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AIRBORNE RADIO DIVISION - SYSTEMS ENGINEERING SECTION

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1 April 1946

ANTENNA NETWORK CORRECTIVES
for
VHF - IFF INTERFERENCES

DECLASSIFIED by NRL Contract
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Declassification authority: NAVY DECLASS MANUAL, 11 DEC 2012, OR SERIES

Prepared by
A. Brodzinsky
R.S.Timm

- Report R-2259 -

FR-2769

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Approved by:

M. K. Goldstein, Head - Systems Engineering Section

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Commordore H. A. Schade, USN
Director, Naval Research Lab.

Preliminary Pages............a-c
Numbered Pages.............. 11
Plates...................... 17
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Problem No. A7.08T-C(ARC)

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NAVAL RESEARCH LABORATORY
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AIRBORNE RADIO DIVISION - SYSTEMS ENGINEERING SECTION

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1 April 1946

ANTENNA NETWORK CORRECTIVES for VHF - IFF INTERFERENCES

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Problem No. A7.08T-C(ARC)

ABSTRACT

This report covers the investigations requested by reference (1) of interference between VHF communication and IFF identification equipments. Reference (2) is an interim report on this problem, and covers the results of a study of antenna relocation techniques for suppressing such interference.

The results of these investigations revealed that mutual VHF-IFF interference was caused almost entirely by radiation and pick-up by the antenna of the VHF-IFF equipments. Reasons for such interference are:

(a) Emission of spurious signals on frequencies other than the fundamental by the transmitting sections of these equipments.
(b) Inadequate selectivity of the receiving sections of these equipments resulting in reception of adjacent channel transmissions.

Special antenna networks developed by the NRL Airborne Interference Group are described which successfully solve this interference problem with a minimum effect on the operation of either the communication or the IFF equipments. The networks are compact, require no installation adjustments or maintenance, and are installed as a simple adaptor unit in the antenna transmission lines of both equipments. Attention is directed to the application of these networks, and other types of transmission-line antenna networks more recently developed, to the interference correction problem covering the Airborne Early Warning (AEW) program.

Since reference (4) shows that most Naval electronic equipments are subject to similar antenna path interference actions, application of such techniques and corrective devices, as described herein, is recommended for elimination of antenna path interferences to other Naval electronic systems.

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TABLE OF CONTENTS

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INTRODUCTION

1. Various fleet activities had reported serious mutual interference between airborn VHF communication transceivers and airborne IFF sets. This interference consisted of excessive noise in the VHF receivers caused by the IFF transmitting sections, blocking of the IFF display on a radar screen, and excessive triggering of the IFF equipments by the VHF transmitter sections. Such mutual interferences not only compromise the performance of both equipments, but in the case of the IFF, practically negated its tactical use.

2. The VHF communication equipments include AN/ARC-1, AN/ARC-4 and AN/ARC-5, while the IFF sets include AN/APX-1 and AN/APX-2. A chart of the frequency range and power output of each set named above is shown on Plate 1. It should be noted that, while the VHF sets are rather conventional transmitter-receivers for voice communication purposes, the AN/APX-1 is a special pulsed transmitter-receiver for identification purposes and the AN/APX-2 includes <u>two</u> transmitter-receivers for such purposes within one case.

3. An initial attempt to solve the interference problem by antenna spacing methods is reported in reference (2), an interim report on the subject problem. This reference concluded that ".... increased antenna spacings are ..... effective in partially reducing the interference effects .....", however, the results obtained were limited in application, and in benefit. Reference (2) fully covers the entire antenna relocation experiments and indicates that the efforts of the group might be more fruitful if directed toward the development of antenna networks to alleviate the interferences despite the discouraging reports on such projects from other groups, which are also quoted in reference (2). The material reported herein, therefore, covers further measurements conducted on interference levels and frequency distributions of the radiations from the VHF-IFF equipments, and describes the successful development of such antenna networks for the VHF-IFF frequency range, 100 to 212 mc/s.

SCOPE OF PROBLEM

4. The directive of reference (1) assigning Problem A7.08T-C requested NRL "to investigate interference from AN/ARC-4, AN/ARC-1 and the VHF components of AN/ARC-5 to the AN/APX-2 ...... and to determine the most satisfactory method of eliminating this interference". The intent of the NRL investigations was to provide a corrective for this interference which would, as far as possible:

(a) Allow completely normal operation of the VHF-IFF equipments.

 [redacted]

(b) Suppress the mutual interference to an acceptable level or lower.

(c) Allow no restrictions as to the placement of the antennas of the equipments on the plane.

(d) Be of the nature that would not require separate operation or constant adjustment, i.e., a "passive" type of corrective that need merely be installed.

