NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, VIRGINIA

ELECTRONICS DIVISION INTERNAL REPORT NO. 278

DESIGN AND PERFORMANCE OF CRYOGENICALLY-COOLED, 14.4-15.4 GHz HEMT AMPLIFIER

M. W. POSPIESZALSKI AND W. LAKATOSH

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DESIGN AND PERFORMANCE OF CRYOGENICALLY-COOLED, 14.4-15.4 GHZ HEMT AMPLIFIER

M. W. Pospieszalski and W. Lakatosh

I. Introduction

This report covers the design and performance of cryogenically-cooled, 14.4-15.4 GHz amplifiers built with commercially-available FHR01FH (Fujitsu) HEMT's. The design was computer optimized for gain and noise performance in a manner similar to previously described X-band designs [1], [2], although a different topology of an input matching network was assumed. A commercially-available Fujitsu HEMT, FHR01FH, was used. The signal and noise model of this transistor was extensively discussed in [3]. The typical parameters measured at the cold input of the amplifier were: minimum noise temperature at midband $T_{min} = 17$ K, average noise temperature over 1 GHz bandwidth $T_{nav} = 19$ K and gain $G_T = 30$ dB ± 2 dB over the same bandwidth. The noise temperature is by a factor of two better in the band center and by a factor of three better at the band edges than for the previous NRAO design [4]. This can be mostly attributed to the use of a much better device (HEMT instead of a FET), but also to a different design approach.

II. Amplifier Design and Realization

Photographs of a finished amplifier are shown in Figure 1. Many design features are similar to the previously described designs [1], [2]. A most notable difference is a topology of an input matching network which consists of (starting at the generator side): a parallel high impedance open-circuited stub, a length of 50 Ω air slab line and length of low impedance slab line (partially filled with teflon). The input and first interstage matching networks were computer optimized to yield minimum average noise in 14.4-15.4 GHz band at 12.5 K ambient temperature, while the interstage coupling network and output network were optimized for gain flatness.

The details of the d.c. separation circuit and bias circuit and their microwave and low frequency equivalent circuits are shown in Figure 2. The comparison between computer predicted and measured performance of the three-stage amplifier (U-5) at room and cryogenic temperature is shown in Figure 3. The experimental data of Figure 3 are taken for all transistors biased at $V_{ds} = 2$ V, $I_{ds} = 10$ mA and $V_{ds} = 2$ V, $I_{ds} = 5$ mA for room and cryogenic temperatures, respectively. The cryogenic measurement was done with all HEMT's illuminated. The computed data are for the circuit description as given in Figures 1 and 2, using the signal and noise model of the FHR01FH HEMT developed in [3]. The input and output return loss measured at room temperature is compared with the model prediction in Figure 4.

The amplifier characteristics were found to be very sensitive to the electrical length of the open-circuited stub. This is because the length of this stub becomes quarter-wave at the frequency of 17.5 GHz. The stub is realized by placing a tinned copper wire of 10 mills in diameter in a channel milled in the amplifier housing (compare Figure 1). The end of the stub rests in a movable rexolite support, which provides at the same time the mechanical stability and required fine tuning.

III. Summary of Performance of K_u-Band Amplifiers

The summary of cryogenic performance of eight K_u-band amplifiers is given in Table I. Full noise and gain characteristics of six of those amplifiers are shown in Figure 5. For most of the amplifiers, the only required tuning procedure was an adjustment of electrical length of the parallel stub by movement of its rexolite support. Indeed, the repeatability of amplifier characteristics was quite good. All the amplifiers were built with FHR01FH HEMT's from lot #C923. The spread in minimum noise temperature at midband was less than 3.5 K for seven amplifiers. This is consistent with the repeatability of noise performance of Fujitsu HEMT's with good pinch-off characteristics, as observed in X-band amplifiers (± 1.5 K) [3], [5], and also with estimated accuracy of measurement (± 2 K in K_u-band).

IV. Conclusions

The design, construction and performance of cryogenically-cooled, 14.4-15.4 GHz HEMT amplifiers were described. The cryogenic noise performance of these amplifiers is believed to be the best yet reported at this frequency.

V. References

[1] M. W. Pospieszalski, "Low-Noise, 8.0-8.8 GHz, Cooled GASFET Amplifier," NRAO Electronics Division Internal Report No. 254, December 1984.

[2] M. W. Pospieszalski, "Design and Performance of Cryogenically-Cooled, 10.7 GHz Amplifier," NRAO Electronics Division Internal Report No. 262, June 1986.

[3] M. W. Pospieszalski, "A New Approach to Modeling of Noise Parameters of FET's and MODFET's and Their Frequency and Temperature Dependence," NRAO Electronics Division Internal Report No. 279, July 1988.

[4] S. Weinreb and R. Harris, "Low-Noise, 15 GHz, Cooled, GaAsFET Amplifier," NRAO Electronics Division Internal Report No. 235, September 1983.

[5] M. W. Pospieszalski, S. Weinreb, R. Norrod and R. Harris, "FET's and HEMT's at Cryogenic Temperatures - Their Properties and Use in Low-Noise Amplifiers," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-36, pp. 552-559, March 1988.

TABLE I. The Summary of Cryogenic Performance of the 14.4-15.4 GHz Amplifiers

	Noise Temp.[1] [K]		Gain[2] [K]	
Amplifier	Minimum	Average	Minimum	Maximum
U-1[3]	20.5	22.8	25.3	29.1
U-2[3]	18.3	22.5	27.2	29.3
U-3	18.2	21.1	28.2	32.1
U-4	18.3	20.0	28.3	31.0
U-5	16.2	18.1	28.7	32.1
U-6	17.4	20.2	27.8	30.6
U-7	15.0	16.0	28.6	30.4
U-8	15.6	19.1	28.1	31.6

[1]Referred to the cold input of an amplifier.

[2]Includes a cold isolator and dewar transition at the output side.

[3]Prototypes.

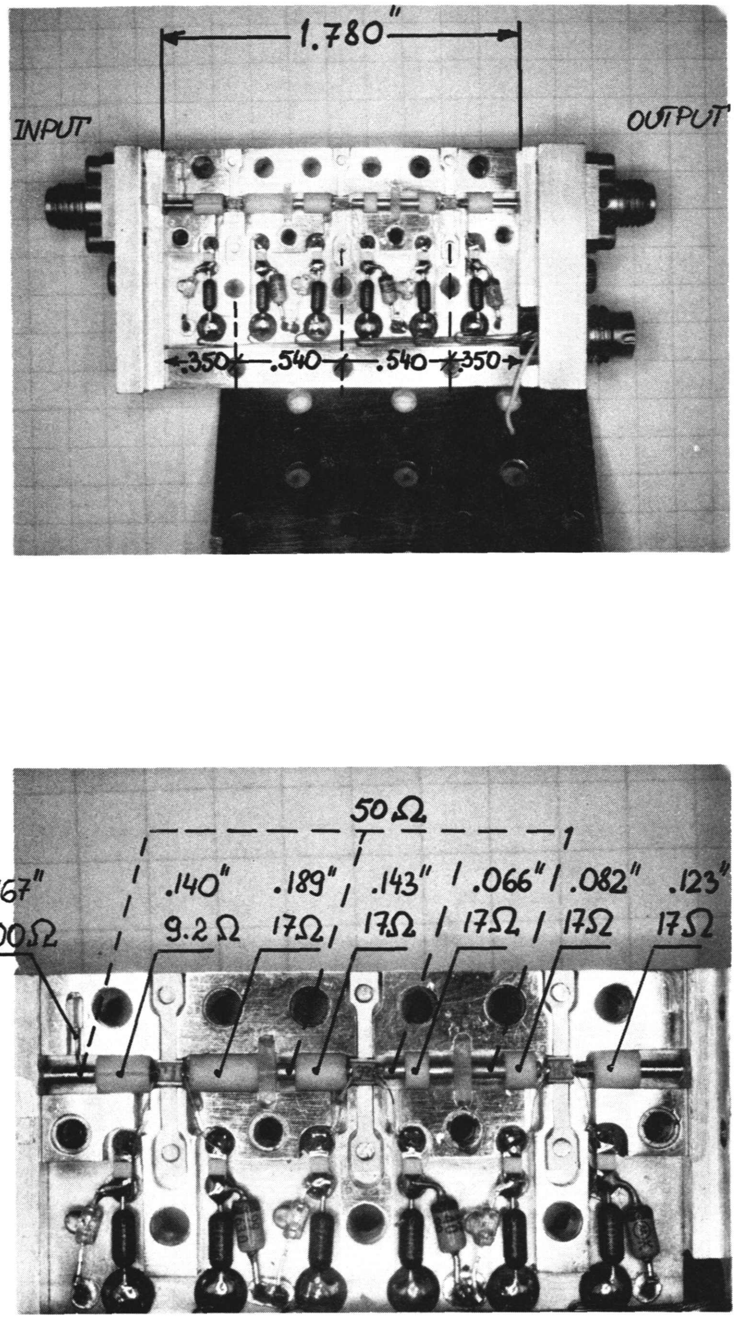


Fig. 1. Three-stage 14.4-15.4 GHz amplifier with cover plate removed.

