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TITLE— Design Considerations for 50 db Bandpass Filter

MM 67 — 6323 — 6

CASE CHARGED— 27703-33

DATE— April 4, 1967

FILING CASES— 27703-1300

AUTHOR— R. S. Hoppough

FILING SUBJECTS— Bandpass Filters
Stub Filters

ABSTRACT

A nine section, bandpass, quarter-wavelength stub filter employing symmetrically tapped stubs and fabricated in stripline using air as the dielectric medium is described.

The unit has a Chebyshev response with a .003 db ripple over an 18 percent bandwidth with 50 db of rejection at the 30 percent bandwidth points and operates at L-band.

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SUBJECT: Design Considerations for 50 db Bandpass Filter - Case 27703-1300

DATE: April 4, 1967

FROM: R. S. Hoppough

MM-67-6323-6

MEMORANDUM FOR FILE

Introduction

The exact synthesis techniques described by Wentzel have resulted in "ideal" synthesis of filters employing distributed components. This paper describes the design of an 18 percent bandwidth, bandpass filter operating at L-band with 50 db of rejection at the 30 percent bandwidth points. The response is Chebyshev with a .003 db ripple in the passband. The filter is a nine section quarter-wavelength stub type employing symmetrically tapped stubs and fabricated in stripline using air as the dielectric medium.

Since the synthesis techniques have been computerized, this paper will deal primarily with the realization of the filter given the synthesized stub impedances.

System Requirements

The required rejection was 50 db at f_o ± 200 MHz with as low a loss and phase deviation as practical across the band f_o ± 92 MHz. The small gain and phase deviations allowed forced the requirement for a match with a return loss of approximately 30 db. The mechanical constraints were less than 3 inches in width, 3/4 inch in height, and an undefined minimum required length.

Design Considerations

It was recognized that an interdigital or comb-line design with an elliptic function response could achieve the low inband insertion loss and high out-of-band rejection; however, the phase response of such a filter would have an extremely steep slope at the band edges and good matches are understood to be difficult to achieve. It was, therefore, decided that the predictability of the stub filter with an air dielectric would result in a more readily realizable configuration to develop in the time allowed. In an attempt to minimize the phase deviation across the band f_o ± 92 MHz, the passband was extended to f_o ± 117 MHz.

Design

A computer program FLTR4[1] was available which computes the passband ripple for various numbers of sections, given: the center frequency, the passband edge frequency and its acceptable loss, and the rejection frequency and its required loss.

This program predicted that 8 sections were required for a return loss of approximately 22 db, 9 sections for 32 db and 10 sections for 38 db.

Since the minimum number of sections would keep the insertion loss to a minimum, 9 sections were chosen as this number is sufficient to obtain the required 30 db return loss.

The synthesis of the 9 sections, .003 db ripple Chebyshev filter with a passband of $f_o \pm 117$ MHz and a rejection of 50 db at $f_o \pm 200$ MHz was performed as described by Wentzel.[2,3] This procedure was computerized by A. K. Johnson with the additional synthesis of the stub filter parameters. The results of this program defined the stub impedances required.

Given a main line impedance of 50 ohms the required impedances of the shorted quarter-wavelength stubs were as follows:

Stub #	Z
1 & 9	12.485
2 & 8	6.425
3 & 7	4.94
4 & 6	4.94
5	4.565

The accuracy of this program was established by running it through the analysis program of Rosler named FILTR2[4]. This theoretical response is shown in Figures 1, 2 and 3.

Realization of Theoretical Model

To afford sufficient mechanical strength, the center conductor thickness was fixed at .064 inches. The ground plane spacing was selected by restricting the highest impedance line (the 50 ohm main line) to be approximately .10 inches.

This was calculated, using the characteristic impedance equations of Cohn[5], to be approximately .170 inches. The actual spacing was chosen to be .164 inches which left .050 inches from either side of the center conductor to the ground planes.

Using the above cavity dimensions, the line widths were then calculated to be as follows:

Z_o (Ohm)	Width (Inches)
50	.098
12.485	.663
6.425	1.376
4.94	1.815
4.565	1.972

These widths were intolerably large and it was decided to use a tapped stub[6] to increase the required stub impedances and thereby decrease their physical width.

Using the 12.485 ohm stub width of .663 inches as the reference impedance and calculating the percent of the stub which is left open at the end by setting the slopes of the admittances equal at band center results in the following:

where $\alpha = \frac{2}{\pi} \cos^{-1} \left(\frac{Z_{o\alpha}}{Z_o}\right)^{\frac{1}{2}}$

$Z_{o\alpha}$ = Equivalent impedance when tapped at the point α.

Z_o = Impedance of stub untapped.

Z_o	$Z_{o\alpha}$	α	Wz_o
12.485	6.425	.491	.663
12.485	4.94	.567	.663
12.485	4.565	.587	.663

This filter was analyzed using the FILTR2 program and the results are shown in Figures 4, 5 and 6.

It can be seen that the response is unsymmetrical and it is shifted low in frequency with one of the passband ripples completely lost.

An analysis of the tapped stub relationships described in MM-66-6323-7 by the author, showed that an exact transformation from a quarter-wavelength stub to a symmetrically tapped stub of twice the original impedance existed.

The filter was then designed using the symmetrically tapped stubs at each location which required the following impedances and line widths.

Z_o	$Z_{o\alpha}$	α	Wz_o
12.485	24.97	.5	.286
6.425	12.85	.5	.642
4.94	9.88	.5	.862
4.565	9.13	.5	.940

The theoretical response of this filter is then identical to that of Figures 1, 2 and 3, and is a considerable improvement over the unsymmetrically tapped stub case and has its widest stub less than 1 inch in width.

Since the individual stubs must be separated by a quarter-wavelength, the main line "foreshortening" due to the stubs was the next consideration. The published junction theory seemed very weak so the difference in phase length of a straight line and lines with the various stubs was measured on a slotted line at band center frequency. This data is plotted in Figure 7. A subsequent check of the modified junction theory of A. G. Franco and A. A. Oliner[7] produced the theoretical data for a TEE junction which is also shown in Figure 7. This theory shows very good correlation with the measured results especially for large junction widths.

The mechanical constraints would not allow much freedom in layout as the stubs took up the total width dimension. Meandered lines were placed between each stub to minimize the overall length. The restriction of 1.5 ground plane spacings between adjacent lines was placed on this meander and thus determined its physical shape.

The corners were derived empirically, using the TDR, and exhibit a slight deviation from theory. The theory, however, hints of this since it imposes a minimum of 5 line widths between corners to eliminate interaction.

The basic meander shown in Figure 8 was used and its electrical length again measured with respect to a straight line to determine its effect on the circuit. A TDR plot of the meandered section showed it to be 50 ± 0.2 ohms throughout. This includes the GR 900 Connector to airline transition which was also derived empirically. This transition was accomplished by tapering the cavity and the center conductor as shown in Figure 8 since the filter cavity required such a small ground plane spacing.

As may be seen in Figure 8 the center conductor was made mechanically rigid by joining the shorted ends of the stubs to a common buss. Tests indicated that the total deflection of the open ends of the stubs, when mounted in the cavity, would not allow them to exceed their elastic limit and therefore disallowed any deformation. The maximum vibration frequency required was 60 Hz which was determined to be well below the mechanical resonance of the structure. However, it was deemed practical to support the open ends of the stubs since center conductors might be distorted by handling in production. These supports would then realign the conductor in the cavity.

Ceramic cylinders .121 inches in length with an OD of .121 inches and an ID of .082 inches were used. Since the ceramic is very strong under tension but weak under sheer, the cylinders were placed in a hole in the cavity and left free at their interface with the center conductor. The added capacitance due to the beads was assumed to be part of the fringing capacitance and taken into account by shortening the open stubs.

The filter was constructed using aluminum as the ground plane and a copper plated aluminum center conductor as shown in Figure 8.

The measured return loss was not as good as anticipated with a minimum of approximately 20 db across the band and capacitive tuning was added to the open ends of the stubs.

The measured response of the tuned filter is shown in Figures 9, 10 and 11. This shows that the design criteria have been met with a return loss in excess of 29 db across the band, a phase difference of less than 20 degrees, an insertion loss less than 0.9 db and a transmission loss of 50 db at the required points.

A photograph of the completed filter is shown in Figure 12. It is 3 inches in width and 16 inches in length. If excess material were machined away from the ground planes to make them .125 inches thick, the overall thickness would be .404 inches.