INTERFERENCE SURVEY

5. It was easy to prove that the major interference present between the equipments was radiated and picked up via the antenna paths by merely replacing each antenna with a shielded dummy load. Therefore, each equipment operated normally except that no radiations could enter or leave the equipments via the antenna path. Under these conditions, only a slight residual level of interference was present, caused by power line noise and case radiations. As determined by the survey methods outlined below, the reasons for such interference were:

(a) Emission of spurious signals on frequencies other than the fundamental by the transmitting sections of these equipments.

(b) Inadequate selectivity of the receiving sections of these equipments resulting in reception of adjacent channel transmissions.

6. In order to determine the nature and extent of the interference between the VHF and IFF airborne equipments, surveys were conducted using the equipments. The survey methods and test equipment used, as outlined below, have known limitations and inaccuracies, but were chosen for convenient comparative use and proved extremely valuable for gathering and analyzing the interference data. The success of the corrective networks, which were subsequently developed from such data, proved at least the limited validity of the survey techniques.

7. The VHF and IFF equipments were set up and operated on a test bench with their respective antennas spaced approximately 15 feet apart. Each equipment was carefully inspected to insure normal operating conditions. The test equipment consisted of a broad band quarter-wave stub antenna used with an RDO superhetrodyne receiver as a search receiver. Two lumped constant type wave traps (T-19/UPR) having a range of 80 to 300 mc/s, were operated in series with the receiving

 [redacted]

antenna for identification of spurious signals from the particular transmitter under investigation. If a strong fundamental signal (fo) blocked the receiver, one of the traps would be tuned to the blocking signal, while the second trap would be used for the identification of spurious responses within range of the second trap. Two transmission line traps (F-20/UPR) having a range of 300 to 3000 mc/s were operated in series with the receiving antenna and the lumped constant traps in the same manner as described above. This method of identifying spurious signals, when used with careful discretion, offered a very reliable means of eliminating all "birdies" or false responses in the receiver caused by IF image responses, overloading of the input and mixer stages, etc. Signal generators of both the pulse and cw types were used during the investigations for determining the relative magnitude of spurious emissions from equipments under investigation. This was accomplished by matching the spurious received signals on an oscilloscope, substituting an artificial signal from a signal generator and matching its amplitude with that of the incoming interfering signal. The manner in which the equipments were arranged for this survey is shown on Plates 2 and 3.

8. Similar survey methods were used in connection with the interference work on the AEW system as reported in references (3) and (4). In reference (4), a more complete analysis is made of the limitations and usefulness of this method of survey and measurement.

INTERFERENCE RESULTS

9. The data obtained from the results of the interference surveys has been plotted on Plates 5 to 11 inclusive. Plates 5, 9, 10 and 11 show the frequency spectrum of the antenna readiations from the AN/APX-2 and AN/ARC-1 equipments, and the effect of inserting filters in the antenna transmission lines of the equipments. In each case, it should be noted that interferences from the VHF or IFF equipments which occur in the IFF or VHF bands respectively, are completely eliminated with the insertion of the proper filter.

10. The type of interference experienced by the AN/APX-1 or -2, IFF equipment, is illustrated by the photographs on Plate 4. These are photographs of the display of an IFF emergency response (long pulse) on an oscilloscope screen, with the IFF interrogator triggering a nearby test transponder. Figure 2 on Plate 4 shows the extreme blocking of the IFF response on the screen of the indicator caused by the presence of interfering signals from an AN/ARC-1 equipment. In contrast to this, Figure 1 on Plate 4, shows a picture of a "normal" display of the IFF response. This "normal" display was obtained merely by inserting a <u>pair</u> of proper antenna networks in the VHF and IFF antenna lines in the presence of the same interference which blocked the picture in Figure 2.

 [redacted]

This "normal" display cannot be distinguished from a picture of interference-free operation of the IFF equipment, i.e., with the AN/ARC-1 equipment off. Very much the same type of interference results as shown on Plates 9, 10, and 11, were found when using the AN/ARC-4 and the AN/ARC-5 communication transmitters.

NETWORK DESIGN

11. A theoretical analysis of filter networks can be found in many texts on communication circuits such as "Communication Engineering" by W. L. Everitt or "Communication Networks" by E.A. Guillemin. The actual equations are not derived here, but are summarized on the chart included as Plate 16. For each low pass and high pass network, the prototype section, the "m" derived sections, and the rearranged "m" derived sections are drawn. Also, the corresponding formulas for impedance and attenuation are listed for each network. It should be noticed that the introduction of the "m" parameter does not affect the impedance characteristic but does affect the attenuation very much. The expression for attenuation is given in terms of a hyperbolic function. However, the attenuation factor, x, while expressed in nepers, can readily be computed from tables and can be converted from nepers to decibels by the factor, 8.686. Therefore, the theoretical impedance and attenuation characteristics of these sections can be computed and graphed.