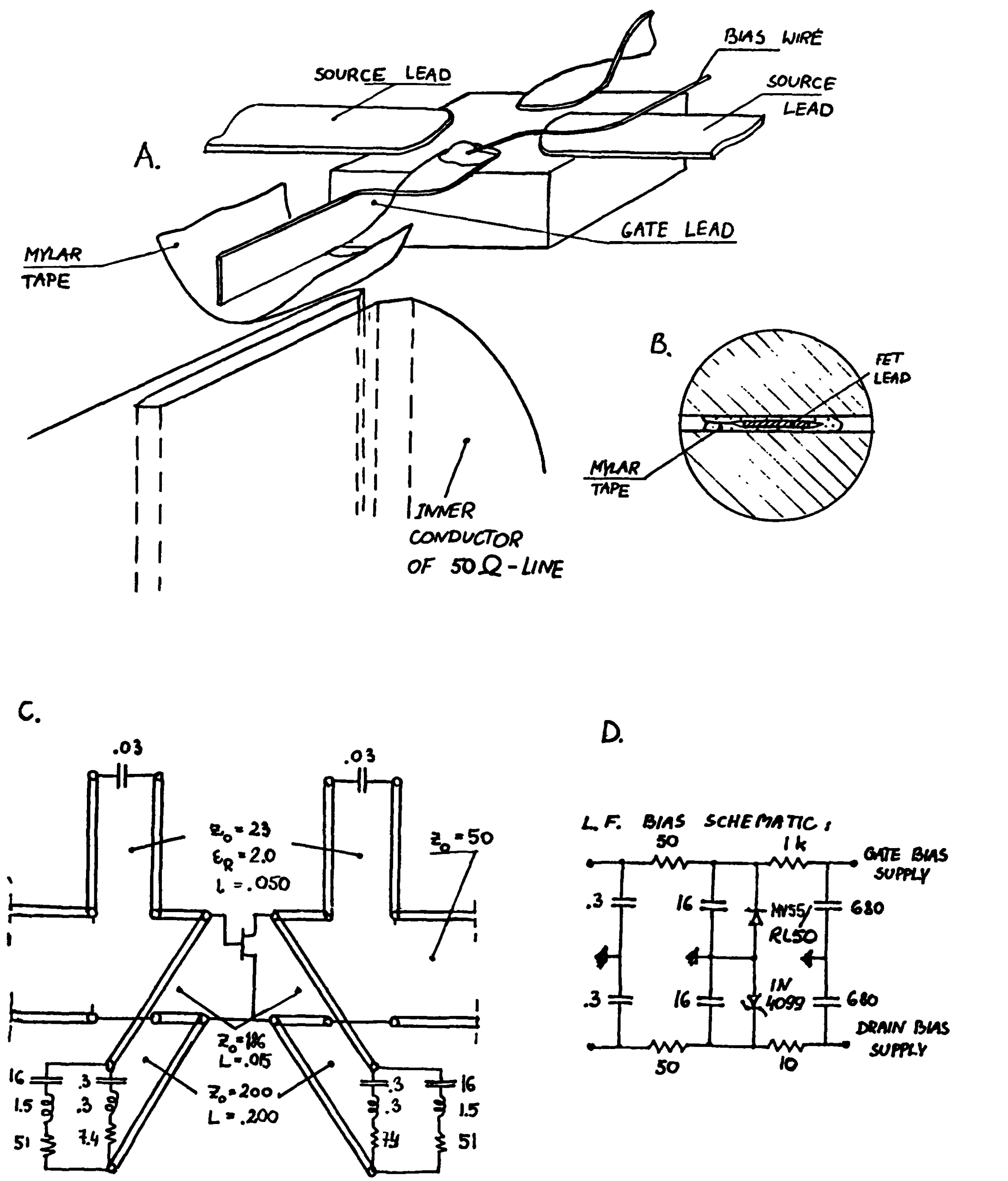


Fig. 2. (A) Schematic view of the realization of the d.c. separation circuit. (B) Cross-section of the reentrant line after assembly. (C) High frequency equivalent circuit of the bias and d.c. separation circuits. (D) Schematic of the bias circuit. Element values are given in ohms, picofarads, nanohenries, and inches.

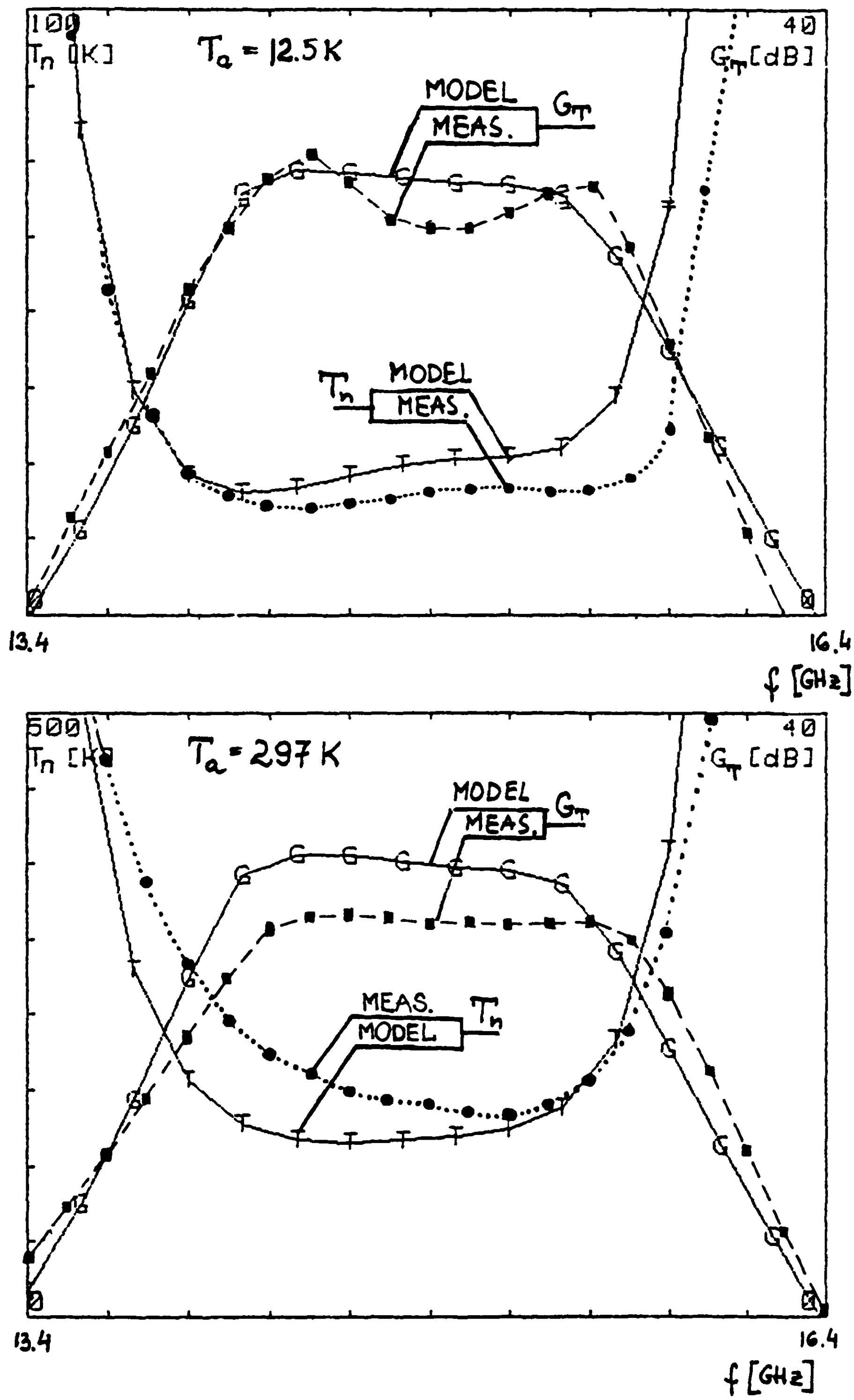


Fig. 3. Comparison between model prediction and measured performance of three-stage, K_u-band, FHR01FH amplifier (U-5) at 297 K and 12.5 K. At room temperature all transistors are biased at V_{ds} = 2 V, I_{ds} = 10 mA. At cryogenic temperature all transistors are biased at V_{ds} = 2 V, I_{ds} = 5 mA.

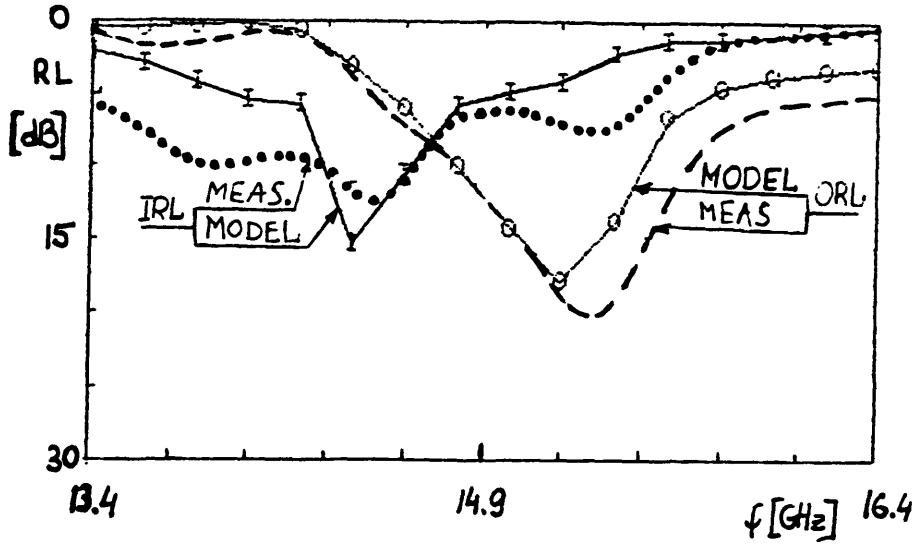
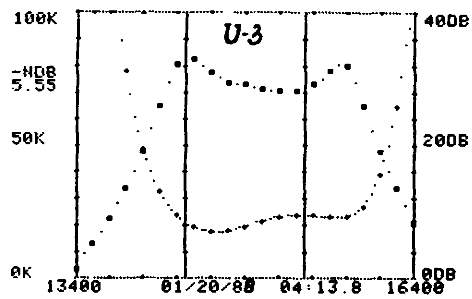
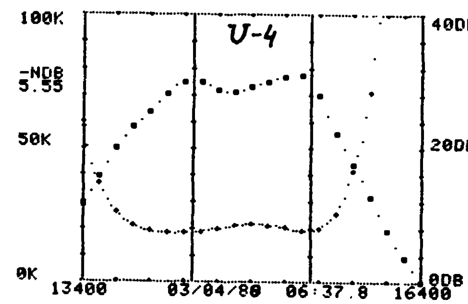


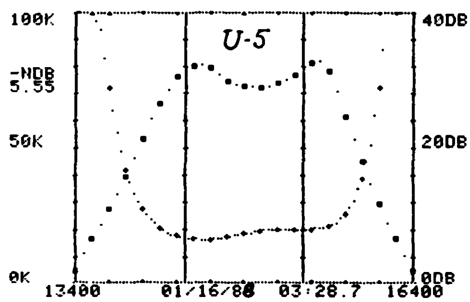
Fig. 4. Comparison between model prediction and measured return loss of the three-stage, K_u-band, FHR01FH amplifier (U-5) at 297 K. All transistors are biased at V_{ds} = 2 V, I_{ds} = 10 mA.



