NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, VIRGINIA

ELECTRONICS DIVISION INTERNAL REPORT NO. 222

(Submitted to Electronics Letters without appendix.)

LOW-NOISE, 10.7 GHz, COOLED, GASFET AMPLIFIER

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NOVEMBER 1981

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LOW-NOISE 10.7 GHz COOLED GASFET AMPLIFIER

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LOW-NOISE 10.7 GHz COOLED GASFET AMPLIFIER

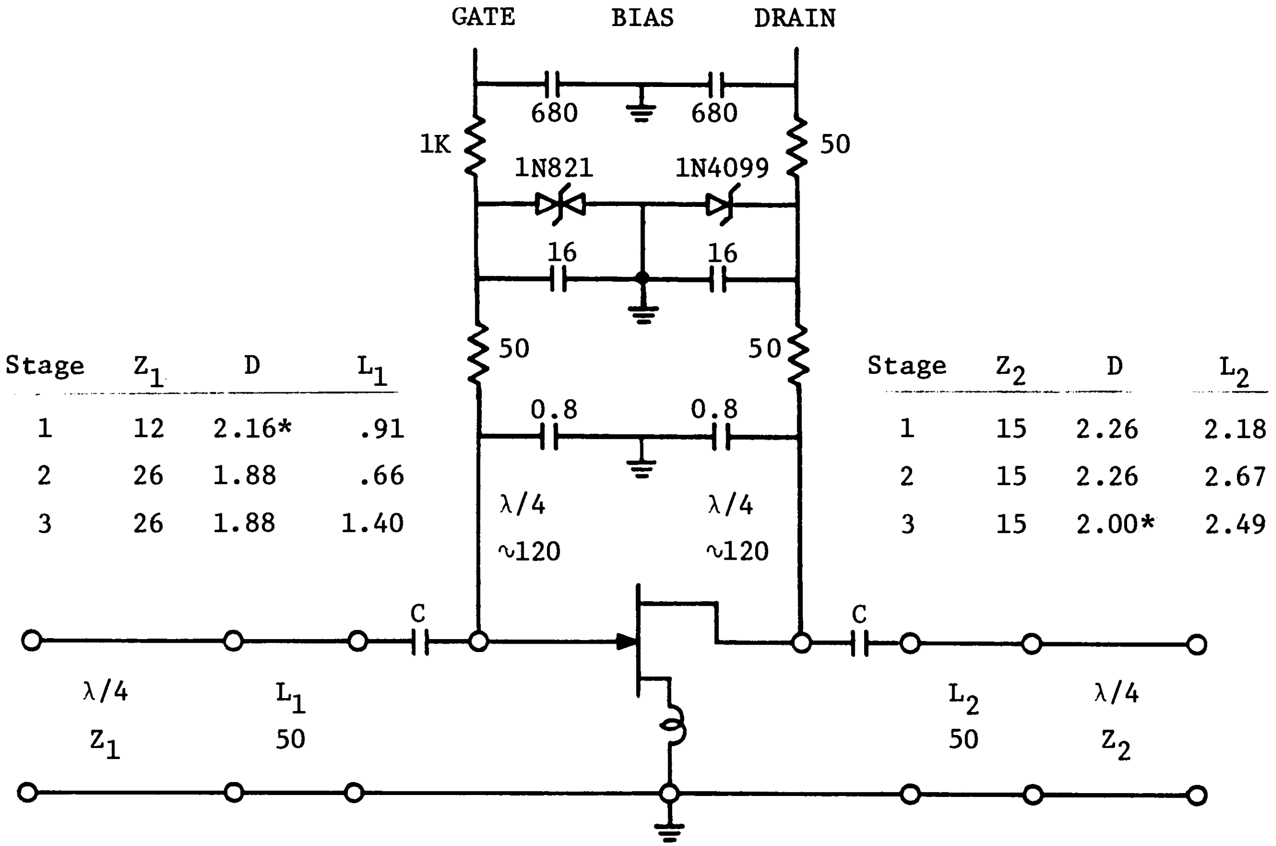
G. Tomassetti, S. Weinreb, and K. Wellington

I. Introduction

A three-stage gallium-arsenide field effect transistor amplifier giving a noise temperature of 29K (0.4 dB noise figure) at a physical temperature of 13K is described. The amplifier utilizes a novel modular construction with coaxial air-lines, sliding $\lambda/4$ transformers, and packaged NE13783 and MGF1403 FET's. Noise parameters of these devices at 300K and 13K are reported.

II. Description

A coupling network which can transform a 50 ohm source or load to any desired impedance consists of a $\lambda/4$ transmission line with characteristic impedance Z_1 in cascade with a transmission line of length, L, and characteristic impedance of 50 ohms as shown in Figure 1. A microstrip realization of this network utilizin $\varepsilon = 2.2$ dielectric with thickness = .25 mm was first tried but was abandoned in favor of the coaxial-line network shown in Figure 2. The coaxial-lines had been used in a previous 5 GHz amplifier [1] and were superior from the standpoint of loss and adjustability. The real part of impedance is varied by changing the diameter and surrounding dielectric of the sliding $\lambda/4$ slug; the distance, L, between this slug and the FET determines the reactance (and hence resonant frequency) of the coupling network. The distance also affects the real part of the impedance, but for $L < \lambda/16$ (as is the case for the FET's used in the 10 to 15 GHz range) the effect is small. A center conductor diameter of 1.25 mm in a 2.74 mm square outer conductor groove is used for the main 50 ohm transmission



Stage	Z_1	D	L_1
1	12	2.16*	.91
2	26	1.88	.66
3	26	1.88	1.40

Stage	Z_2	D	L_2
1	15	2.26	2.18
2	15	2.26	2.67
3	15	2.00*	2.49

Fig. 1. Schematic of single-stage of three-stage amplifier. The quantity, D, in the tables is the diameter in mm of the λ/4 transformer inner-conductor which is surrounded by PTFE when denoted by * after the D value.