12. Plate 17 shows curves of equations (1) and (4) from Plate 16 with f/f_c as the frequency scale, where f_c is the cut-off frequency, and $Z_0/\sqrt{2L/C}$ as the ordinate, where $\sqrt{2L/C}$ is the zero-frequency characteristic impedance of the network. It can be seen that, plotted in this manner, equations (5) and (8) are the reciprocals of equations (1) and (4) respectively, and that the frequency factors are also inverted. Therefore, one set of impedance curves contains all the information for all the impedance equations by merely using the proper impedance and frequency scales. For the curves as plotted in Plate 17, the impedance values for "T" section networks are the reciprocals of the indicated scale values. In the case of high-pass networks derived from "T" or "Pi" section prototypes, the same curves are used, with (a) the reciprocal of the frequency scale shown and (b) the proper choice of impedance scale depending on whether the section is a "T" or "Pi " prototype. The attenuation curves are the same for "T" or "Pi" sections, but the frequency scale is as shown, or inverted, depending on whether the section is low or high pass respectively.

13. Appendix I includes a development of an actual network from the equations and design factors of Plates 16 and 17. This Appendix also describes the methods of obtaining close frequency tolerance resonant circuits from the computed L and C values. Constructional details and electrical specifications of both the high and low pass networks are detailed in reference (7). It should be pointed out, that

 [redacted]

an extension of the usual design procedures used in determining network constants from the theoretical impedance curves enabled the NRL group to obtain very good impedance matching and very sharp filter cut-off characteristics within restricted frequency limits. This extension was developed by the NRL group and is also described in Appendix I. Circuit diagrams, attenuation curves and photographs of the networks finally used for correcting the VHF-IFF interference are shown on Plates 12 through 15. From the attenuation curves for the networks shown on Plate 13, it can be seen that the insertion loss in the transmission band of either equipment caused by introducing the networks in the antenna lines is everywhere less than 2.5 db and averages approximately 1.0 db. The attenuation of signals in the suppression band exceeds 50 db which is almost a half-million times reduction in power. The actual results in terms of interference reduction has been pointed out above in Paragraph 9.

14. The networks are fixed adaptor-type units, which do not require any adjustment or alignment, and are merely inserted into the antenna transmission line any place between the equipment and the antenna. The F-32/ARC-1 low-pass network was installed in the antenna transmission line of the AN/ARC-1, AN/ARC-4, or AN/ARC-5 communication sets and allowed free transmission of power from 100 to 147 mc/s while highly suppressing any radiation between 156 and 212 mc/s. The F-33/APX-13 high-pass network was installed in the antenna transmission line of the AN/APX-1, AN/APX-2, or AN/APX-13 sets and allowed free transmission of power from 156 to 212 mc/s while highly suppressing any radiation between 100 and 146 mc/s. Thus, with a 10 mc/s "buffer band" between the VHF and IFF bands, the two antennas of the two equipments have been completely isolated in frequency response and they may then be located at practically any place on an airplane with only one or two feet separation without experiencing mutual interference.

SUMMARY OF RESULTS

15. The antenna networks described herein, which were developed as correctives for VHF-IFF interference, have been shown to provide a highly efficient means of reducing antenna interactions between VHF and IFF equipments in the 100 to 212 mc/s band. No study was made of the power line and case radiated interference existing between these equipments because its magnitude was so much smaller than the antenna interference, its effect on mal-functioning of the equipment was much less disruptive, and methods for reducing and eliminating it were known. Even without attempting corrections of the various non-antenna interference paths, the use of the antenna networks in the VHF and IFF equipments resulted in a reduction of the mutual interference to such an extent that:

(a) The complete 156-212 mc/s operating band of the IFF equipment was not blocked, falsely interrogated, or interrupted in operation by use of any VHF communication channel from 100 to 146 mc/s.

 [redacted]

(b) The entire 100-146 mc/s operating band was made available for unrestricted VHF communication use without interference from IFF equipments.

(c) Normal operations were obtained irrespective of the location of the antenna of either equipment on the plane.

(d) The average loss in sensitivity or power output over the entire operating band of either equipment caused by inserting these networks in their respective antenna transmission lines amounted to less than 1.0 db. The greatest loss experienced (near cut-off) was less than 2.5 db.