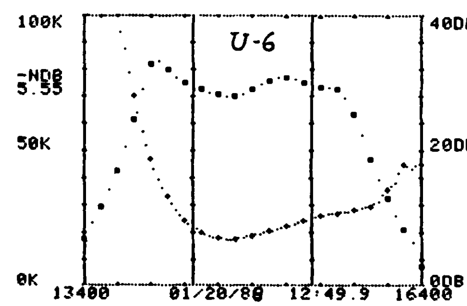
F,GHZ	NOISE	GAIN,DB	F,GHZ	NOISE	GAIN,DB
14.150	32.4	25.9	14.30	23.4	32.2
14.450	18.9	32.8	14.60	17.3	30.8
14.750	17.7	29.4	14.90	19.3	29.2
15.050	21.1	28.3	15.20	22.9	28.1
15.350	23.5	28.2	15.50	23.2	29.1
15.650	22.6	31.1	15.80	22.9	31.8



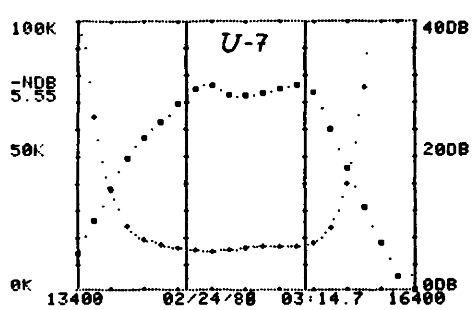
F,GHZ	NOISE	GAIN,DB	F,GHZ	NOISE	GAIN,DB
14.150	18.2	28.1	14.30	18.2	29.9
14.450	18.7	29.8	14.60	19.7	28.7
14.750	20.8	28.3	14.90	21.4	29.1
15.050	21.1	29.8	15.20	20.0	30.7
15.350	18.9	30.9	15.50	19.7	27.8
15.650	25.4	22.1	15.80	41.1	17.4



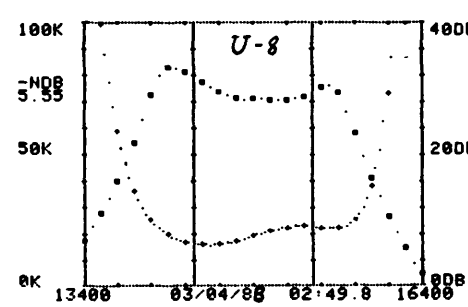
F,GHZ	NOISE	GAIN,DB	F,GHZ	NOISE	GAIN,DB
14.150	20.5	26.5	14.30	17.6	30.4
14.450	16.3	31.9	14.60	16.2	31.5
14.750	17.0	29.5	14.90	18.2	28.9
15.050	19.2	28.7	15.20	20.0	29.3
15.350	19.9	30.7	15.50	19.9	32.3
15.650	20.9	31.1	15.80	25.4	24.5



F,GHZ	NOISE	GAIN,DB	F,GHZ	NOISE	GAIN,DB
14.150	32.6	31.8	14.30	24.3	30.0
14.450	19.7	28.9	14.60	17.8	28.1
14.750	17.4	27.8	14.90	18.6	29.0
15.050	20.0	30.1	15.20	22.0	30.6
15.350	24.0	29.9	15.50	25.7	29.2
15.650	26.8	28.8	15.80	27.6	25.2



F,GHZ	NOISE	GAIN,DB	F,GHZ	NOISE	GAIN,DB
14.150	17.0	24.8	14.30	15.9	27.5
14.450	15.2	29.8	14.60	14.9	30.3
14.750	15.3	29.0	14.90	16.2	28.8
15.050	16.6	29.0	15.20	16.6	29.8
15.350	16.4	30.4	15.50	17.7	29.4
15.650	23.3	23.9	15.80	39.6	18.1



F,GHZ	NOISE	GAIN,DB	F,GHZ	NOISE	GAIN,DB
14.150	19.6	33.2	14.30	16.8	32.4
14.450	15.7	30.9	14.60	15.8	29.4
14.750	17.0	28.3	14.90	18.9	28.4
15.050	20.8	28.1	15.20	22.4	28.2
15.350	22.7	28.7	15.50	22.3	30.2
15.650	22.0	29.3	15.80	25.1	23.1

Fig. 5. Cryogenic performance of six K_u-band amplifiers under optimal bias conditions. The noise temperature is referred to cold input of an amplifier. The measured gain characteristics include the contribution of the cold isolator at the output and the dewar transition (about 1 dB of loss).

APPENDICES

Appendix I. Parts List for K_u-Band HEMT Amp (14.4-15.4 GHz)

Appendix II. Drawings

A. Amplifier Alignment Procedure

B. Stub Dielectric Support

C. Chassis

D. Amplifier Cover

E. Transistor Strap

F. Output End Plate

G. Input End Plate

H. Coaxial Transformer

I. Support Inner Conductor

J. Interstage Inner Conductor

K. Output SMA Modified

L. Input SMA Modified

PARTS LIST Ku-Band HEMT Amp (14.4-15.4 GHz) DATE August 1988 REVISION

ITEM	QUANTITY	REF. DESIG.	DESCRIPTION	MFG.	PART NUMBER
1	1		Amplifier alignment procedure	NRAO	C53208M017
2	1		Stub dielectric support	NRAO	A53208M020
3	1		Chassis	NRAO	C53208M009, Rev. C
4	1		Amplifier cover	NRAO	B53208M010
5	6		Transistor strap	NRAO	A53208M011, Rev. A
6	1		Output end plate	NRAO	A53206M072, Rev. D
7	1		Input end plate	NRAO	A53206M071, Rev. D
8	1 ea.		Coaxial transformer	NRAO	A53208M016
9	2		Support inner conductor	NRAO	A53208M012, Rev. A
10	2		Innerstage inner conductor	NRAO	A53208M013, Rev. B
11	1		Output SMA modified	NRAO	A53208M015, Rev. A
12	1		Input SMA modified	NRAO	A53208M014, Rev. A
13	1		Power connector	Omni-Spectra	ER-7S-6
14	3		HEMT	Fujitsu	FHR01FH
15	6		HEMT bias leads, #36 AWG Beldsol	Belden	8058
16	6		Bias wires, #30 AWG Beldsol	Belden	8055
17	1		LED, bias wire, #30 AWG	Alpha	1851

Appendix I

PARTS LIST Ku-Band HEMT Amp (14.4-15.4 GHz) DATE August 1988 REVISION ________

ITEM	QUANTITY	REF. DESIG.	DESCRIPTION	MFG.	PART NUMBER
18	6		0.08x3/16 filister hd. screws, gold-plated		
19	2		2-56 x 1/2" socket head SS screws	All-Metal	
20	2		2-56 x 3/8" socket head SS screws	All-Metal	
21	4		2-56 x 3/16" socket head SS screws	All-Metal	
22	4		2-56 x 1/4" socket head SS screws		
23	12		4-40 x 1/4" socket head SS screws	All-Metal	
24	1		4-40 x 3/8" socket head SS screw	All-Metal	
25	1		4-40 x 1/2" socket head SS screws	All-Metal	
26	6		.3 pF chip capacitors	ATC	100-A-0R3-B-P-150
27	6		16 pF chip capacitors	ATC	100-A-160-K-P-50
28	6		680 pF chip capacitors	ATC	100-B-681-M-P-50
29	9		50 ohm chip resistors	Mini-Systems	WA13PG-500-J-S
30	3		10 ohm 1/8 W metal film resistor	Corning	RLR05C-10R0-FS
31	3		1000 ohm 1/8 W metal film resistor	Corning	RLR05C-1001-FS
32	3		Diode Zener	Motorola	IN4099
33	6		LED	Litronix	RL-50
34			Solder, 2% silver	Ersin	SN-62-.028

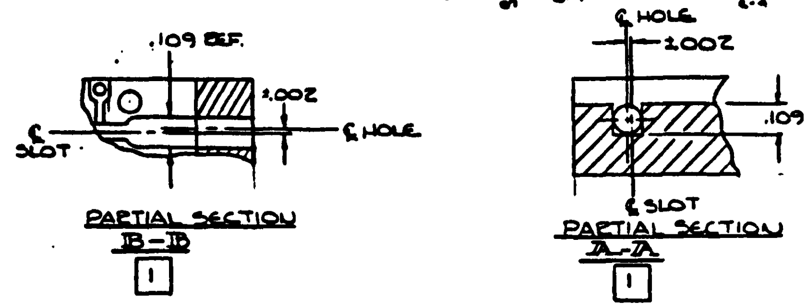
PARTS LIST Ku-Band HEMT Amp (14.4-15.4 GHz) DATE August 1988 REVISION