Conclusion

A bandpass filter meeting the design objectives has been constructed. It is anticipated that the cost of this unit will be approximately $100.00 in production quantities through the use of stamping and casting techniques which have been developed for fabricating this type structure. The unit is expected to be highly reliable even under adverse shock and vibration. Additional effort will be devoted to eliminating the necessity for tuning by utilizing a new computer program which is currently being written to facilitate exact dimensioning of center conductor and cavity by calculating mechanical dimension changes required to obtain nominal electrical characteristics.

Acknowledgment

I would like to acknowledge my appreciation for F. D. Guerry's suggestions on the mechanical layout of the filter and for L. J. Freeman's effort in the construction and testing of the unit.

WL-6323-RSH-NMW

R. S. Hoppough
R. S. HOPPOUGH

Att.
Figures 1 - 12
References
67-3861-WL

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1. Theriot, E. J. "Exact Synthesis of Microwave Bandpass Filters Using Shorted Stubs," MM-66-6323-5, August 15, 1966.

2. Wentzel, R. J. "Exact Design of TEM Microwave Networks Using Quarter-Wave Lines," IEEE Trans. MTT-12, January, 1964, pp 94-111.

3. Wentzel, R. J. and Horton, M. C. "General Theory and Design of Optimum Quarter-Wave TEM Filters," IEEE Trans. MTT-13, May, 1965, pp 316-327.

4. Rosler, L. "FILTR2, A Program for the Analysis of Distributed Networks," MM-64-2813-29, December 7, 1964.

5. Cohn, S. B. "Problems in Strip Transmission Lines," IRE Trans. MTT-3, March, 1955.

6. Di Piazza, G. C. "The Narrow Band Maximally Flat Quarter-Wave Coupled Strip Transmission Line Filter," MM-62-6436-4.

7. Franco, A. G. and Oliner, A. A. "Symmetric Strip Transmission Line TEE Junction, "IRE Trans. MTT-10, March, 1962, pp 118-124.

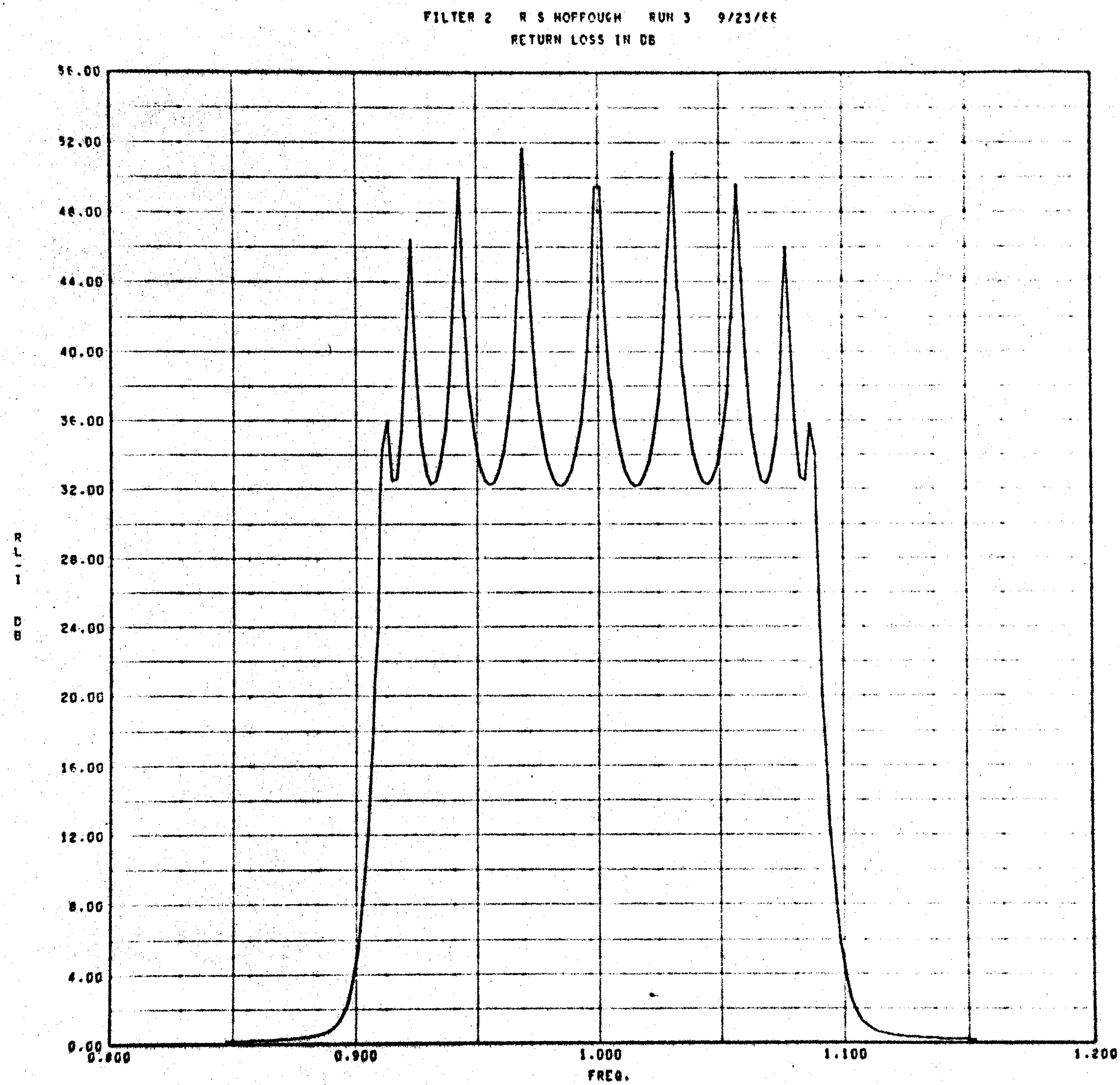
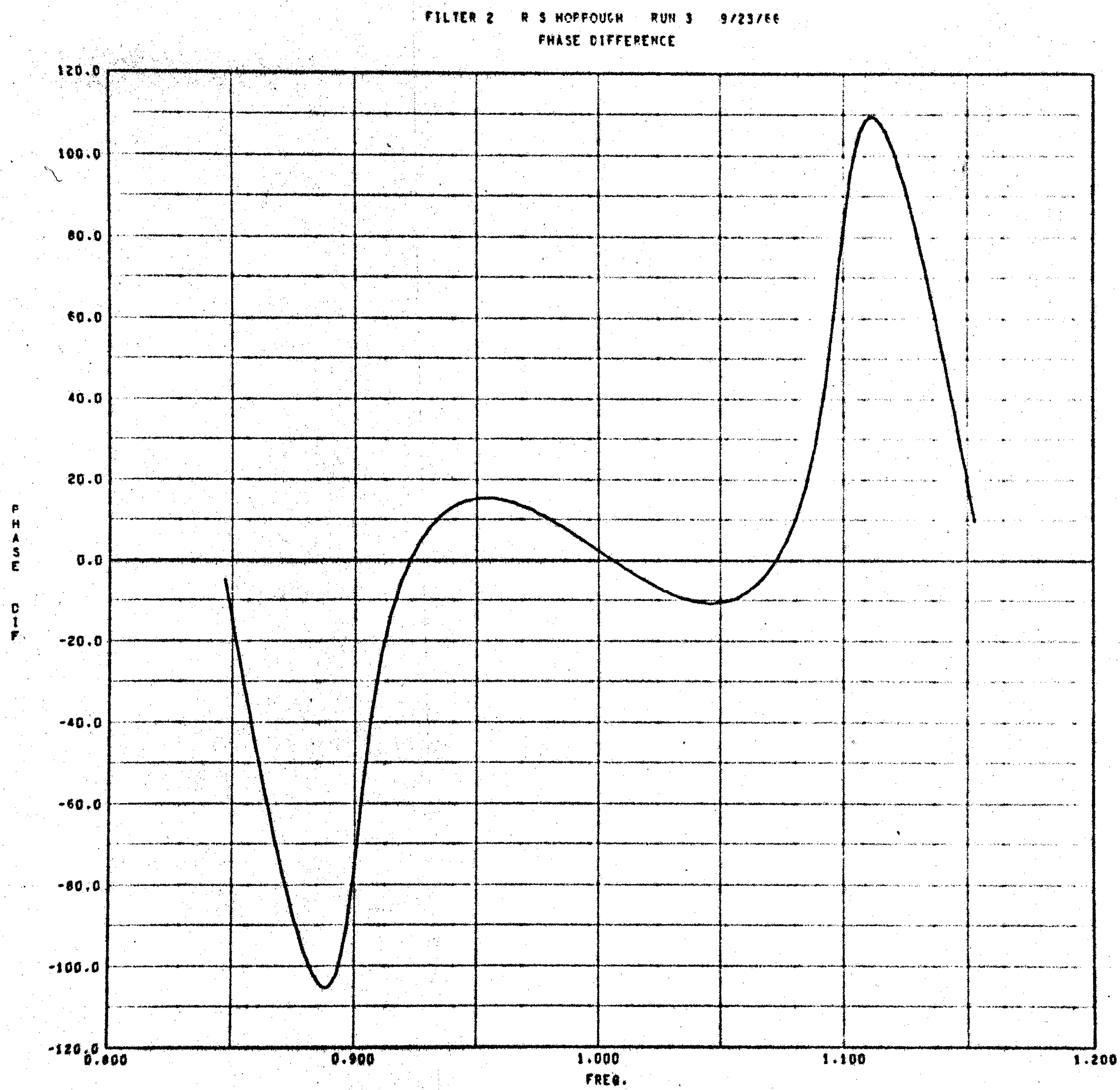