16. These successful results were achieved, notwithstanding published reports concluding that such operation (of the VHF-IFF equipments) would be impossible without placing a wide 'buffer' band between the VHF and IFF bands and that it was "considered impractical to solve this (interference) problem by the use of filters ......". (References 5 and 6.) It is important to note that continued research on antenna networks by the same Interference Group, involving the use of transmission line sections and distributed constants, has resulted in the development of newer types of networks which have even greater efficiency and utilization factors and are capable of withstanding very much higher average and peak power. Such new networks allow for an extension of the upper limit of the VHF communications band from 146 to 150 mc/s, which extends the utilization of the allocated band to over 95%. These results are reported in reference (3).

[redacted]

CONCLUSIONS

The following conclusions are drawn from the results of the investigation reported herein:

1. The mutual antenna interference between VHF communications and IFF equipments results in serious compromise in the operational use of these equipments.

2. This mutual antenna interference is due to:

   (a) Emission of spurious signals on frequencies other than the fundamental by the transmitter sections of these equipments.

   (b) Inadequate selectivity of the receiving sections of these equipments resulting in reception of adjacent channel transmission.

3. The use of the antenna networks described herein permits interference-free operation of the IFF equipments within the entire IFF frequency band (156 - 212 mc/s) and interference-free operation of the VHF communications equipments in the normal VHF communication band (100 - 146 mc/s). Without these antenna networks, utilization of less than 50% of either band was obtainable.

4. The required antenna networks are capable of mass production, and have the following suitable characteristics:

   (a) Fixed adaptor type units requiring no installation adjustements and no maintenance.

   (b) Pass band insertion loss of 1.0 db average (2.5 db maximum at one end of the band).

   (c) Attenuation band rejection between 50 and 60 db,

5. Newer types of transmission line antenna networks, developed by the NRL Airborne Interference Group for correcting interferences to AEW equipments, allow for even higher utilization of the VHF communications band (from 100 - 146 mc/s to 100 - 150 mc/s) with more efficient mechanical and electrical characteristics, These new development types are reported in references (3) and (4).

[redacted]

RECOMMENDATIONS

It is recommended that:

1. The antenna networks developed for correcting VHF-IFF interferences be incorporated as standard equipment on all VHF and IFF equipments.

2. Investigations be made covering interference levels of other Naval electronic equipments and the feasibility of correcting such interferences with antenna networks similar to those described herein.

3. Further research be conducted on antenna networks and other interference correction devices, with the possibility of incorporating such correctives as integral parts of all Naval electronic equipments.

ACKNOWLEDGMENTS

The original experimental and theoretical work on the subject problem was prosecuted by the writers under the active technical leadership of M. K. Goldstein. At that time J. B. Reynolds, assisting with the network design details. The final interference-level data presented in this report was gathered by H. W. Chitty.

[redacted]

REFERENCES

1. BuAer confidential ltr. to NRL, Aer-E-3161TRM, F42-1/85, dated 19 May 1944, Assignment directive for Problem No. A7.08T-C (ARC).

2. NRL confidential ltr. No. C-F42-1/85(312), Ser. 310-730, dated 15 August 1944, covering antenna spacing and frequency separation experiments on the subject problem.

3. NRL confidential Report No. R-2766 dated March 1946 entitled "AEW Interference Report A, Airborne Problem".

4. NRL confidential Report No. R-2767 dated March 1946 entitled "AEW Interference Report B, Shipboard Problem".

5. ARL Test Report No. 168, dated 26 November 1942, Filters for the Elimination of Mutual Interference Between the SCR-695(IFF) and SCR-522 (VHF), Aircraft Radio Laboratory, (War Department), Wright Field, Dayton, Ohio.

6. Aircraft Radio Laboratory, ARL Engineering Report No. 329, dated 6 October 1942, Study of Interference between IFF ... Equipments and other Radio Equipments Installed in the same Airplane.

7. NRL confidential ltr. No. F42-1/85(312) Ser. 310-17/45 dated 12 February 1945, VHF-IFF Interference Correctives for Project "Cadillac".

