS) 1 REQ'D SCALE - 1/1
TYP. DEPTH OF CUT
NATIONAL BUREAU OF STANDARDS
DETAILS
DYE LASER SYSTEM
Z - 1/342 D

FORM NBS-114A (1-71)

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7. AUTHOR(S) D. A. Jennings and D. L. Baldwin	8. Performing Organization
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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

In this paper is presented the design of a flashlamp-pumped dye laser capable of emitting light pulses 500 ns wide (FWHM) with a risetime of 300 ns. The energy output in the visible region of light is 1 to 10mJ with an energy conversion efficiency of about 0.01% at a repetition rate of 30 pps. The design of an acousto-optic modulator used to mode-lock the dye laser by intracavity loss modulation is presented. The laser output for a given cavity length depends on the frequency and voltage applied to the modulator; a 10% - 100% modulated output can be obtained with 1 V rms - 20 V rms, whereas a train of light pulses narrower than 0.8 ns (FWHM) can be obtained with 80 V rms.

17. KEY WORDS (Alphabetical order, separated by semicolons)
Acousto-optic modulator; flashlamp-pumped dye laser; mode-locking; sub-nanosecond pulses.

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