FILTER 2 R S HOFFOUGH RUN 3 9/23/66
RETURN LOSS IN DB
56.00
52.00
48.00
44.00
40.00
36.00
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
R L - I D B
0.800
0.900
1.000
1.100
1.200
FREQ.

FIGURE 1



FILTER 2 R S HOPFOUGH RUN 3 9/23/66
PHASE DIFFERENCE
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
PHASE DIF
0.800
0.900
1.000
1.100
1.200
FREQ.

FIGURE 2

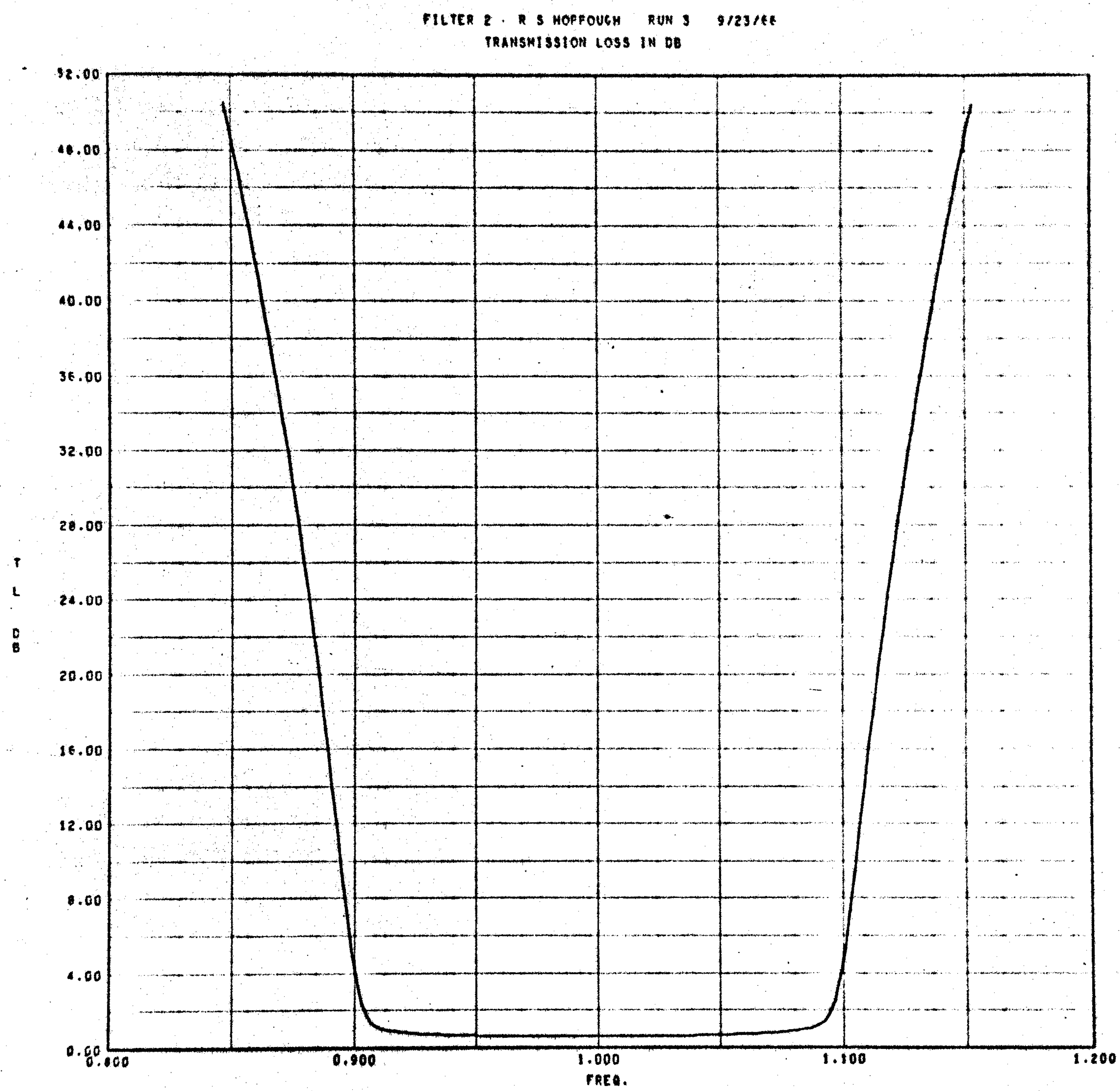

FILTER 2 · R S HOPFOUGH RUN 3 9/23/66
TRANSMISSION LOSS IN DB
52.00
48.00
44.00
40.00
36.00
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
T L · D B
0.800
0.900
1.000
1.100
1.200
FREQ.