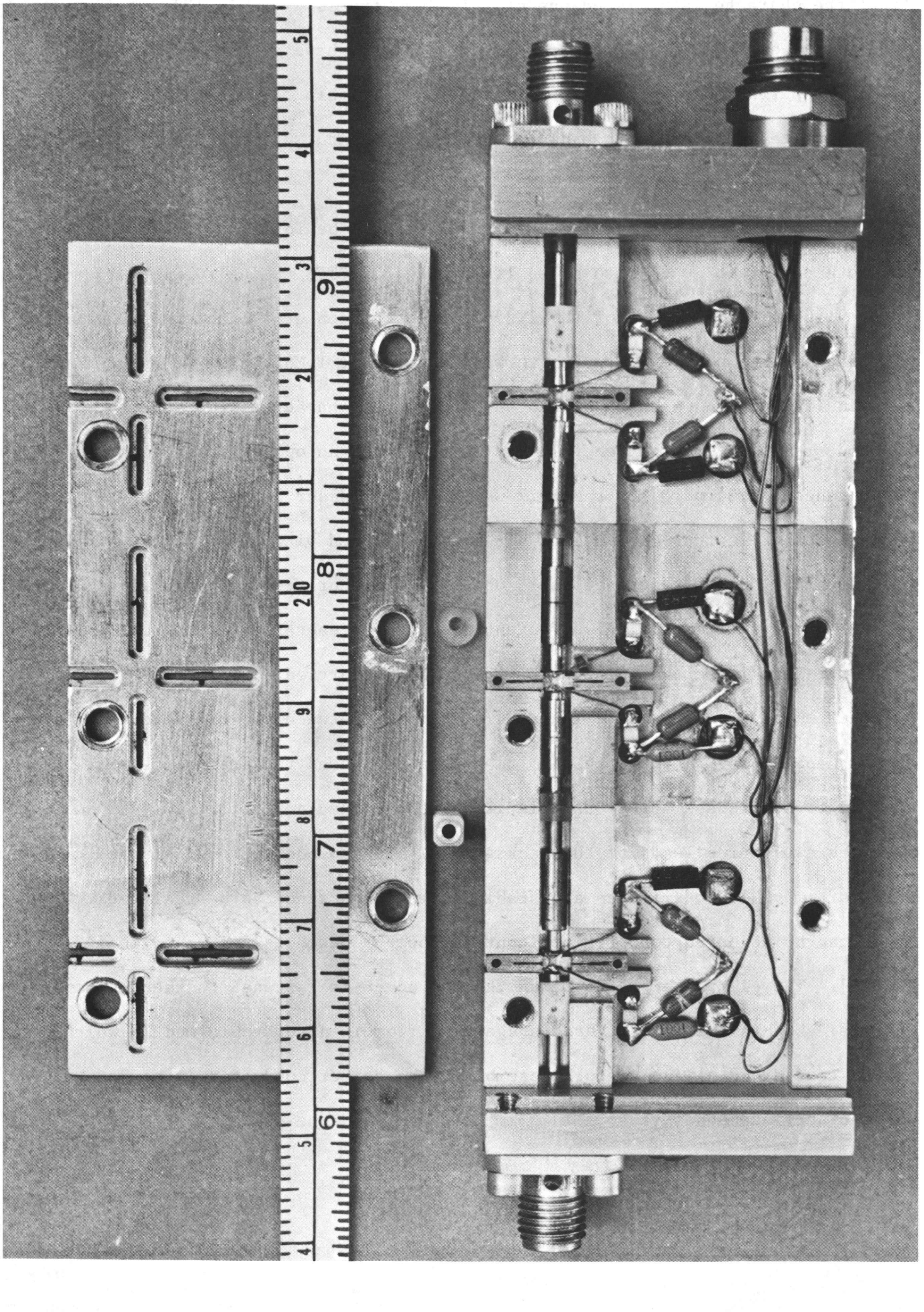


Fig. 2. Photograph of 3-stage amplifier with cover removed.

line; the characteristic impedance of this geometry is given in [2]. A flat cover forms one wall of the outer conductor and may have adjustment slots without affecting performance significantly. Values of Z_1, slug diameter, and L appropriat for a 3-stage amplifier with a NE13783 first stage and MGF1403 second and third stages are given in Figure 1.

Convenient low-loss DC blocking capacitors can be formed by inserting the FET gate and drain leads into holes lined with #22 PTFE tubing (O.D. = .94 mm, I.D. = .43 mm) in the ends of the 1.25 mm diameter center conductors. A capacitanc of .12 pf per mm of insertion length was measured at 1 MHz. The re-entrant transmission line formed in this way has an approximate characteristic impedance of 39 ohms, relative propagation velocity of 0.72, and an open-circuited end fringing capacitance of .04 pf. For the 10.7 GHz amplifier described here, the gate and drain leads are cut to 4.6 mm, and 4.3 mm is inserted within the center conductor; the resulting series reactance is -5 ohms. For higher frequency amplifiers, the length is cut shorter giving sufficient capacitive reactance to tune out the parasitic lead inductance of the FET. DC bias is carried to the FET by .13 mm diameter wires of approximate length $\lambda/4$ soldered between the FET lead and chip bypass capacitors. A small toroid [3] is placed around the drain bias wire of stage 2 to suppress a 15 GHz oscillation of the cooled amplifier.

The two source leads of the packaged FET are grounded through slotted clamps which are movable to allow an adjustable source inductance to be realized. These leads can be adjusted to optimize input and output match as described in [4] and [5]. The clamps become tight as the top cover is fastened to the amplifier chassis. Each stage of the three-stage amplifier is a separable module which can be tested and aligned before assembly. The center conductor is bonded with a cyano-acrylate adhesive to a 1.25 mm thick polystyrene support which is captivated within the housing. A plug and socket arrangement similar to the SMA connectors is used between stages. The spacing between stages, an important parameter in the performance, is not easily adjustable and was optimized at approximately 0.2 λ electrical length between λ/4 transformers by computer modeling of a two-stage amplifier. Some adjustment of this length is possible by changing the transformer dielectric.

III. Results

The three-stage amplifier was optimized utilizing a scalar network analyzer and an automatic noise measuring system utilizing an Apple II Plus computer. A Hewlett-Packard HP-346B calibrated noise diode connected to amplifier input through a calibrated HP-8493B, 20 dB attenuator was used as a noise standard; this was compared against a liquid-nitrogen noise standard and no significant error was found. For cooled measurements a cryogenic refrigerator [6] was utilized and the 20 dB attenuator was also cooled to decrease inaccuracy due to uncertainty of the noise diode and dewar input line loss and reflections.

In order to minimize the amplifier noise, the performance was measured for three different input λ/4 transformer slugs at three first-stage bias currents at 300K and 13K amplifier temperatures. These tests were performed for the Nippon Electric NE13783 and Mitsubishi MGF1403 transistors with resulting noise parameters given in Table I. These noise parameters refer to the three-stage amplifier and differ somewhat from the FET device noise parameters due to second and third stage noise. The reference plane for the parameters is at the gate-lead to package interface of the first stage.

The noise temperature, gain, input return loss, and output return loss of an optimum 3-stage amplifier without isolators are shown in Figure 3 for

TABLE I - Measured Noise Parameters

	NE137*		MGF1403†	
	300K	13K	300K	13K
T_{min}	180 ± 5	27 ± 2	191 ± 20	44 ± 5
R_{opt}	5 ± 1	3 ± 1	5 ± .6	4.5 ± .6
X_{opt}	8 ± 5	8 ± 5	3 ± 5	3 ± 5
$1/g_n$	28 ± 15	60 ± 40	8 ± 5	30 ± 15
Z_1 OPT λ/4	15.8	12.2	15.8	15

*Biased at V_D = 4V and I_D = 8.7 mA @ 300K and 3.7 mA @ 13K.