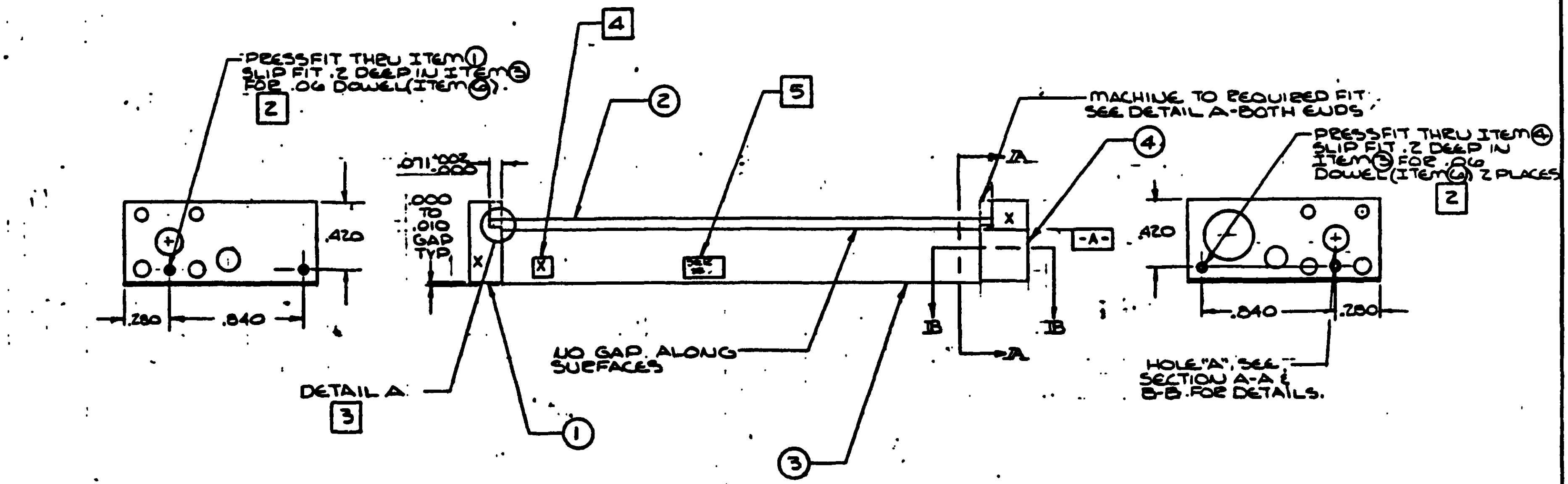
ITEM	QUANTITY	REF. DESIG.	DESCRIPTION	MFG.	PART NUMBER
35			Flux, rosin liquid	Lester	#1544
36			Mylar tape	Scotch	RT-56
37			Input stub, #30 AWG	Belden	8025

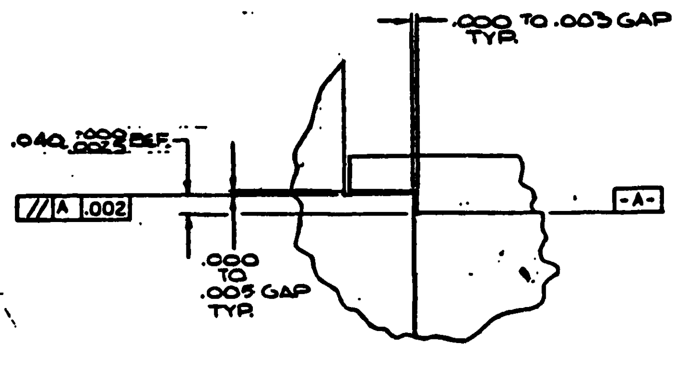
REV.	DATE	DRAWN BY	APPR'V'D BY	DESCRIPTION
A	4-15 87	GM		8-4 ... WAS .020
B	4-24 87	GM		RELOCATED DOWEL HOLES 8-4

NOTES: (RECOMMENDED PROCEDURE, DIFFERENT PROCESS MAY BE USED AS LONG AS ALIGNMENTS SHOWN ARE SATISFIED)

1. ALIGN HOLE 'A' PARTS ① + ④ WITH .109 SLOT IN PART ③ AS SHOWN. PARTS SHOULD BE CLAMPED USING 3 AVAILABLE SCREW HOLES.
2. DRILL & REAM DOWEL HOLES AS SHOWN, & REASSEMBLE PARTS WITH DOWELS.
3. MILL ITEMS ① + ④ TO FIT COVER AS SHOWN.
4. MATCH MARK ITEMS ① ③ ④ IN APPROXIMATE AREA SHOWN WITH IDENTIFIER STATED IN WORK ORDER.
5. PUNCH SERIAL # IN APPROXIMATE AREA SHOWN WITH NUMBER STATED IN WORK ORDER.
6. DISASSEMBLE AND APPLY 75 μin Au PLATE.







DETAIL A
10 x SCALE

ITEM	PART #	DESCRIPTION
6	STOCK	1/16 DIA. S.S. DOWEL x 3/8 LG.
5		
4	A53206M072	OUTPUT ENDPLATE
3	C53208M009	MODULE
2	B53208M010	COVER
1	A53206M071	INPUT ENDPLATE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: ANGLES ±
3 PLACE DECIMALS (.XXX): ±
2 PLACE DECIMALS (.XX): ±
1 PLACE DECIMALS (.X): ±

MATERIAL: AS NOTED

FINISH: 6

NEXT ASSY | USED ON

VLBA PROJECT: 15 GHz F.E

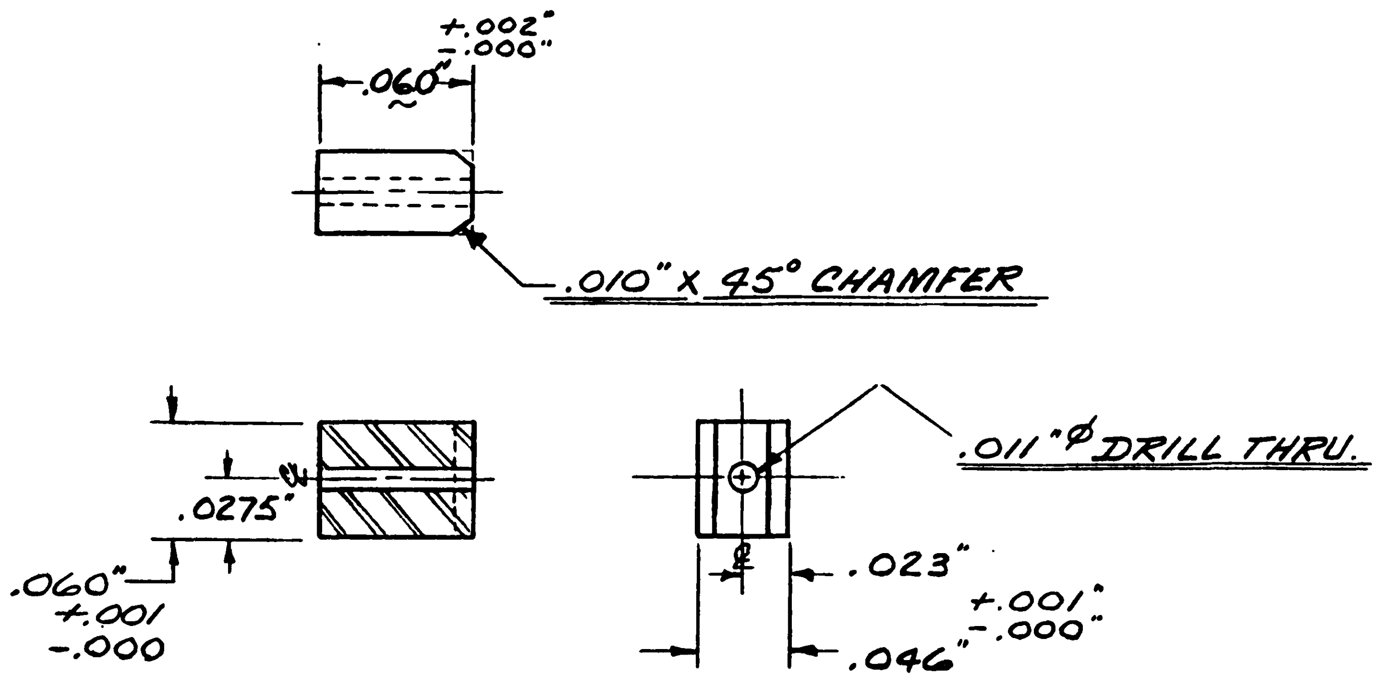
TITLE: AMPLIFIER ALIGNMENT PROCEDURE

NATIONAL RADIO ASTRONOMY OBSERVATORY

DRAWN BY: G. MORRIS — DATE: 8-17-87
DESIGNED BY: — DATE:
APPROVED BY: — DATE:

SHEET NUMBER 1:1 — DRAWING NUMBER C53208M017 — REV. B — SCALE 2X

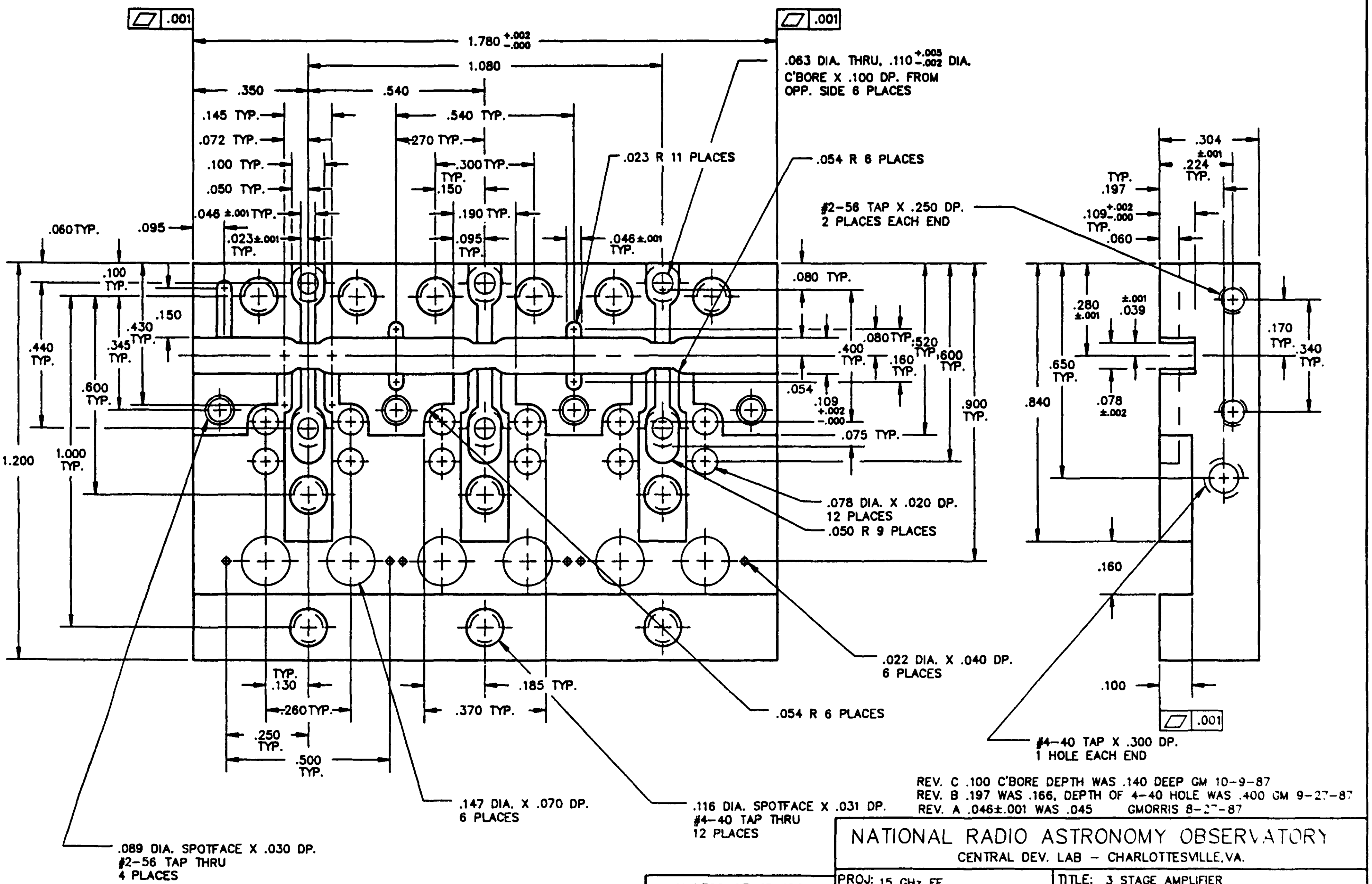
Appendix II.A



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLES ±
ACE DEC. (xxx) ±
ACE DEC. (xx) ±
LACE DEC. (x) ±

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLBA

PROJ: 15 GHZ. HEMT	TITLE: STUB DIELECTRIC SUPPORT
MATERIAL: REXOLITE	DRAWN BY: WL — DATE: 8-88
FINISH:	DESIGNED BY: — DATE:
	APPROVED BY: — DATE:
SHEET NUMBER:	DRAWING NUMBER: A53208M020 — SCALE: 10:1



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REV. B .197 WAS .166, DEPTH OF 4-40 HOLE WAS .400 GM 9-27-87
REV. A .046±.001 WAS .045 GMORRIS 8-27-87

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLES±
3 PLACE DEC: ± .005
2 PLACE DEC: ±
1 PLACE DEC. ±

NATIONAL RADIO ASTRONOMY OBSERVATORY
CENTRAL DEV. LAB – CHARLOTTESVILLE, VA.

PROJ: 15 GHz FE	TITLE: 3 STAGE AMPLIFIER MODULE		
MATERIAL: ETP COPPER	DRAWN BY: G.MORRIS	DATE: 8-87	
FINISH: GOLD PLATE	DESIGNED BY: M.P	DATE. 8-87	
	APPROVED BY:	DATE:	
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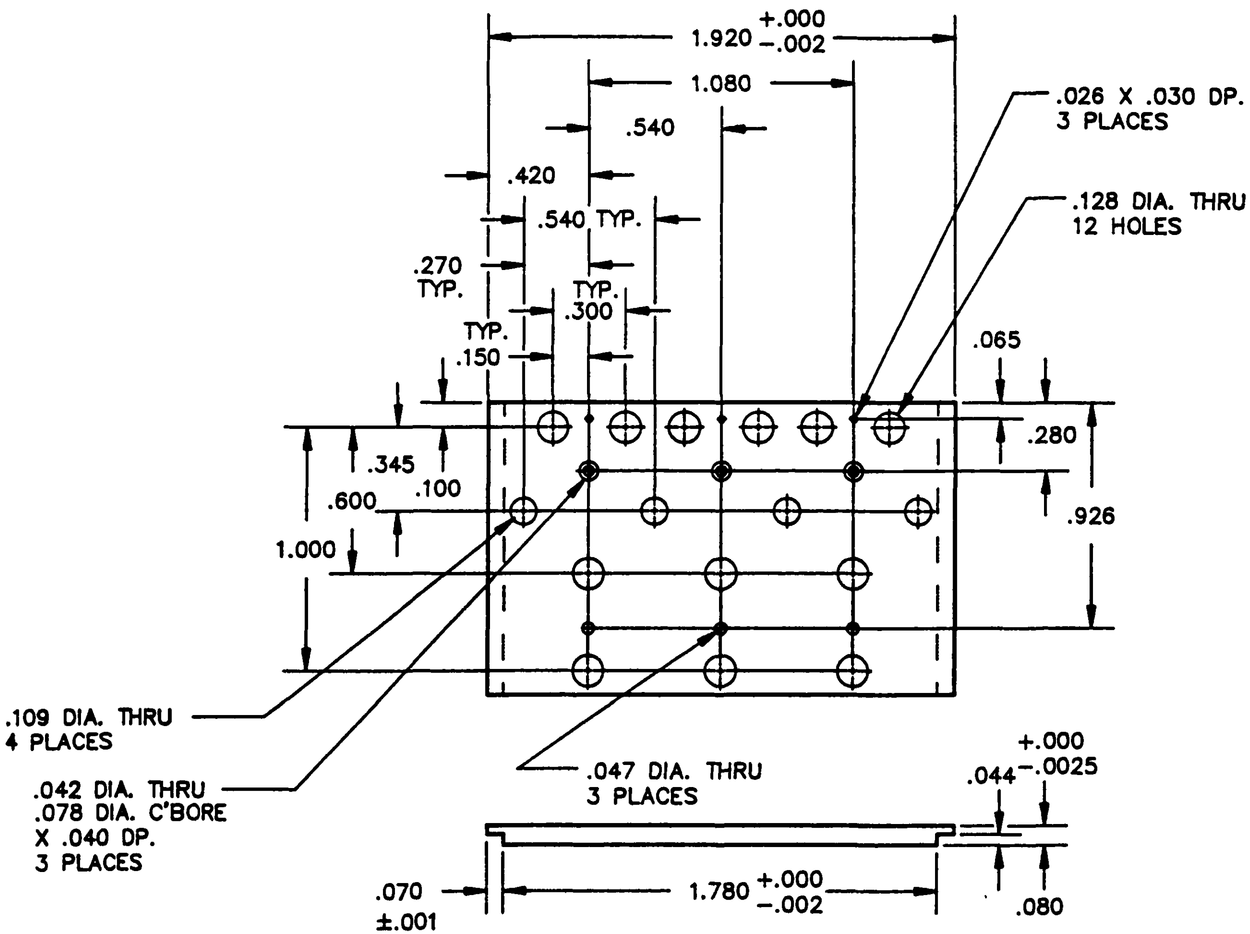
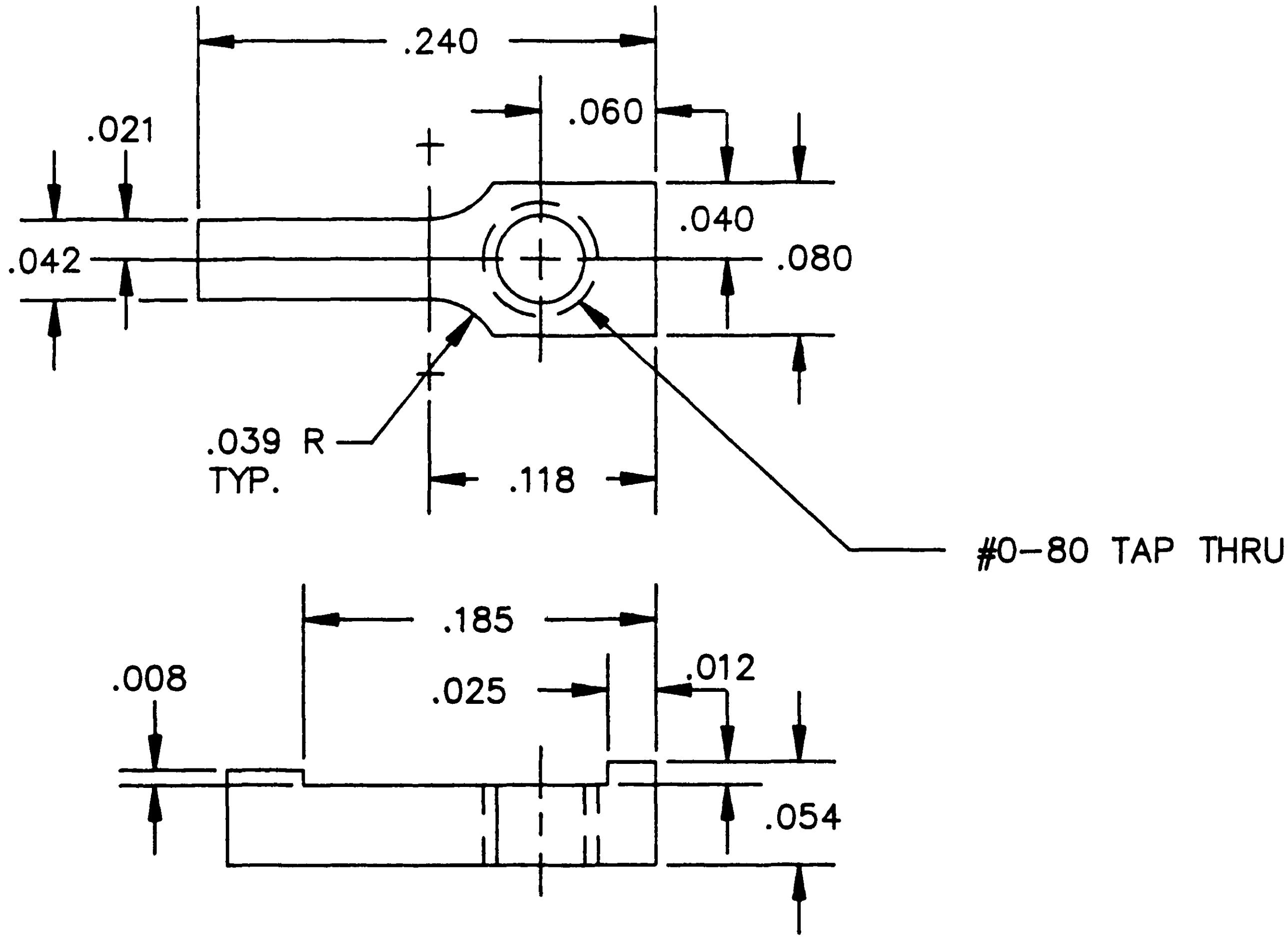