FIGURE 3

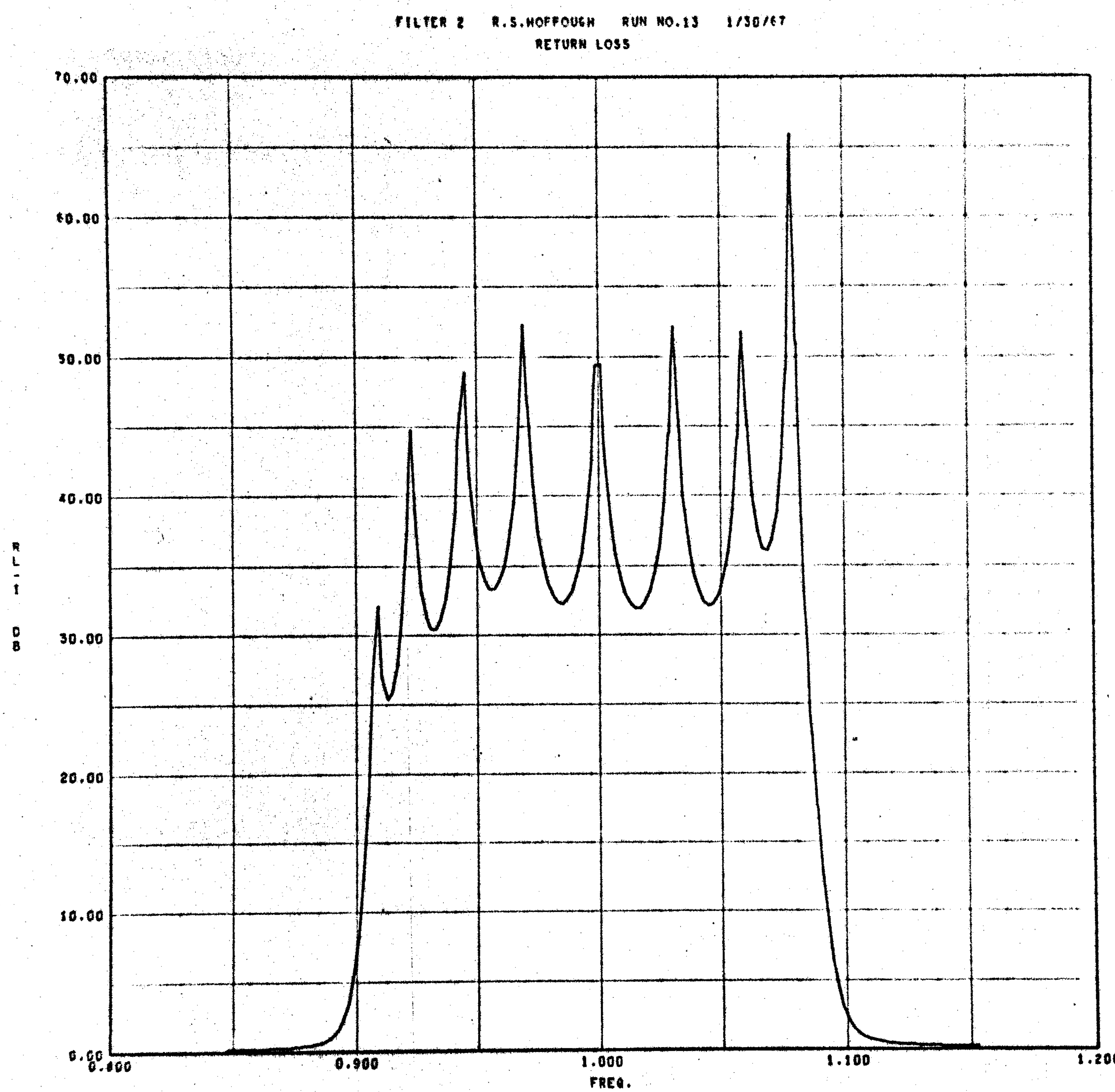

FILTER 2 R.S.HOFFOUGH RUN NO.13 1/30/67
RETURN LOSS
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
RL-I DB
0.800
0.900
1.000
1.100
1.200
FREQ.

FIGURE 4

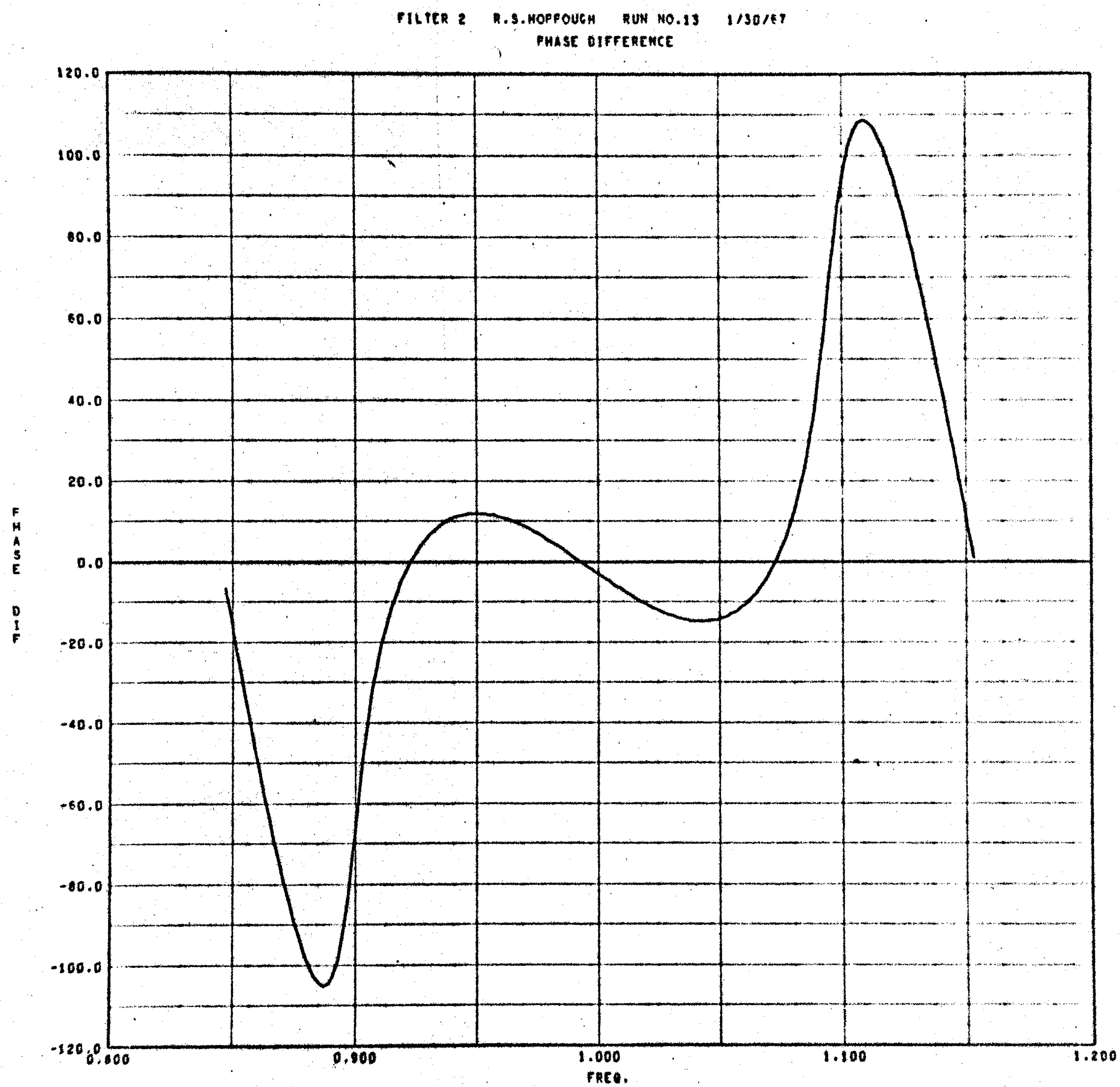

FILTER 2 R.S.HOPFOUGH RUN NO.13 1/30/67
PHASE DIFFERENCE
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
PHASE DIF
0.800
0.900
1.000
1.100
1.200
FREQ.