†Biased at V_D = 4V, I_D = 8.7 mA.

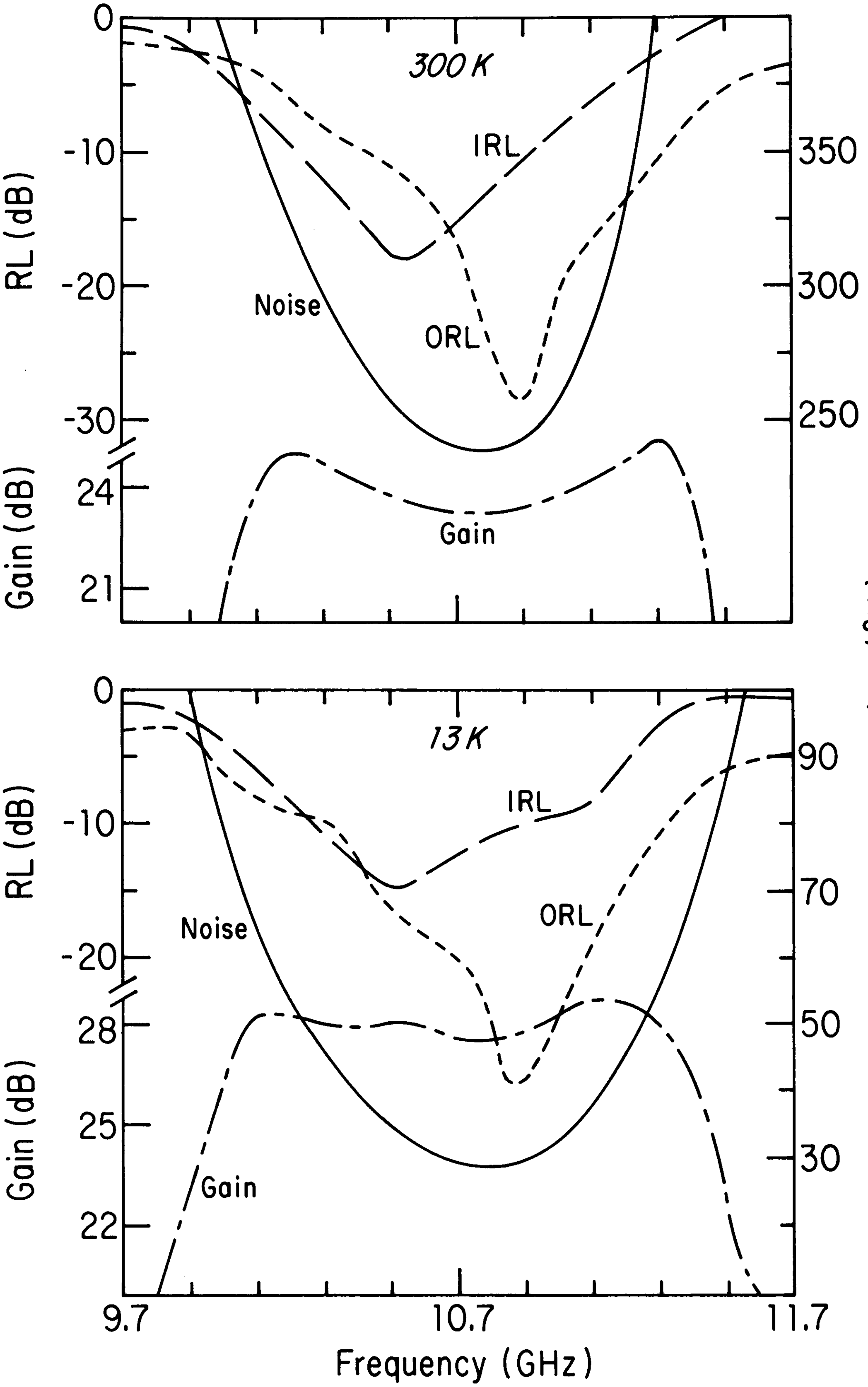


Fig. 3. Noise temperature, gain, input return loss, and output return loss of optimized 3-stage amplifier without isolators.

both 300K and 13K operation. The amplifier is optimized for a 29K noise temperatu at band center and has an average noise temperature of 36K over a 1 GHz bandwidth. With slightly different tuning, a noise temperature of 26K was measured but less bandwidth was achieved. The amplifier is stable for any phase sliding short at input or output; however, an isolator may be necessary to improve input and output match, especially for wide band applications. Several commercial isolators specified for 243K to 358K operation, were tested at 13K and it was found that an Aertech unit [7] gave an input return loss of ≥ 20 dB over a 10 to 11 GHz band but increased noise temperature to 36K.

REFERENCES

[1] G. Tomassetti, R. Ambrosini, and G. Sinigaglia, "Amplificatori a MESFET per Microonde," Internal Report #46, Laboratorio di Radioastronomia, CNR, Bologna, Italy, 1981.

[2] *Reference Data for Radio Engineers*, 5th edition, Int. Tel. and Tel., 1970, Sams, p. 22-22.