NATIONAL RADIO ASTRONOMY OBSERVATORY
CENTRAL DEV. LAB – CHARLOTTESVILLE, VA.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLES±
3 PLACE DEC:± .005
2 PLACE DEC:±
1 PLACE DEC:±

PROJ: 15 GHz FE	TITLE: 3 STAGE AMPLIFIER COVER
MATERIAL: ETP COPPER	DRAWN BY: G.MORRIS — DATE: 8-87
	DESIGNED BY: M.P — DATE: 8-87
FINISH: GOLD PLATE	APPROVED BY: — DATE:
SHEET NUMBER	DRAWING NUMBER B53208M010 — REV: — SCALE: 1:1



REV. A .240 WAS .225 GMORRIS 10-29-87

NATIONAL RADIO ASTRONOMY OBSERVATORY

CENTRAL DEV. LAB - CHARLOTTESVILLE, VA.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

TOLERANCES

ANGLES±

3 PLACE DEC: ±.002

2 PLACE DEC: ±

1 PLACE DEC: ±

PROJ: 15 GHz FE

TITLE: TRANSISTOR STRAP

MATERIAL: BRASS

FINISH:

DRAWN BY: GM — DATE: 8-87

DESIGNED BY: M.P — DATE: 8-87

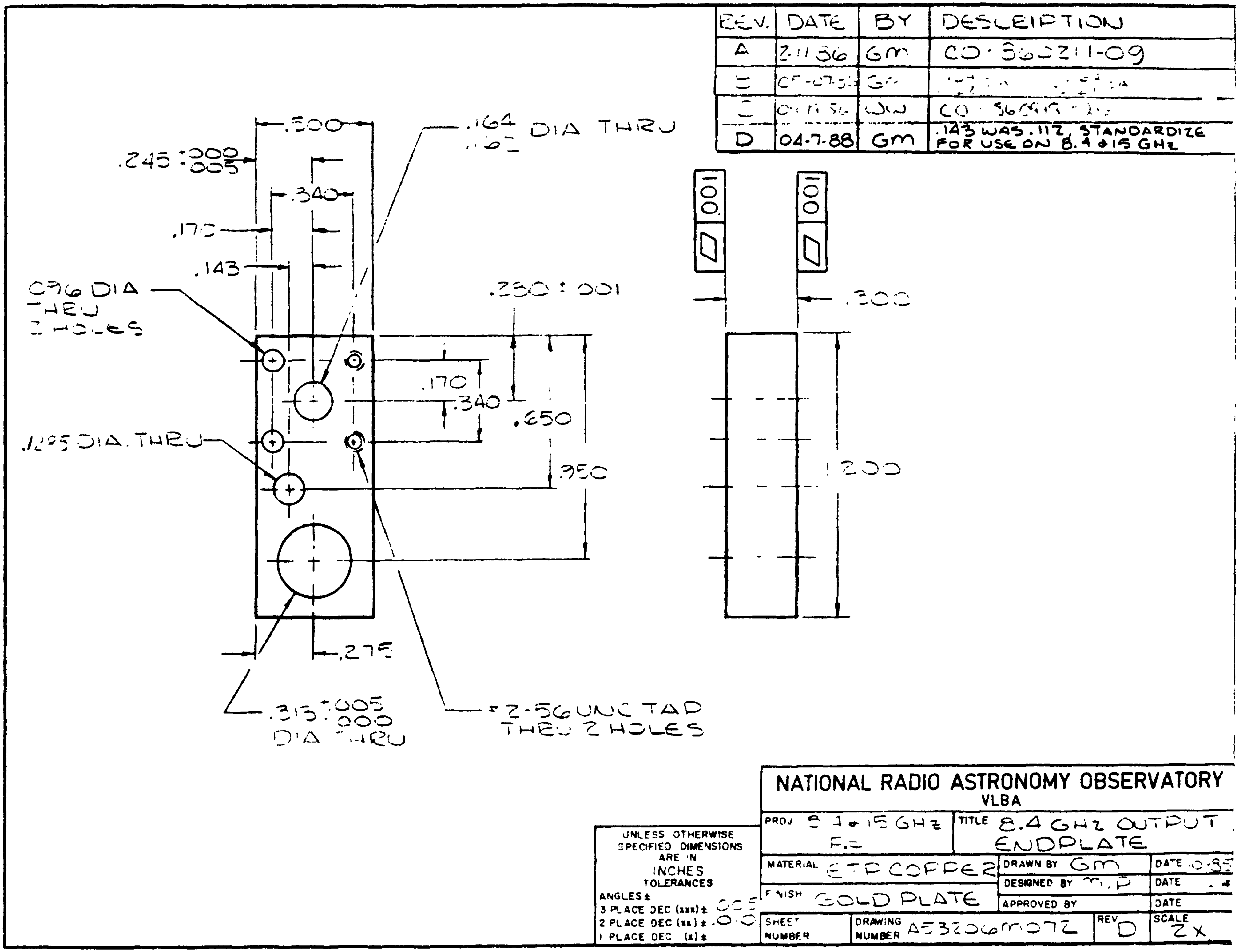
APPROVED BY: — DATE:

SHEET NUMBER

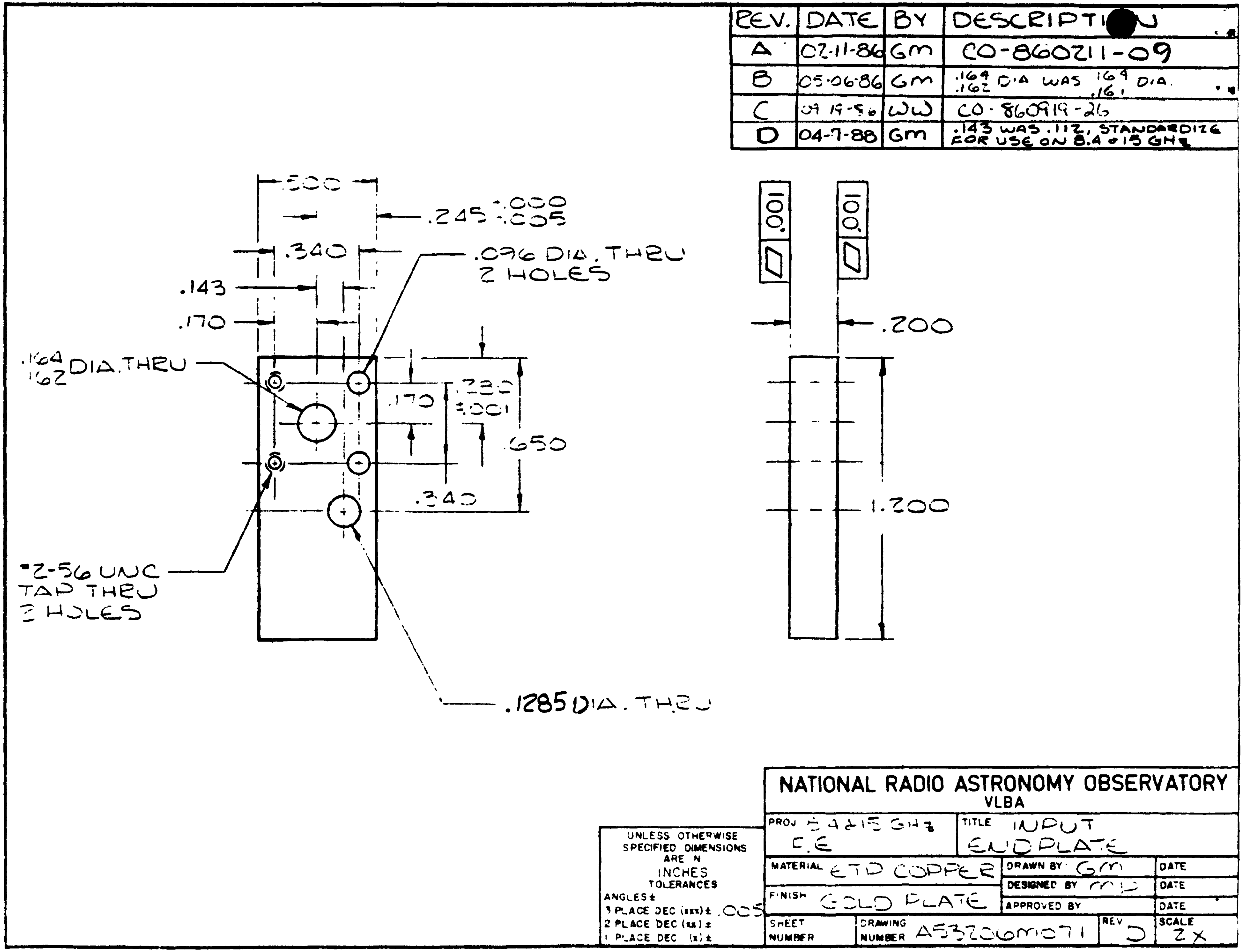
DRAWING NUMBER A53208M011

REV: A

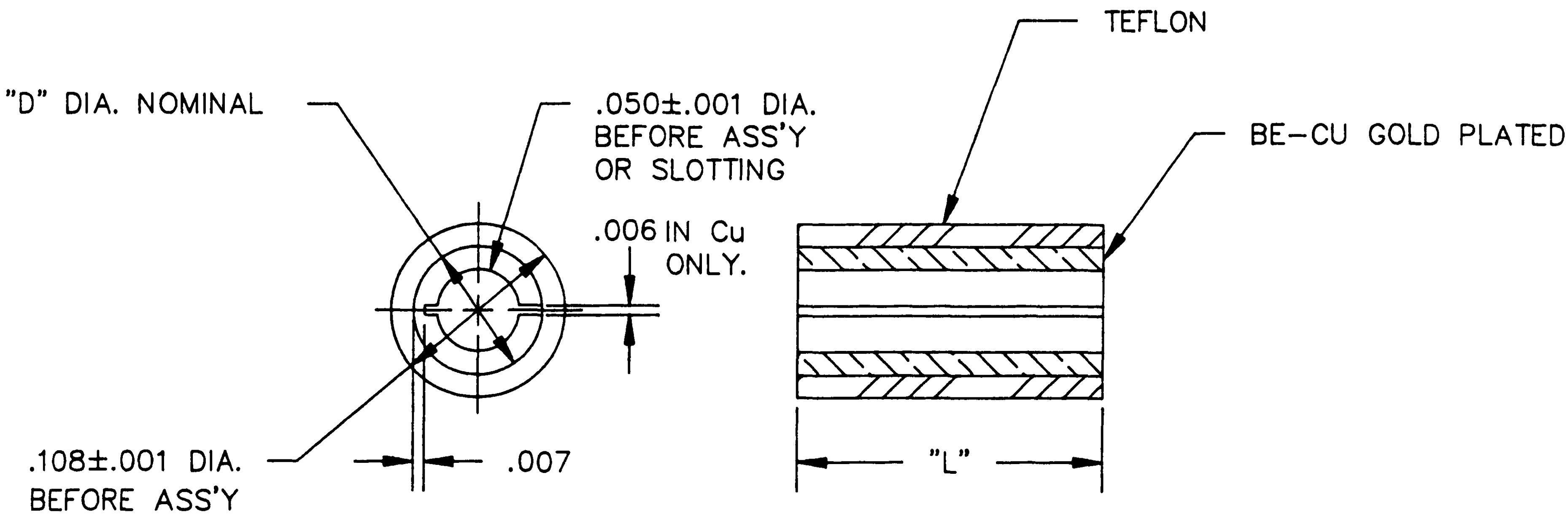
SCALE: 10:1



Appendix II.F



Appendix II.G

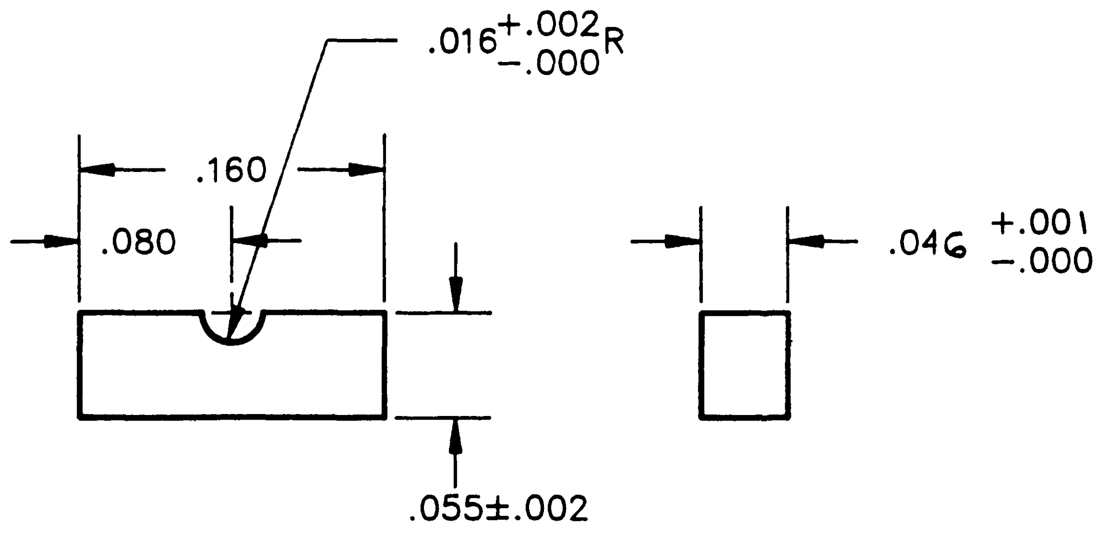


DASH #	"L"	"D"
-6	.189	.080
-5	.143	.080
-4	.124	.080
-3	.082	.080
-2	.066	.080
-1	.145	.094

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLES±
3 PLACE DEC: ± .002
2 PLACE DEC: ±
1 PLACE DEC. ±

NATIONAL RADIO ASTRONOMY OBSERVATORY
CENTRAL DEV. LAB – CHARLOTTESVILLE, VA.

PROJ: 15 GHz FE		TITLE: COAXIAL TRANSFORMER	
MATERIAL: SEE ABOVE		DRAWN BY: GM	DATE: 8-87
		DESIGNED BY: M.P	DATE: 8-87
FINISH: SEE ABOVE		APPROVED BY:	DATE:
SHEET NUMBER	DRAWING NUMBER A53208M016	REV:	SCALE: 10:1

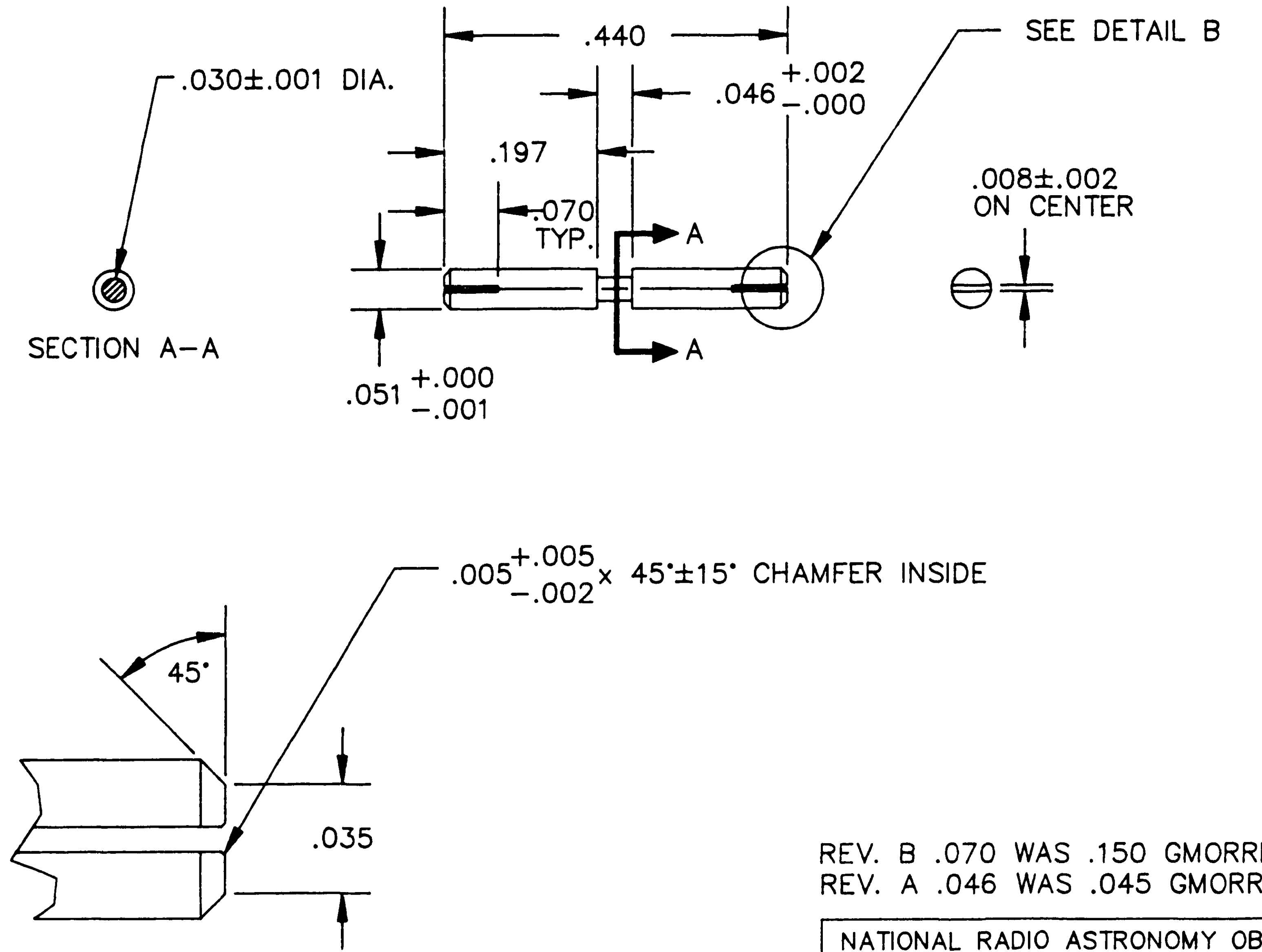


REV. A .046 +.001 −.000 WAS .045 +.002 −.000 GM 8-27-87

NATIONAL RADIO ASTRONOMY OBSERVATORY
CENTRAL DEV. LAB – CHARLOTTESVILLE, VA.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ANGLES± 3 PLACE DEC: ± .005 2 PLACE DEC: ± 1 PLACE DEC. ±	PROJ: 15 GHz FE	TITLE: SUPPORT– INNER CONDUCTOR	
	MATERIAL: REXOLITE	DRAWN BY: GM	DATE: 8–87
		DESIGNED BY: M.P	DATE: 8–87
	FINISH:	APPROVED BY:	DATE:
	SHEET NUMBER	DRAWING NUMBER A53208M012	REV: Δ / SCALE: 1:1