[redacted]

APPENDIX I
DESIGN CALCULATIONS FOR A LOW-PASS NETWORK

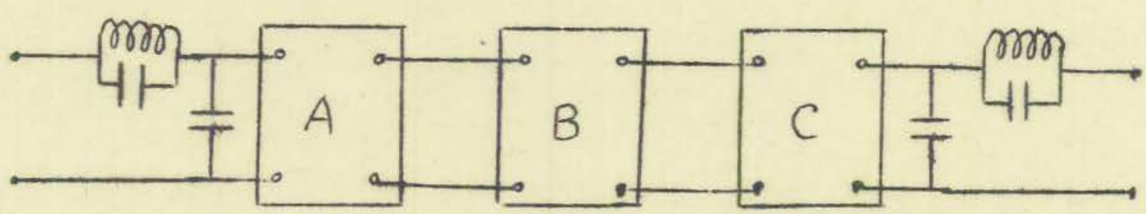
From the impedance and attenuation curves on Plate 17 and some supplementary information, a given network may be explicitly designed. Let us assume that a low-pass network is to be designed for the AN/ARC-1 equipment with the following characteristics:

(a) 50 ohm impedance
(b) Pass 100 to 146 mc/s.
(c) Attenuate 156 to 212 mc/s

This immediately sets the cut-off frequency (f_c) at some point between 146 and 156 mc/s. Let us take f_c at 152 mc/s. Therefore, the frequency ratio limits of the pass band are $100/152 = 0.67$, and $146/152 = 0.96$. These limits are indicated on Plate 17. Now we must select one of the "m" curves which has the least impedance variation between the limits, 0.67 and 0.96. The curve for "m" = 0.6 is selected, and the mean value of the $Z_o/\sqrt{2L/C}$ intercepts for this curve between the limits, 0.67 and 0.96, is 0.85. However, Z_o, the input impedance of the network is specified above as 50 ohms. Therefore, $\sqrt{2L/C} = 50/0.85 = 59$. Use of a lower value of "m" would actually realize a better impedance characteristic , however, this would result in too low a value of "L" for practical consideration. From the expression for the cut-off frequency, $f_c = 1/\pi\sqrt{2LC}$, we may obtain a value for $\sqrt{2LC}$ and, thereby solve equations for explicit values of "L" and "C", thus:

$$L = 0.062 \text{ u H} \qquad C = 12.4 \text{ uuf}$$

We may now compute the values of all the components of an "m" = 0.6, "m" - derived low-pass Pi-section rearranged as a T-section. According to theory, we may split this T-section into halves, and insert between the halves any number of prototype low-pass and "m"-derived low-pass Pi-sections having the above prototype "L" and "C" values. These inserted sections will match perfectly in the pass-band for any "m" value, but will have varying attenuation characteristics with different values of "m". Thus, we have the following configuration, where each inserted section has the form of circuit (4) of Plate 16:



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The remaining design problem is the selection of optimum values of "m" for insert-sections A, B, and C. From the curves and equations we can arbitrarily choose "m's" to provide fairly evenly spaced infinite attenuation peaks. Thus for A we choose m = 0.31; for B, m = 0.45; for C, m = 0.69.

Using these values of L, C, and "m" we may then easily compute the values of each arm of each section. Combining the various impedances which are in series or parallel, we arrive at the final network shown on the upper part of Plate 12.