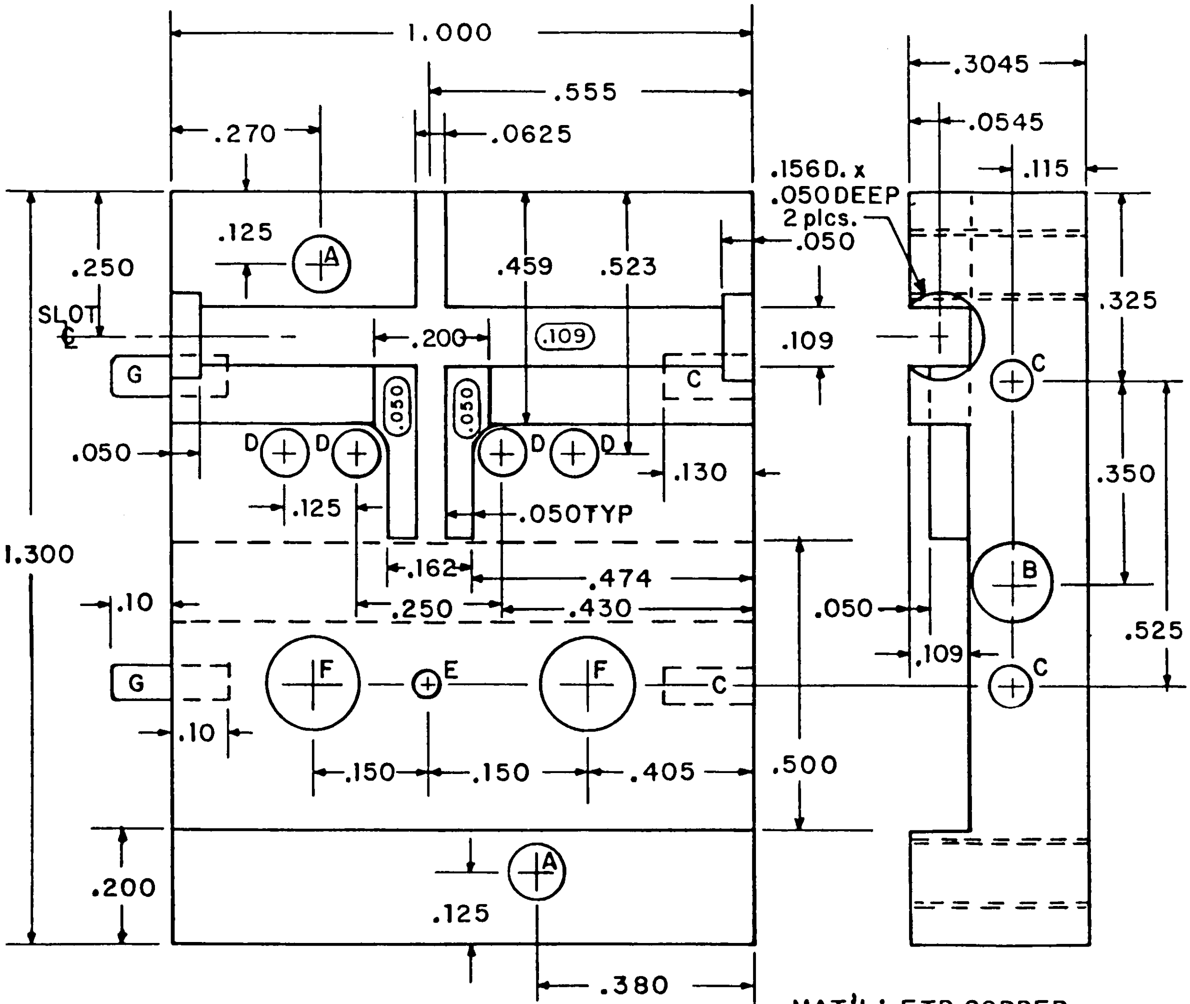
[3] Micrometals, Inc., Anaheim, CA, type T5-6 ferrite core.

[4] D. R. Williams, W. Lum, and S. Weinreb, "L-Band Cryogenically-Cooled GaAs FET Amplifier," *Microwave Journal*, vol. 23, no. 10, October 1980, pp. 73-76.

[5] S. Weinreb, "Low-Noise Cooled GASFET Amplifiers," *IEEE Trans. on Microwave Theory and Technique*, vol. MTT-28, no. 10, October 1980, pp. 1041-1054.

[6] CTI Cryogenics, Waltham, MA, model 1020 cryogenic refrigerator.

[7] Aertech Industries, Inc., Sunnyvale, CA, model ASI-8012 isolator, S/N 723.



A - 4-40 TAP THRU - 2 PLCS.
B - No. 29 DRILL THRU - 1 PLC.
C - HOLES FOR CLOSE FIT ON O/P SECTION PINS
D - .078 D. x .020 DEEP - 4 PLCS.
E - .022 D. x .130 DEEP
F - .156 D. x .080 DEEP - 2 PLCS.
G - LOCATING PINS .0625 D. S/S - 2 PLCS.

MAT'L: ETP COPPER
GOLD PLATE

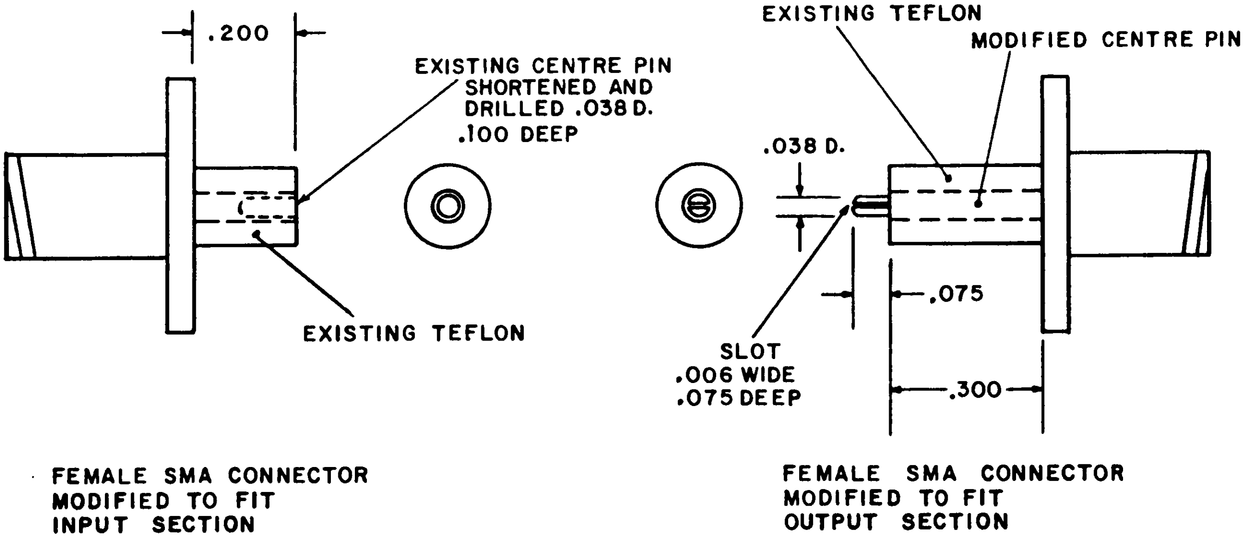
⬭ NUMBER IN OVAL
DENOTES MILL DEPTH

NATIONAL RADIO ASTRONOMY
OBSERVATORY

TITLE: 10.7GHz AMP MODULE

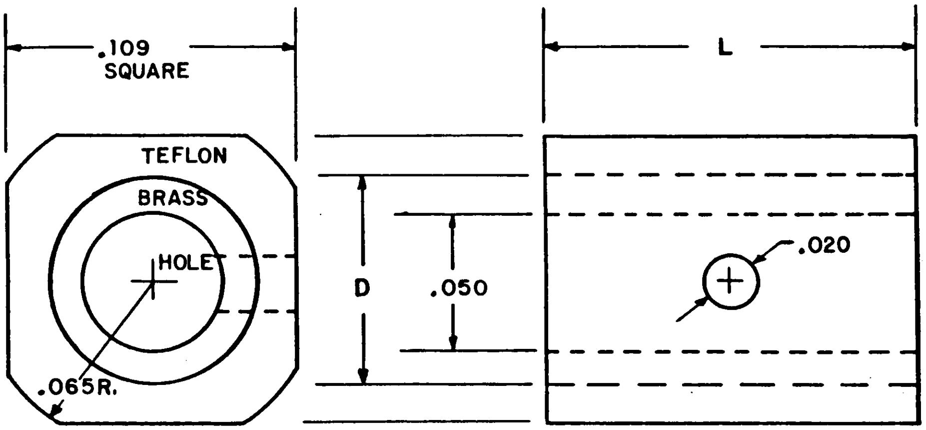
DSGN. BY: K.J. WELLINGTON
APPD. BY: S. WEINREB DATE: 8/26/81
DWG. NO A2613 M40

Appendix 1.A.