FIGURE 5

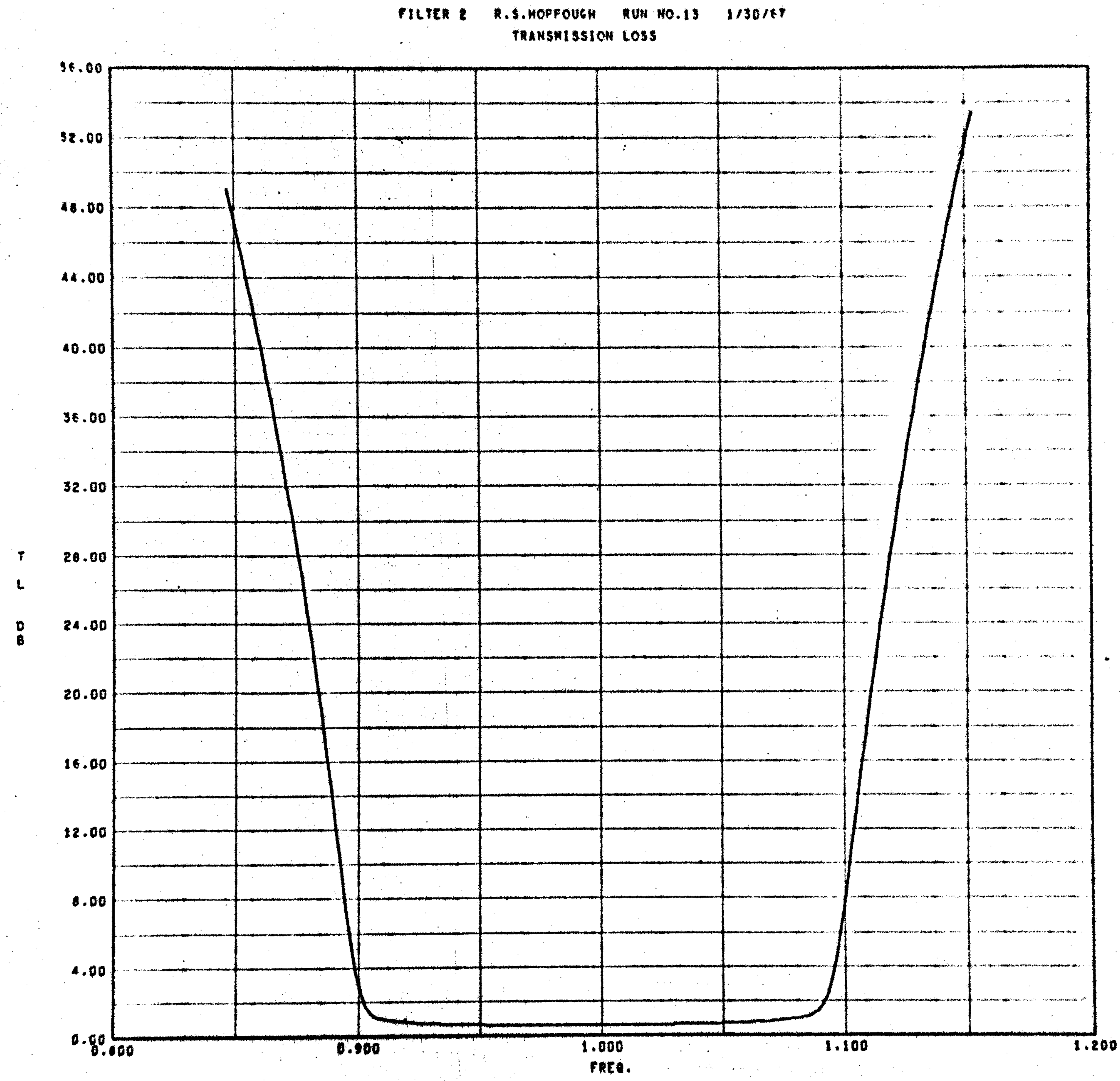

FILTER 2 R.S.HOPFOUGH RUN NO.13 1/30/67
TRANSMISSION LOSS
T
L
DB
56.00
52.00
48.00
44.00
40.00
36.00
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
0.800
0.900
1.000
1.100
1.200
FREQ.

FIGURE 6

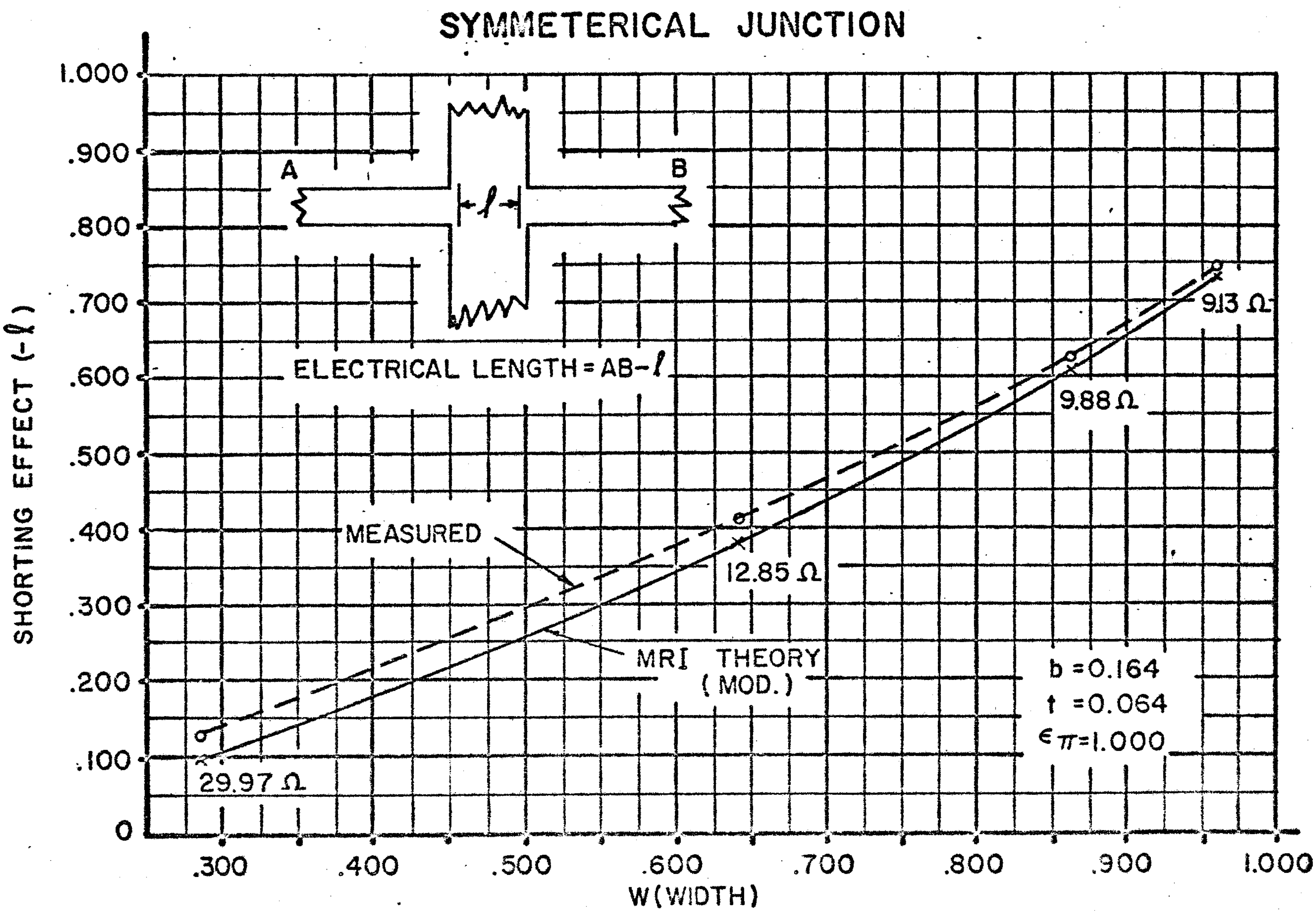
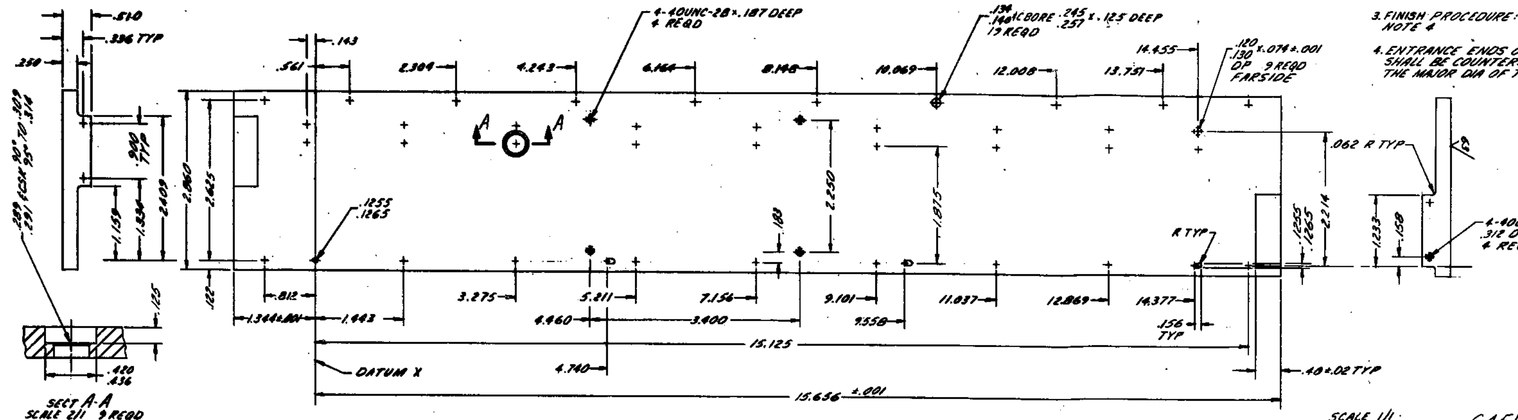

SYMMETERICAL JUNCTION
A
B
ℓ
ELECTRICAL LENGTH = AB−ℓ
MEASURED
MRI THEORY (MOD.)
29.97 Ω
12.85 Ω
9.88 Ω
9.13 Ω
b = 0.164
t = 0.064
ϵπ = 1.000
SHORTING EFFECT (−ℓ)
W (WIDTH)
0
.100
.200
.300
.400
.500
.600
.700
.800
.900
1.000

FIGURE 7

REVISIONS				
SYM		DESCRIPTION	DATE	APPROVAL
A		REDESIGN	[illegible]	
B		ADDED: TAPPERS & .074 DP HOLES.	[illegible]	
C		GENERAL REVISIONS TO PREPARE FOR USE IN PREAMP.	[illegible]	[illegible]
D		ADDED: 2 ADDITIONAL PIN HOLES TO ALIGN CONDUCTOR	[illegible]	[illegible]
E		CHANGED: ALIGNMENT HOLES WERE FOR .062 PINS	[illegible]	[illegible]
F		CHANGED: FINSH, 2.322 TABS ON CONDUCTOR WERE 2.379. ADDED: HOLES FOR TUNING SCREWS IN COVER	[illegible]	[illegible]