Appendix II.I

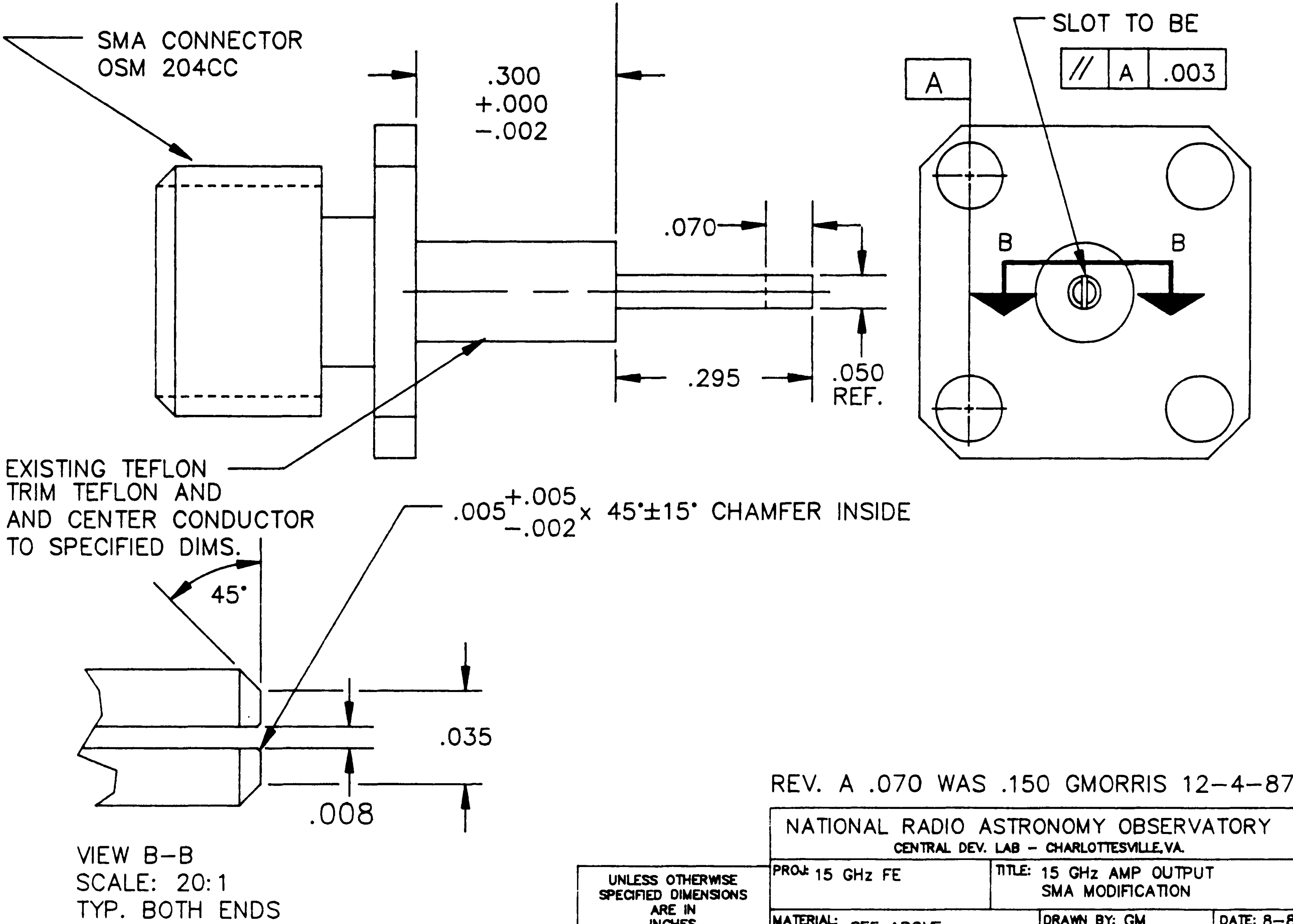


REV. B .070 WAS .150 GMORRIS 12–4–87
REV. A .046 WAS .045 GMORRIS 8–27–87

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLES±
3 PLACE DEC: ±.005
2 PLACE DEC: ±
1 PLACE DEC. ±

NATIONAL RADIO ASTRONOMY OBSERVATORY
CENTRAL DEV. LAB – CHARLOTTESVILLE, VA.

PROJ: 15 GHz FE		TITLE: INTERSTAGE INNER CONDUCTOR	
MATERIAL: BRASS		DRAWN BY: GM	DATE: 8–87
		DESIGNED BY: M.P	DATE: 8–87
FINISH: GOLD PLATE		APPROVED BY:	DATE:
SHEET NUMBER	DRAWING NUMBER A53208M013	REV: B	SCALE: 5:1



REV. A .070 WAS .150 GMORRIS 12-4-87

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLES±
3 PLACE DEC: ±.002
2 PLACE DEC: ±
1 PLACE DEC. ±

NATIONAL RADIO ASTRONOMY OBSERVATORY CENTRAL DEV. LAB - CHARLOTTESVILLE,VA.				
PROJ: 15 GHz FE		TITLE: 15 GHz AMP OUTPUT SMA MODIFICATION		
MATERIAL: SEE ABOVE		DRAWN BY: GM		DATE: 8-87
		DESIGNED BY: M.P		DATE: 8-87
FINISH: GOLD PLATE		APPROVED BY:		DATE:
SHEET NUMBER	DRAWING NUMBER A53208M015		REV: A	SCALE: 5:1

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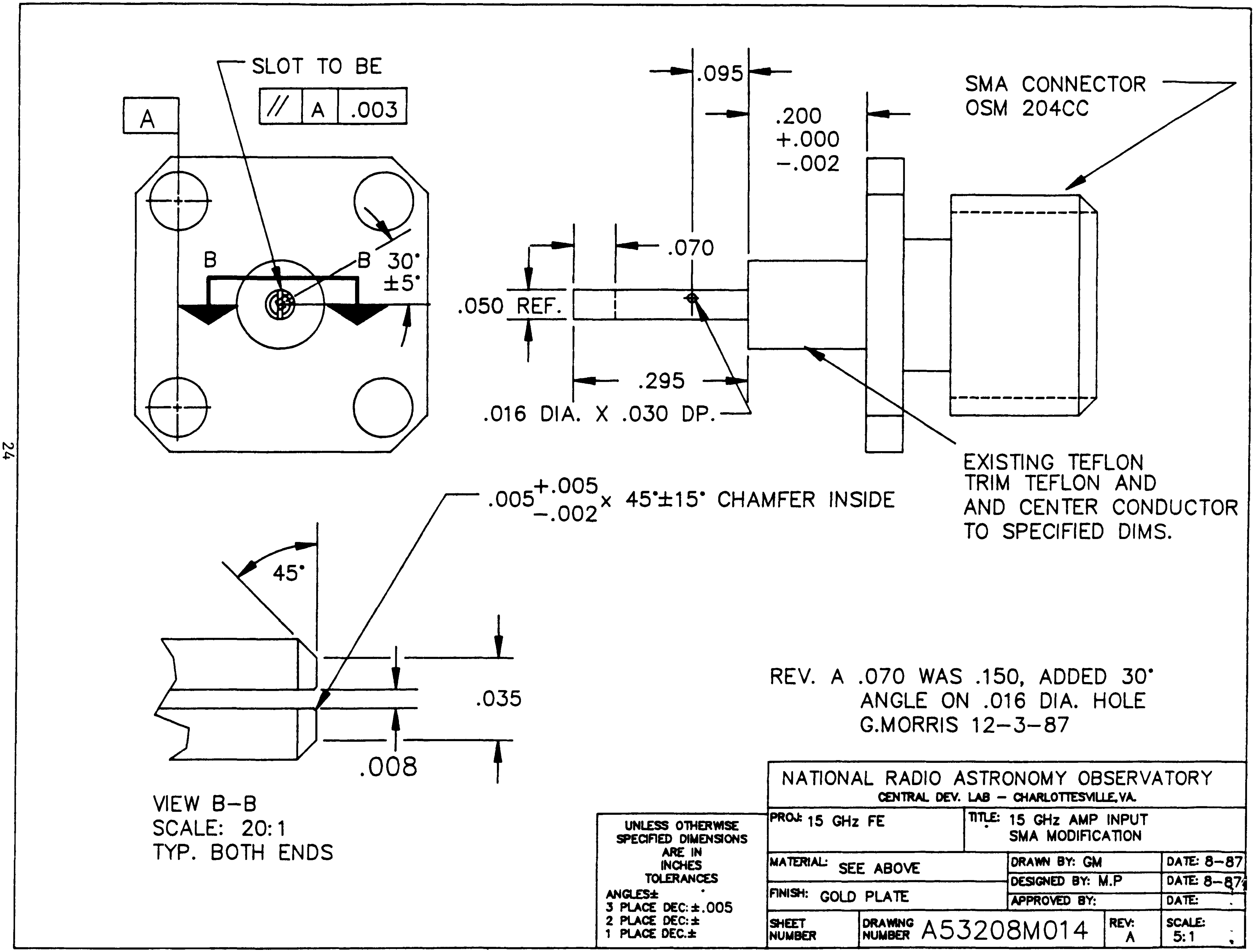

Appendix II.L