Appendix 1.B.

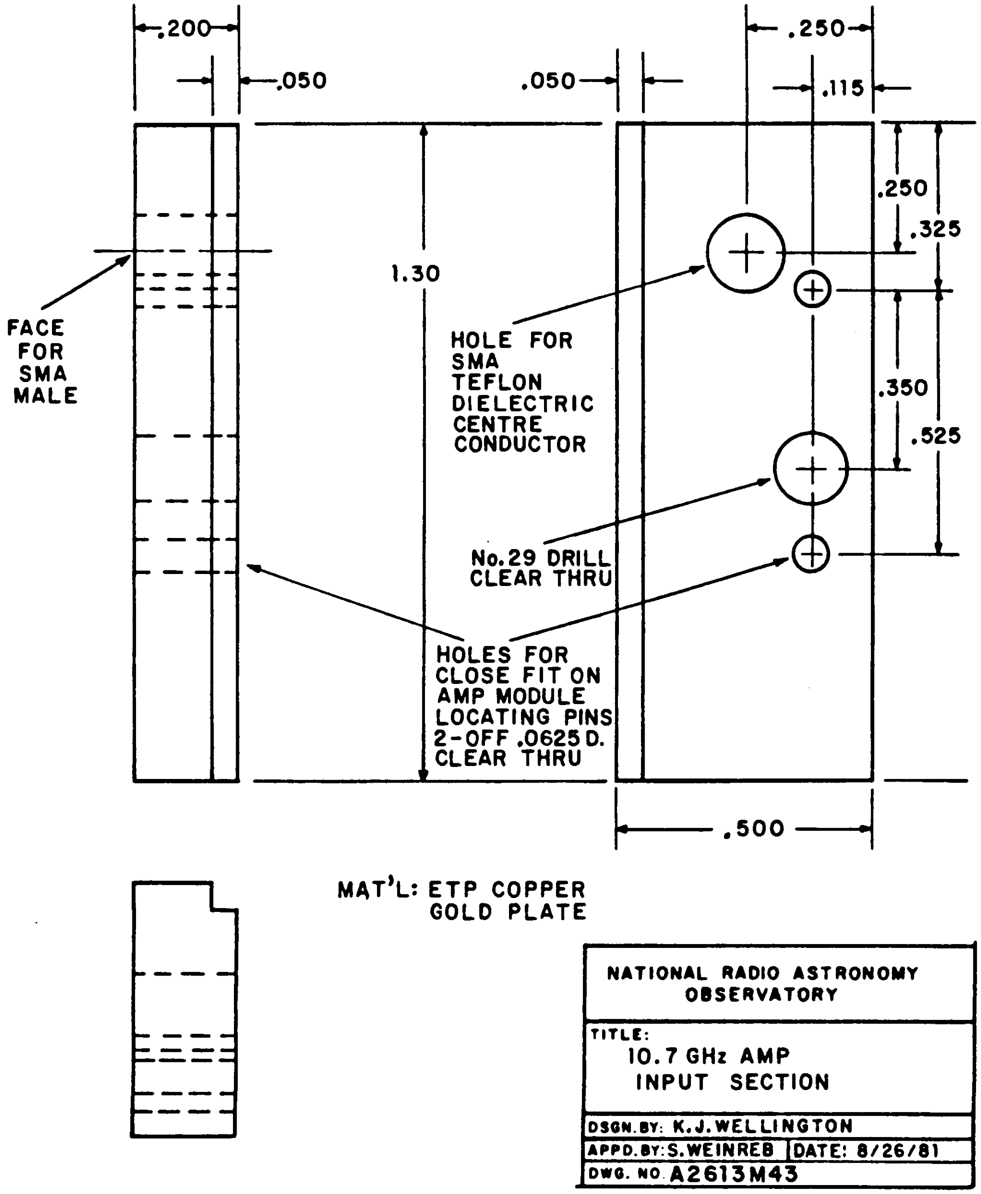
NATIONAL RADIO ASTRONOMY OBSERVATORY
TITLE: 10.7 GHz AMP
CONNECTORS, MODIFICATIONS
DSGN. BY: K. J. WELLINGTON
APPD. BY: S. WEINREB DATE: 8/26/81
DWG. NO. A2613M41