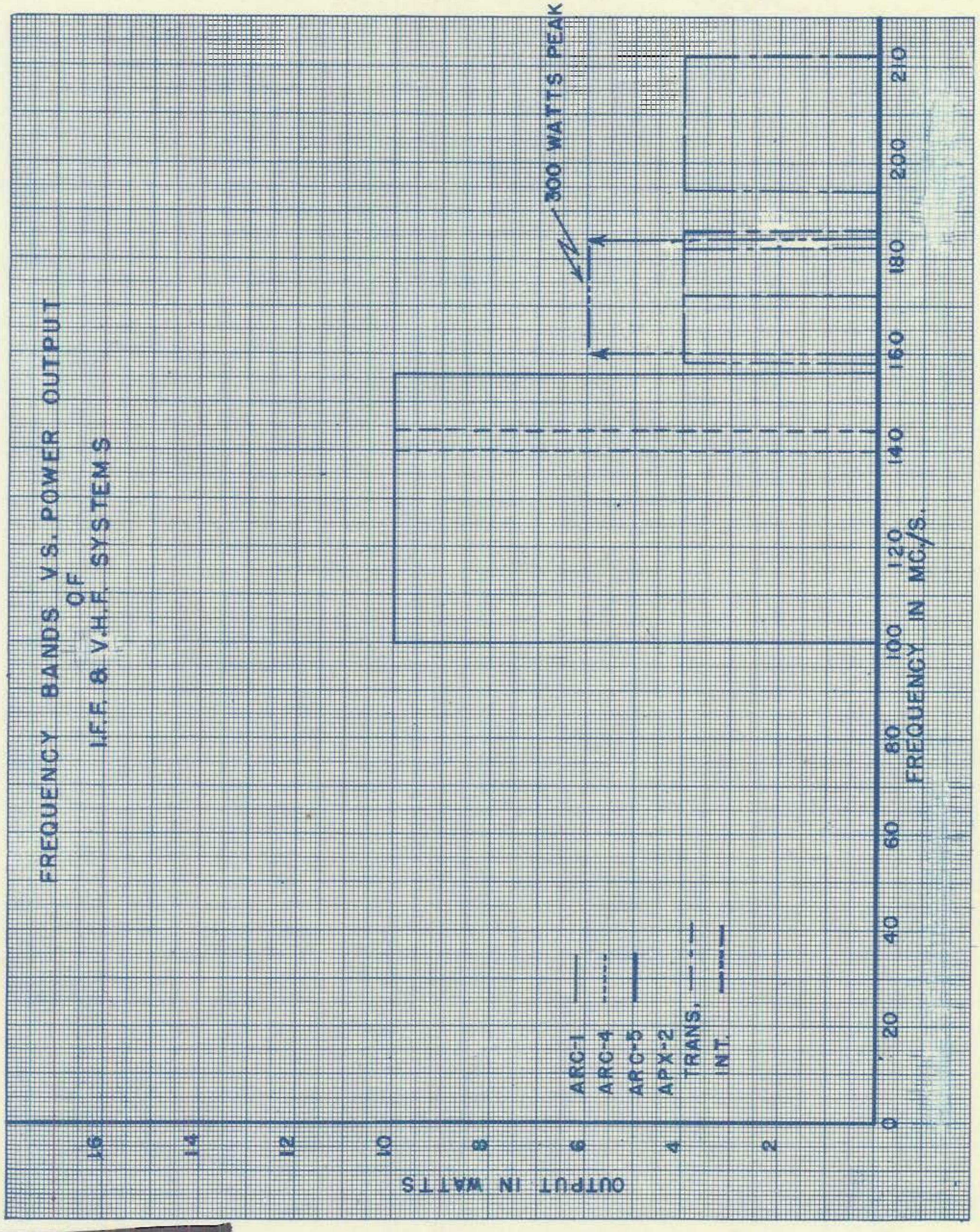
The actual realization of this network depended upon the ability of obtaining design values of L and C indicated on the circuit diagram. The construction of the network is well illustrated in the photographs on Plates 14 and 15. The resonant circuits were obtained as a unit, the condenser being chosen first and the coil adjusted until the indicated resonant frequency was reached. For example, the first tank circuit (upper part of Plate 12) was obtained by selecting an 18.3 µuf condenser ± 2%, and then soldering a 2-turn coil across the ends of the condenser. This tank circuit was then placed in the field of a coil normally connected and excited by a Boonton, Type 160-A, Q-meter. At its exact frequency, this tank circuit would then act as an absorption type wavemeter, with the Q-meter. Q-dial acting as the resonance indicator. The 2-turn tank coil was adjusted until a resonant frequency of 190 mc/s was obtained. The same procedure was carried out to obtain all other tank circuits.

A similar procedure was used for obtaining the resonant circuits for the high-pass network. The circuits were resonated as parallel tanks and then connected into the circuit in series.

The values of the condensers to ground in the low-pass network were actually selected at 1.5 uuf less than the design values in order to compensate for that much capacity to ground which was inherent in the feed-through seals used in construction. Lead lengths were kept as physically short as possible in order to reduce to a minimum any extraneous inductances and capacities.