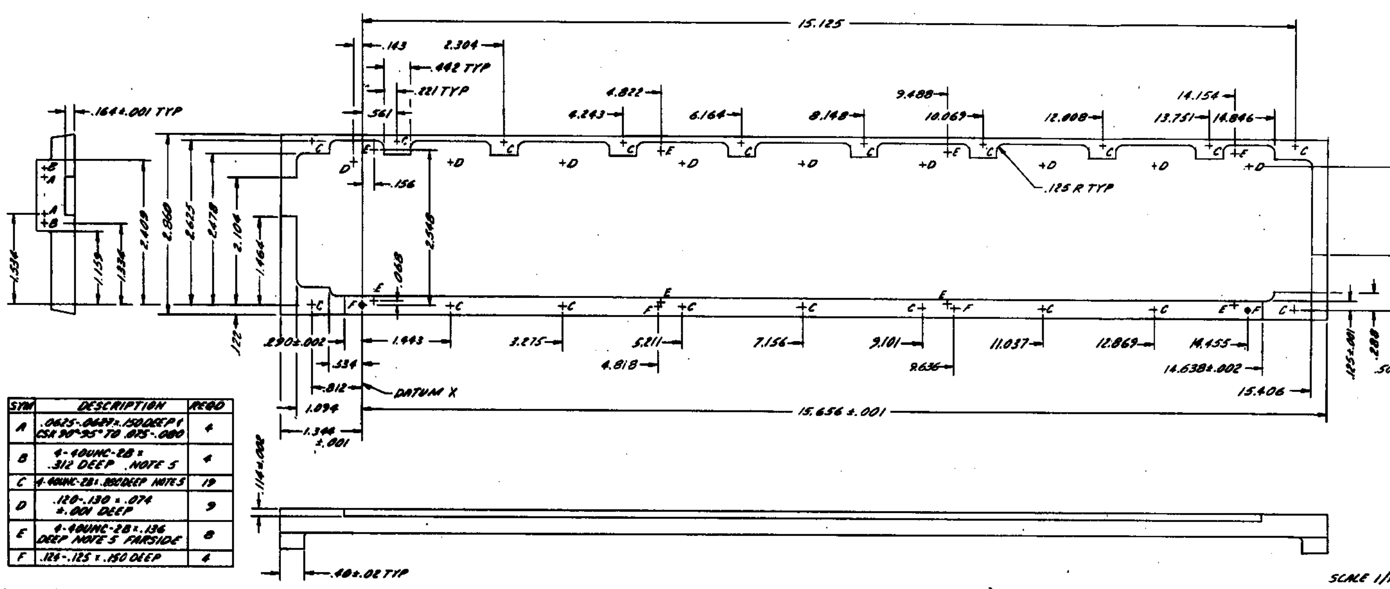
NOTES:
1. MATL: ALUMINUM, 6061-T6, QQ-A-250/11.
2. TOLERANCES ARE ±.005 UNLESS OTHERWISE SPECIFIED.
3. FINISH PROCEDURE: SEE G451967-3 NOTE 4
4. ENTRANCE ENDS OF TAPPED HOLES SHALL BE COUNTERSUNK 100°±10° TO THE MAJOR DIA OF THREAD +.02 -.0



SCALE 1/1

G451967-1

NOTES:
1. MATL: ALUMINUM, 6061-T6, QQ-A-250/11.
2. TOLERANCES ARE ±.005 UNLESS OTHERWISE SPECIFIED.
3. FINISH INSIDE OF HOUSING $\sqrt[63]{}$.
4. FINISH PROCEDURE: SEE G451967-3 NOTE 4
5. ENTRANCE ENDS OF TAPPED HOLES SHALL BE COUNTERSUNK 100°±10° TO THE MAJOR DIA OF THREAD +.02 -.0

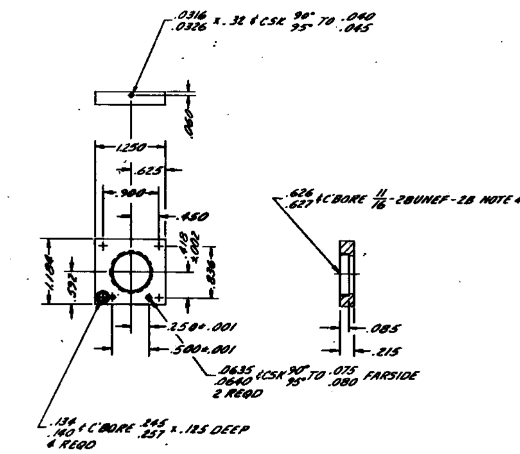


SYM	DESCRIPTION	REQD
A	.0625-.0629 x .150 DEEP & CSK 90°-95° TO .075-.080	4
B	4-40UNC-2B x .312 DEEP . NOTE 5	4
C	4-40UNC-2B x .250 DEEP NOTE 5	19
D	.120-.130 x .074 ±.001 DEEP	9
E	4-40UNC-2B x .136 DEEP NOTE 5 FARSIDE	8
F	.124-.125 x .150 DEEP	4

SCALE 1/1

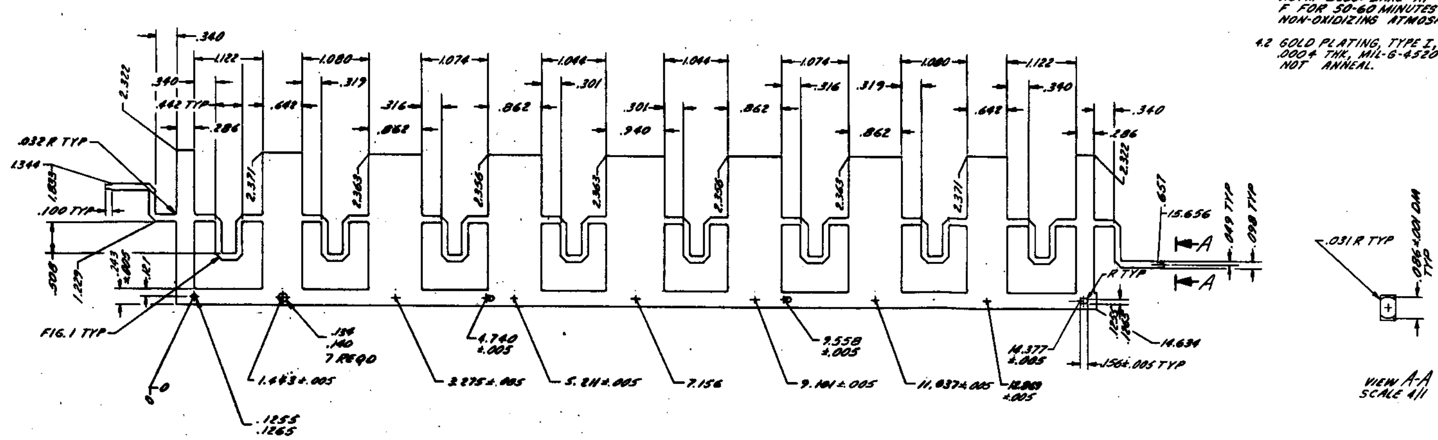
G451967-2

NOTES:
1. MATL: ALUMINUM, 6061-T6, QQ-A-250/11.
2. TOLERANCES ARE ±.005 UNLESS OTHERWISE SPECIFIED.
3. FINISH: CHEMICAL FILM, ALODINE 1200, GA3104.
4. ENTRANCE ENDS OF TAPPED HOLES SHALL BE COUNTERSUNK 100°±10° TO THE MAJOR DIA OF THREAD +.02-.0.



G451967-5

NOTES:
1. MATL: .064±.001 THK ALUMINUM, 6061-T6, QQ-A-250/11.
2. TOLERANCES ARE ±.002. UNLESS OTHERWISE SPECIFIED.
3. FINISH ALL OVER $\sqrt[32]{}$.
4. FINISH PROCEDURE:
   - 4.1 COPPER PLATING, EXCEPT .0003-.0006 THK, MIL-C-14550. PROCEDED BY ZINCATE DIP, ASTM-B253. BAKE AT 250°-275° F FOR 50-60 MINUTES IN A NON-OXIDIZING ATMOSPHERE.
   - 4.2 GOLD PLATING, TYPE I, .0002-.0004 THK, MIL-G-45204. DO NOT ANNEAL.