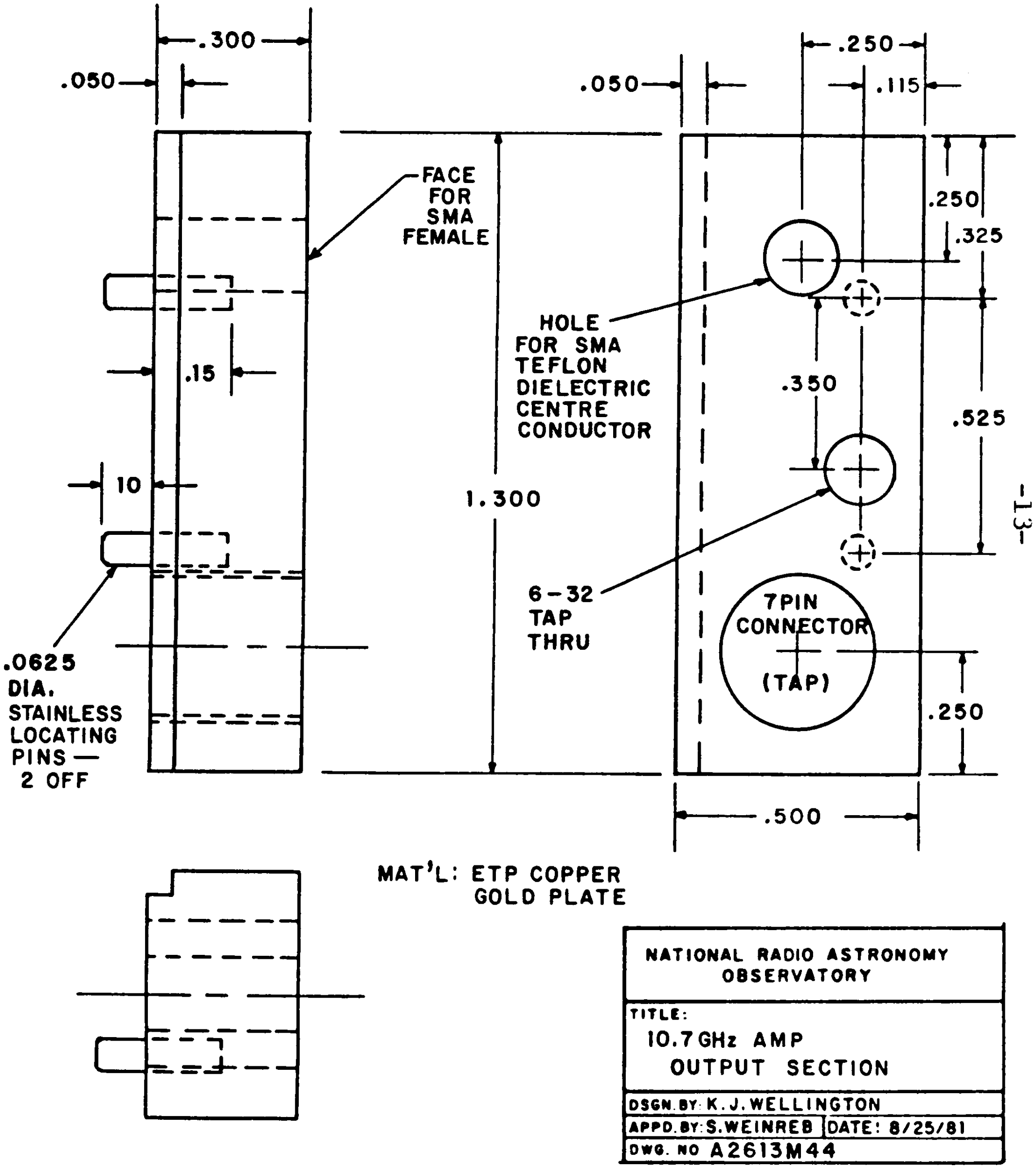
Zφ	D	L	TEFLON
12	.085	.190	YES
18	.074	.190	YES
15	.079	.190	YES
22	.067	.190	YES
10	.089	.190	YES
26	.063	.190	YES
31.3	.05	.173	Rexolite No Brass
34.5	.05	.190	YES No Brass
26	.074	.276	No
15	.089	.276	No

NATIONAL RADIO ASTRONOMY OBSERVATORY
TITLE: 10.7 GHz AMP
COAXIAL TRANSFORMERS
DSGN. BY: S. WEINREB DATE: 5/9/81
APPD. BY: DR. BY:
DWG. NO A2613 M42

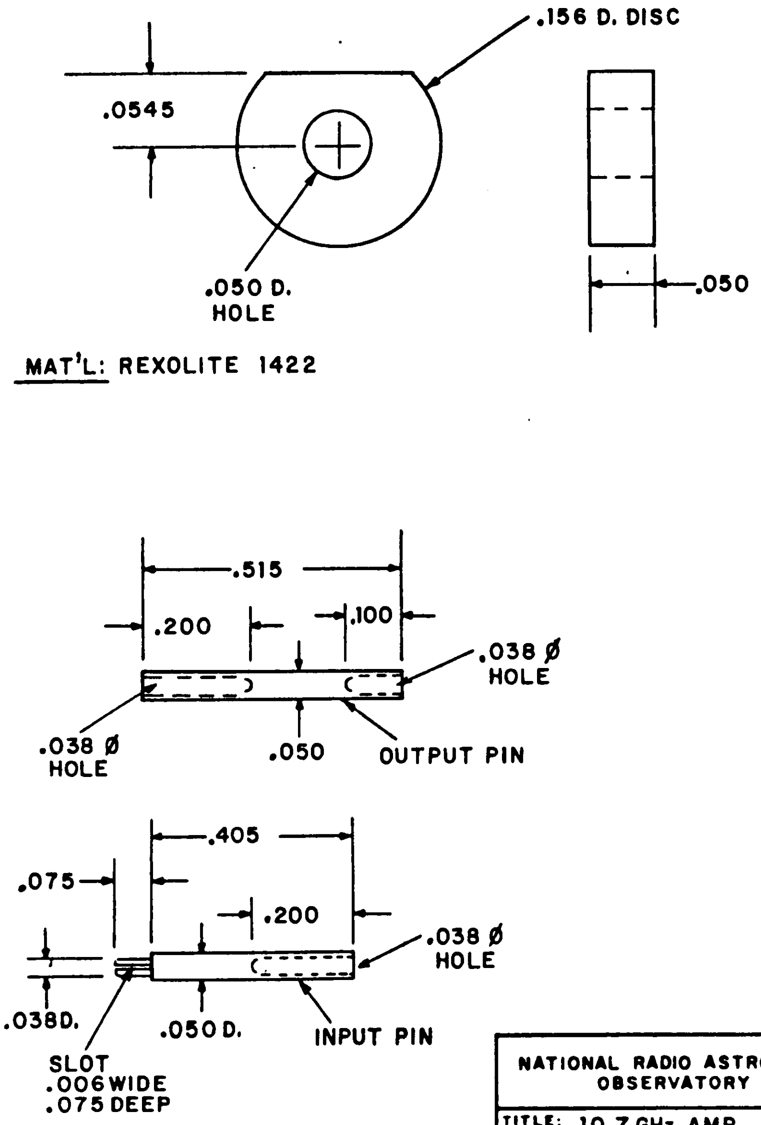
Appendix 1.C.



Appendix 1.D.



Appendix 1.E.