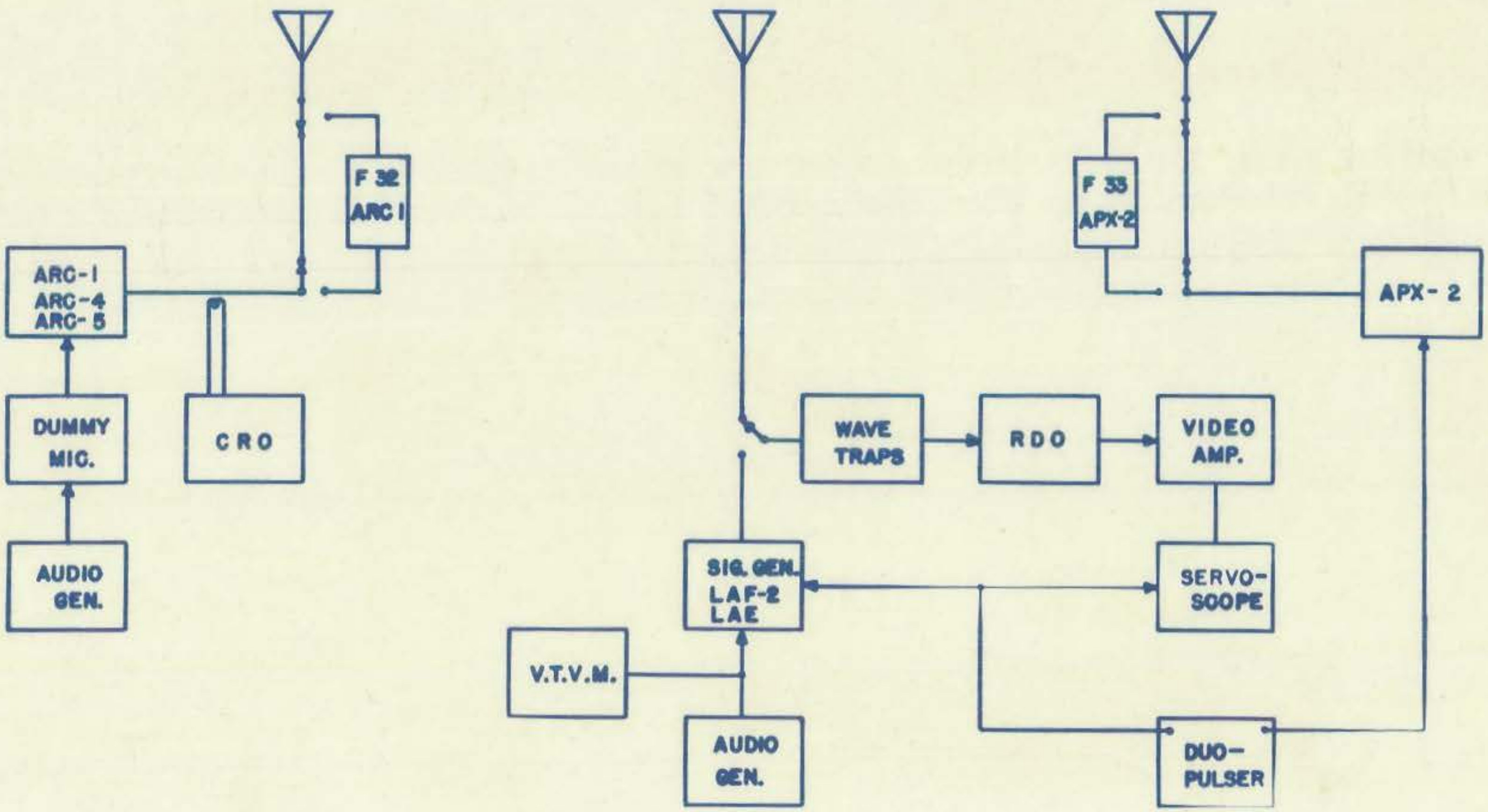
The actual attenuation characteristics of the completed networks over the pass and attenuation bands are shown graphically in Plate 13.

 [redacted]


FREQUENCY BANDS VS. POWER OUTPUT
OF
I.F.F. & V.H.F. SYSTEMS
300 WATTS PEAK
ARC-1
ARC-4
ARC-5
APX-2
TRANS.
INT.
0
20
40
60
80
100
120
140
160
180
200
210
FREQUENCY IN MC/S.
2
4
6
8
10
12
14
16
OUTPUT IN WATTS

[redacted]