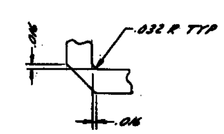
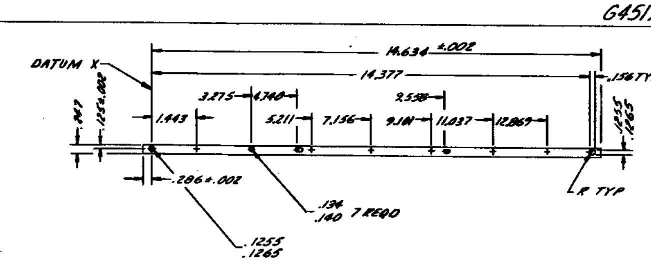


FIG. 1
SCALE 4/1

SCALE 1/1

G451967-3

NOTES:
1. MATL: .050±.001 THK ALUMINUM, 6061-T6, QQ-A-250/11.
2. TOLERANCES ARE ±.005 UNLESS OTHERWISE SPECIFIED.
3. FINISH PROCEDURE: SEE G451967-3 NOTE 4



SCALE 1/2

G451967-4

CASE: 27703-33
PROJ: R5226

LAYOUT APPROVALS

FILTER

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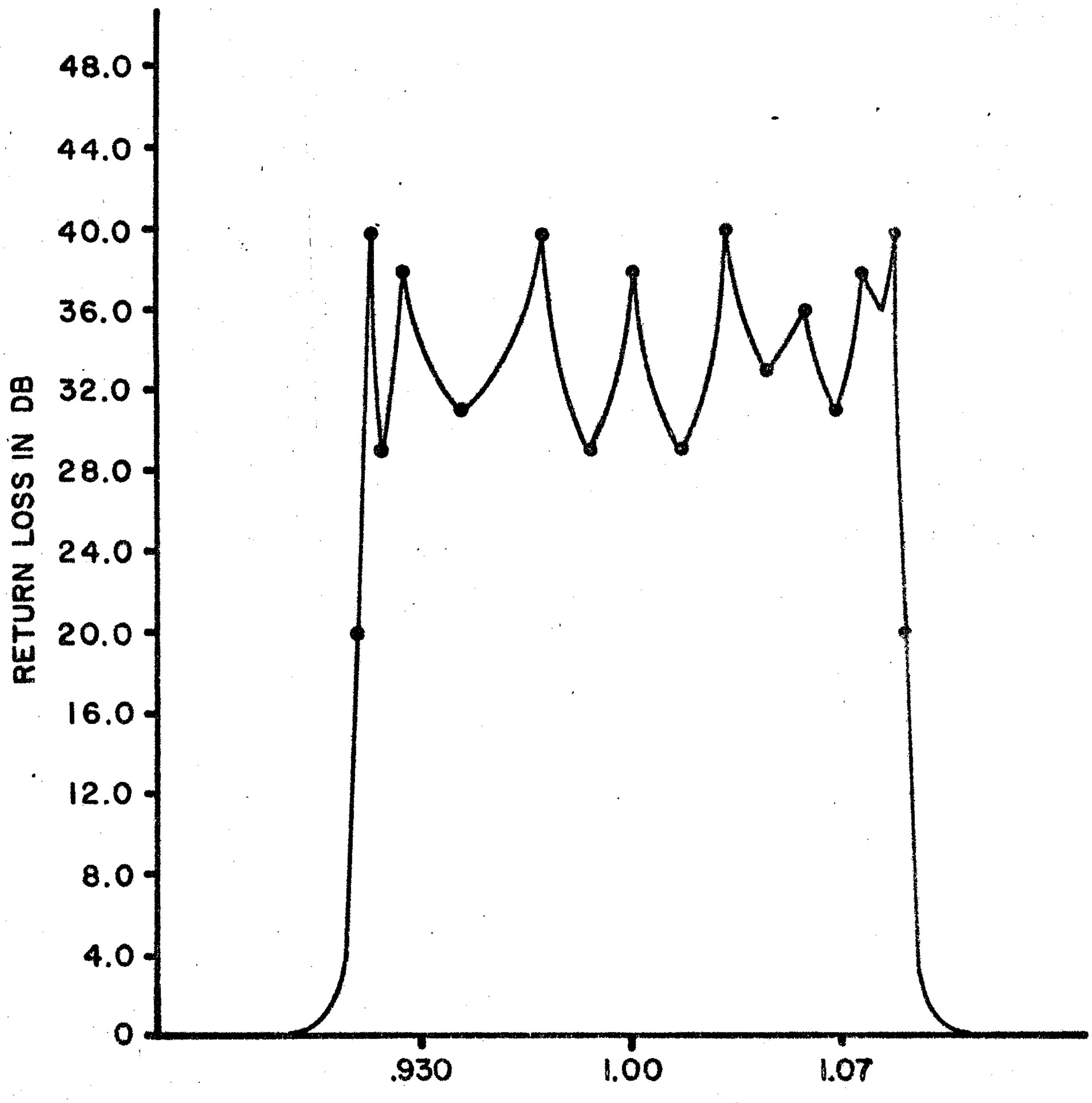
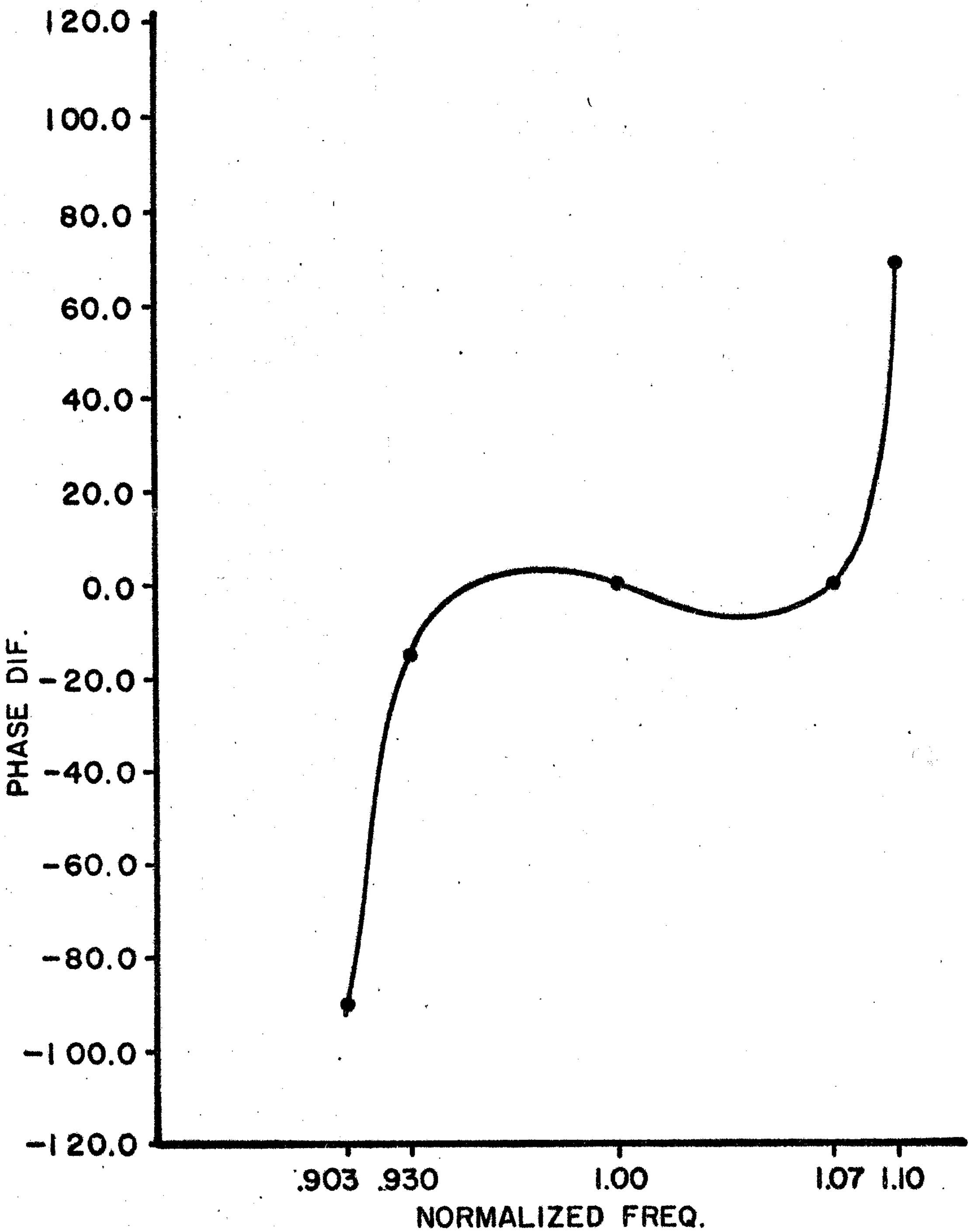
G451967