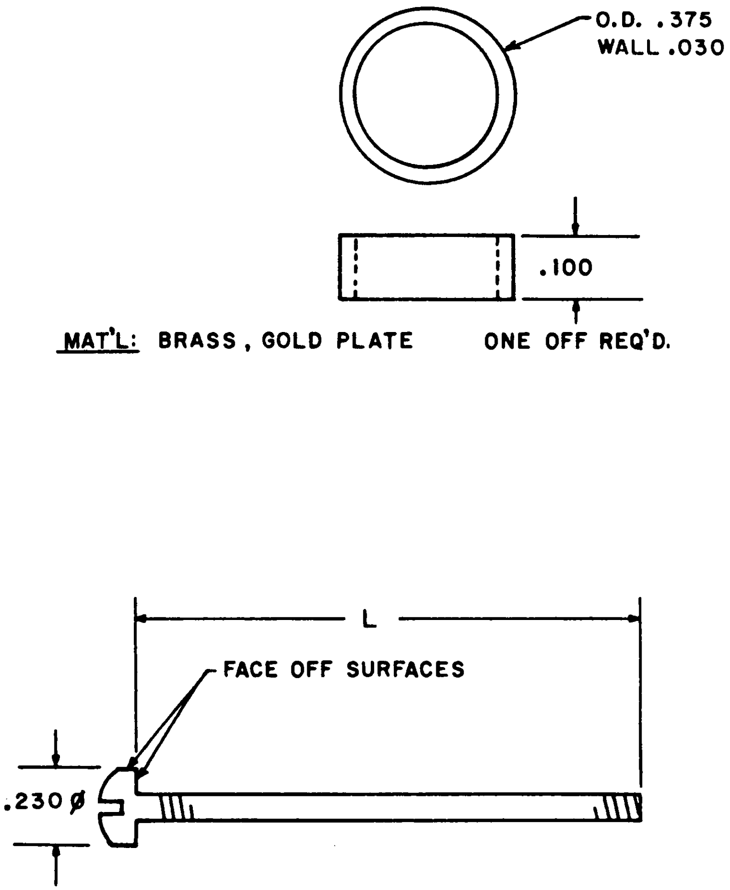


MAT'L: REXOLITE 1422

MAT'L: Be – Cu
GOLD PLATE

NATIONAL RADIO ASTRONOMY OBSERVATORY
TITLE: 10.7 GHz AMP
INTERSTAGE PINS &
COAX LINE SUPPORTS
DSGN. BY: K. J. WELLINGTON
APPD. BY: S. WEINREB DATE: 8/26/81
DWG. NO. A2613M45

Appendix 1.F.



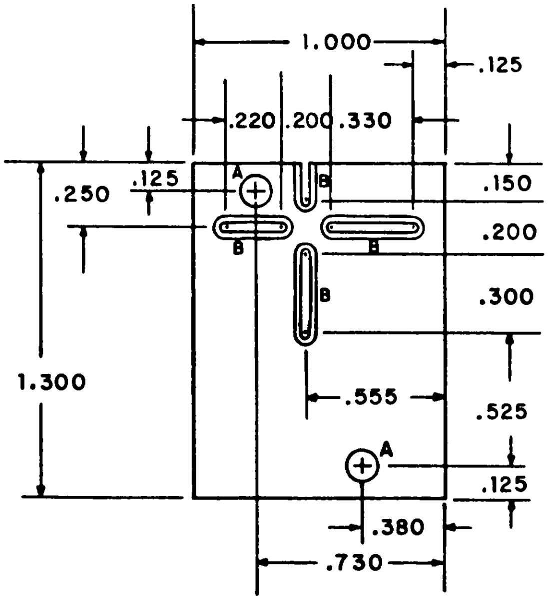
MAT'L: BRASS, GOLD PLATE ONE OFF REQ'D.

No. STAGES	L (MKI)
ONE	1.50
TWO	2.50
THREE	3.50

MAT'L: 6-32 x 4" ROUND HEAD SCREW
(ZINC CHROMATED STEEL; McMASTER-CARR
CAT. No. 90301A022), GOLD PLATE

NATIONAL RADIO ASTRONOMY OBSERVATORY
TITLE: 10.7 GHz AMP POWER-
CONNECTOR SPACER &
MODULE SCREW
DSGN. BY: K. J. WELLINGTON
APPD. BY: S. WEINREB DATE: 10/1/81
DWG. NO. A2613M46

Appendix 1.G.

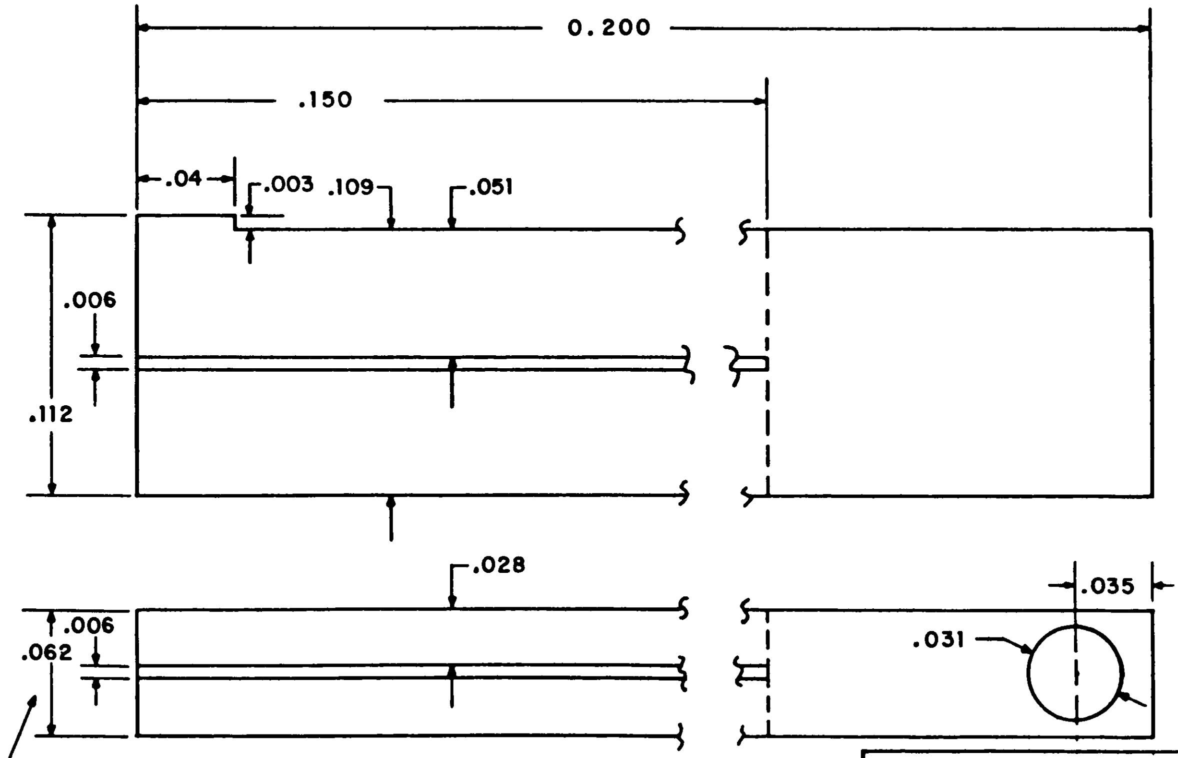


A — 4-40 CLEAR HOLE
B — ADJUSTMENT SLOTS — FIRST CUT .072 x .040 DEEP;
SECOND CUT .025 MILL CLEAR THRU

MAT'L: ETP COPPER 1/16" THICK
GOLD PLATE

NATIONAL RADIO ASTRONOMY OBSERVATORY
TITLE: 10.7GHz AMP TUNING COVER, ONE STAGE
DSGN. BY: K. J. WELLINGTON
APPD. BY: S. WEINREB DATE: 9/30/81
DWG. NO. A2613M47

Appendix 1.H.