FIGURE 8



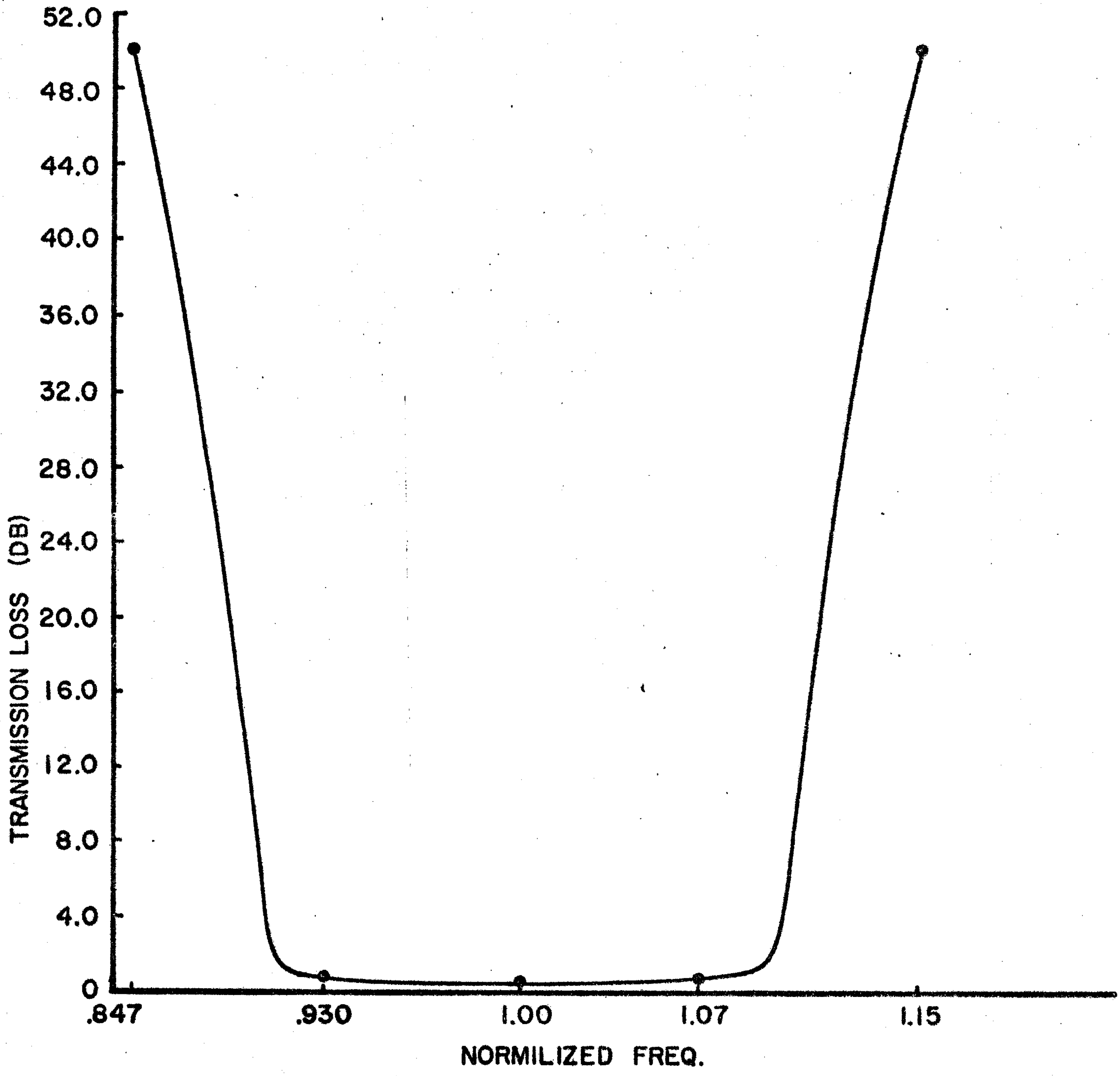
MEASURED RETURN LOSS

FIGURE-9



MEASURED PHASE DIF.

FIGURE-10



MEASURED TRANSMISSION LOSS

FIGURE-11

67-3801-WL

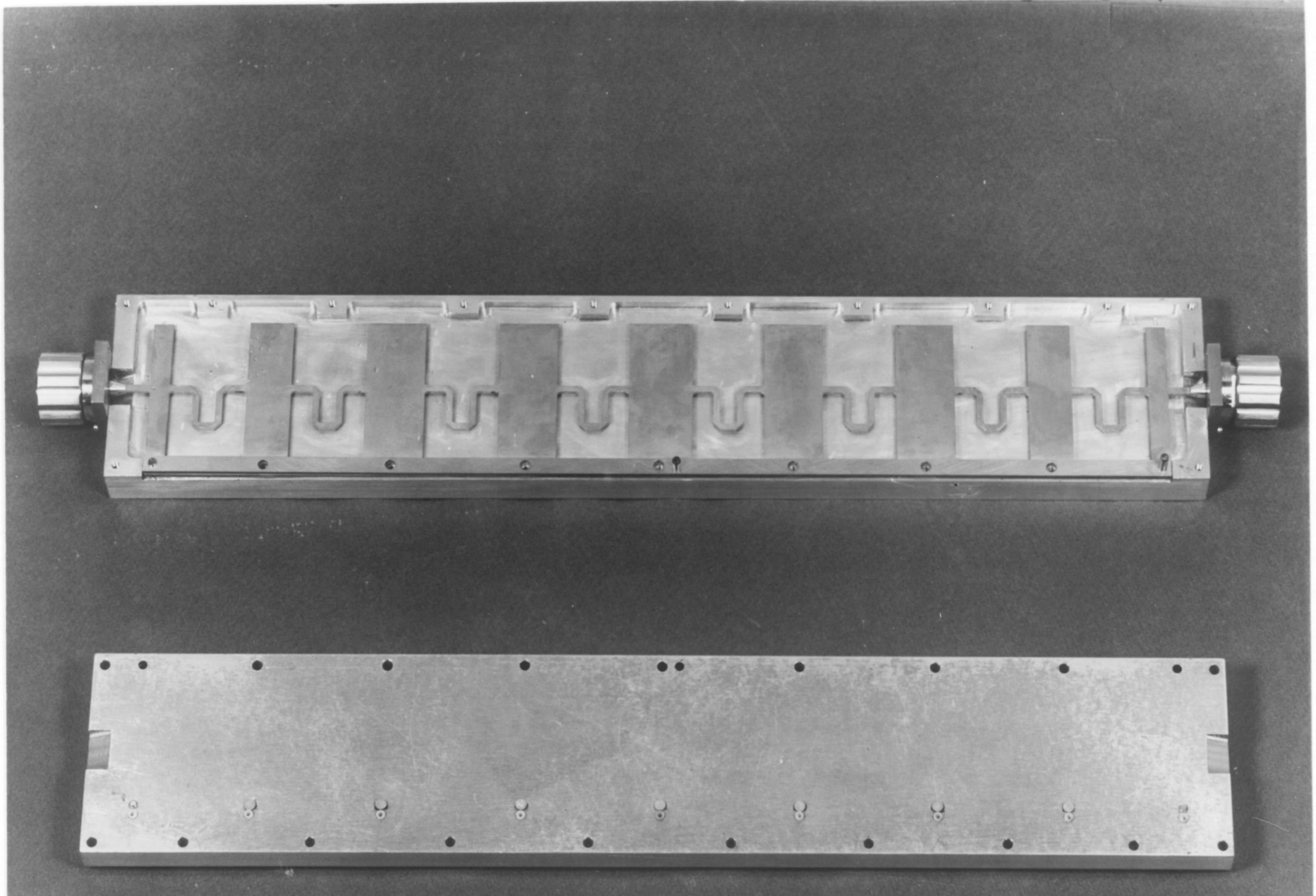


FIGURE 12