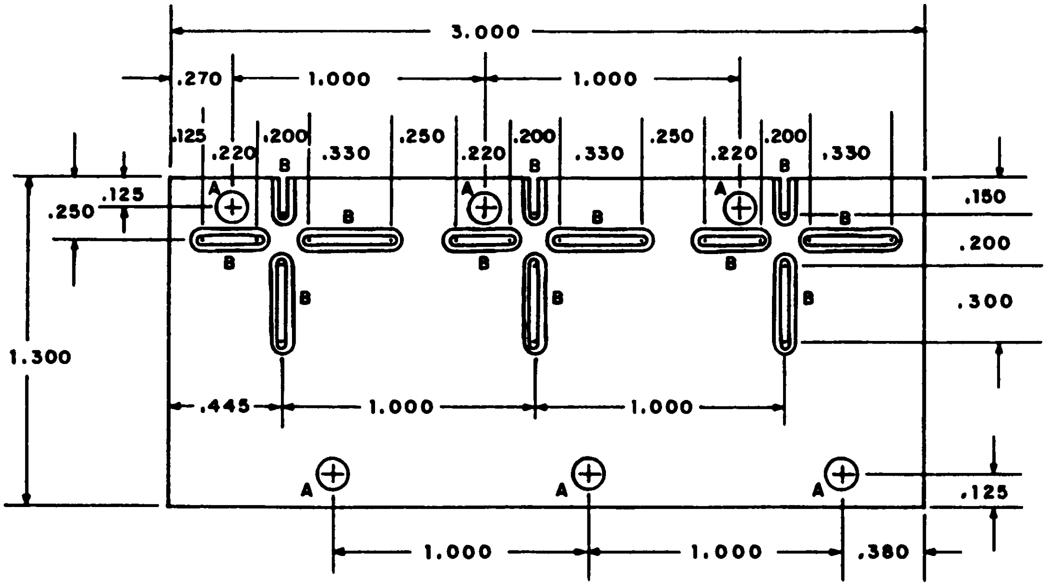


— FOR SLIDING FIT
IN AMP MODULE SLOT

MAT'L: Cu — GOLD PLATE

NATIONAL RADIO ASTRONOMY OBSERVATORY
TITLE: 10.7 GHz AMP SOURCE LEAD CLAMP
DSGN. BY: K. J. WELLINGTON
APPD. BY: S. WEINREB DATE: 8/23/81
DWG. NO. A2613M48

Appendix 1.I.



A — 4-40 CLEAR HOLE
B — ADJUSTMENT SLOTS — FIRST CUT .072 MILL, .040 DEEP
— SECOND CUT .025 MILL, CLEAR THRU

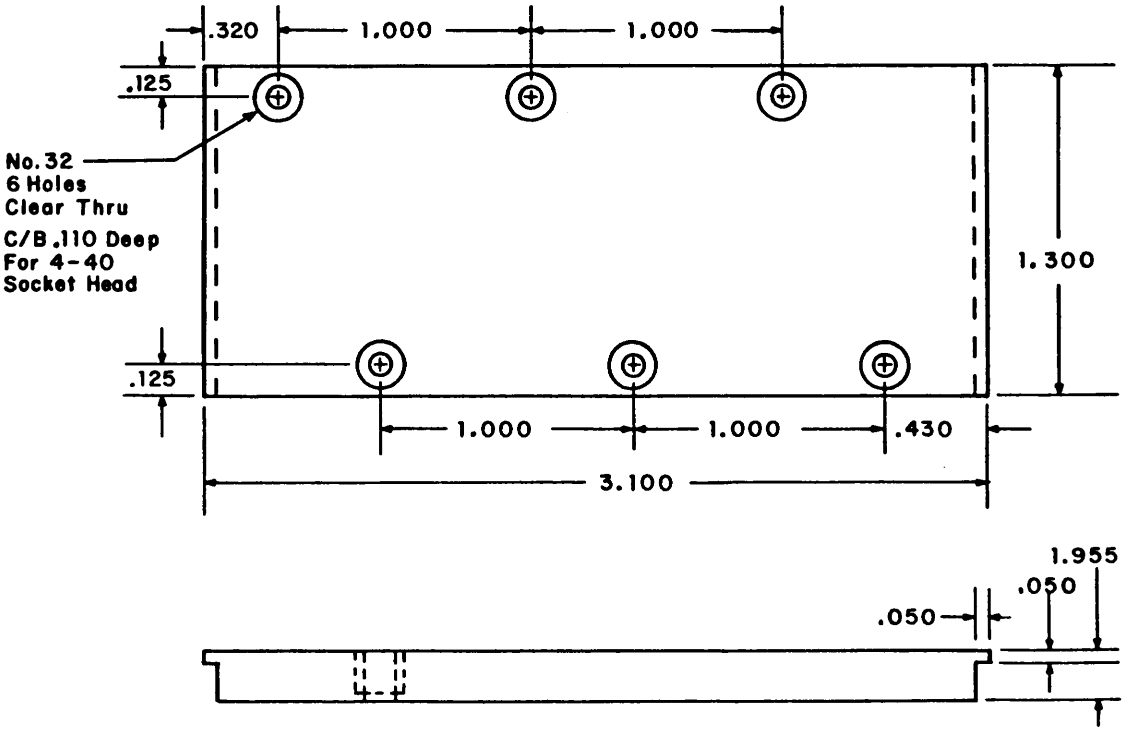
MAT'L: ETP COPPER, 1/16" THICK
GOLD PLATE

NATIONAL RADIO ASTRONOMY
OBSERVATORY

TITLE:
10.7 GHz AMP TEST COVER
3 STAGE

DSGN. BY: K. J. WELLINGTON
APPD. BY: S. WEINREB DATE: 9/15/81
DWG. NO. A2613M49

Appendix 1.J.



No. 32
6 Holes
Clear Thru
C/B .110 Deep
For 4-40
Socket Head

MAT'L: ETP COPPER
GOLD PLATE

NATIONAL RADIO ASTRONOMY
OBSERVATORY

TITLE:
10.7 GHz AMP LID

DSGN. BY: K. J. WELLINGTON
APPD. BY: S. WEINREB DATE: 8/26/81
DWG. NO A2613M50

Appendix 1.K.