TEST EQUIPMENT LAYOUT



R-2769 PLATE 2

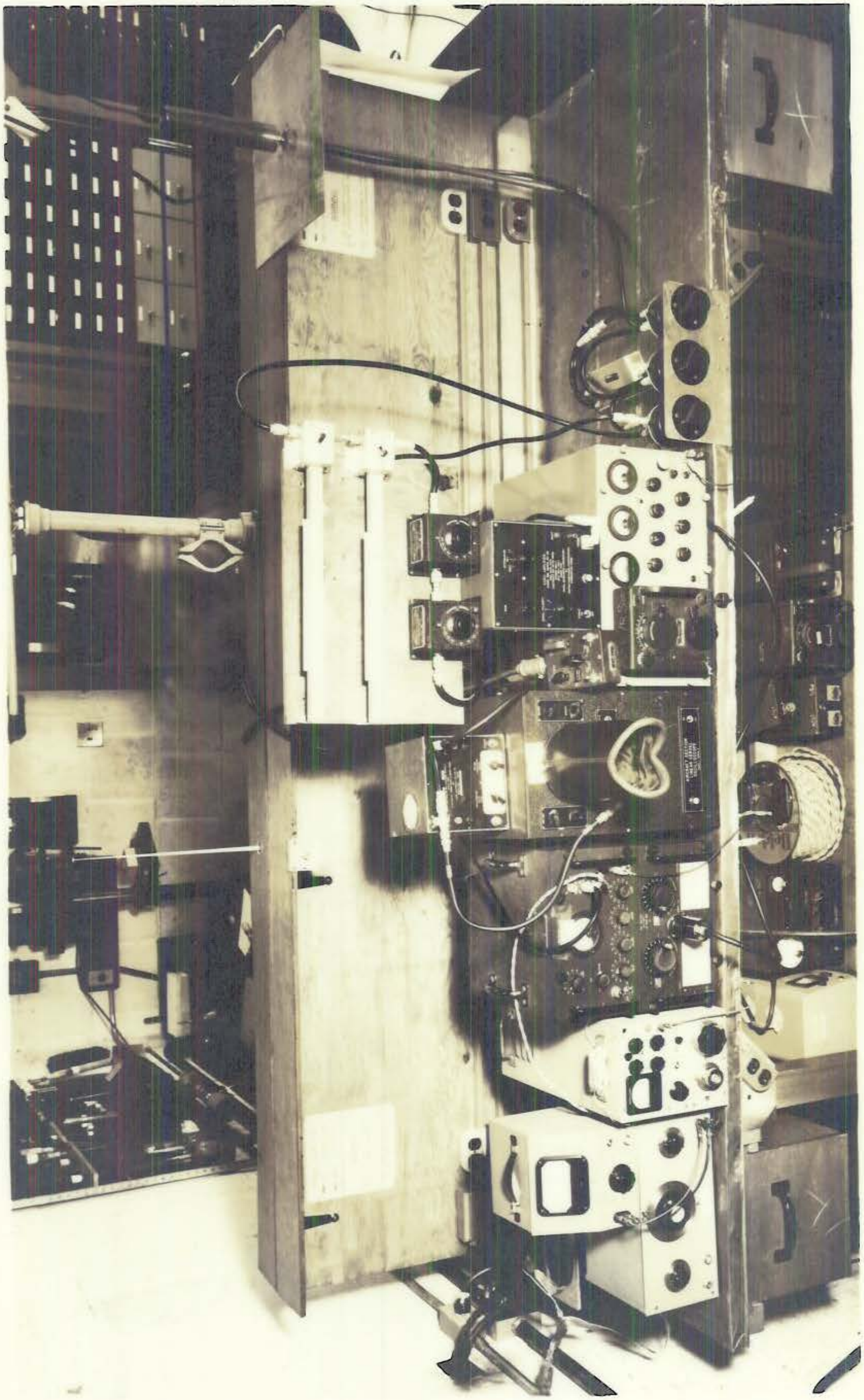


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PLATE 3

INTERFERENCE ON APX-2 BY VHF EQUIPMENT

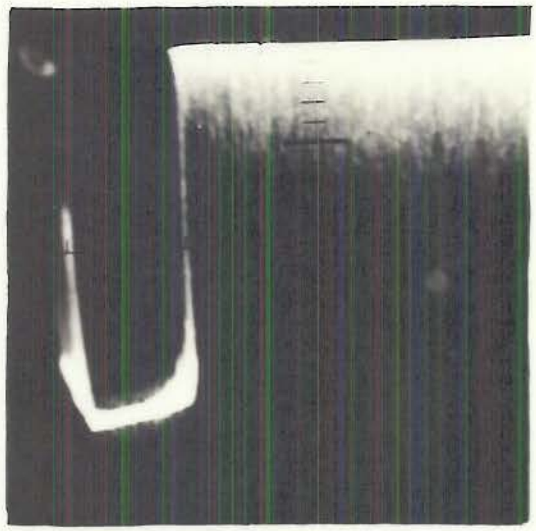

FIG. 1
WITH FILTER

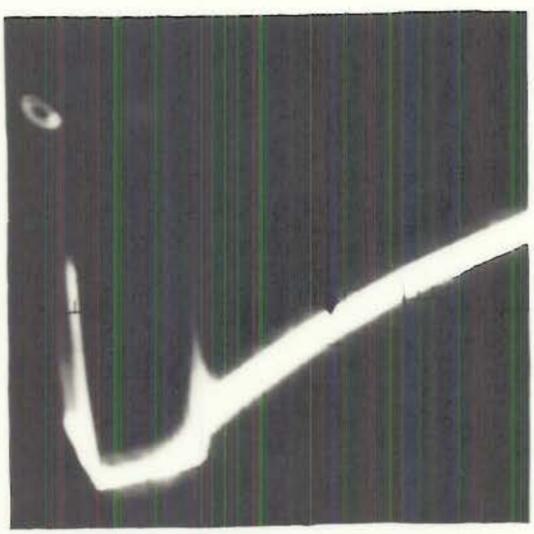

FIG. 2
WITHOUT FILTER

INTERFERENCE SURVEY OF AN/APX-2 I.F.F. EQUIPMENT

"A" BAND 158 MC.

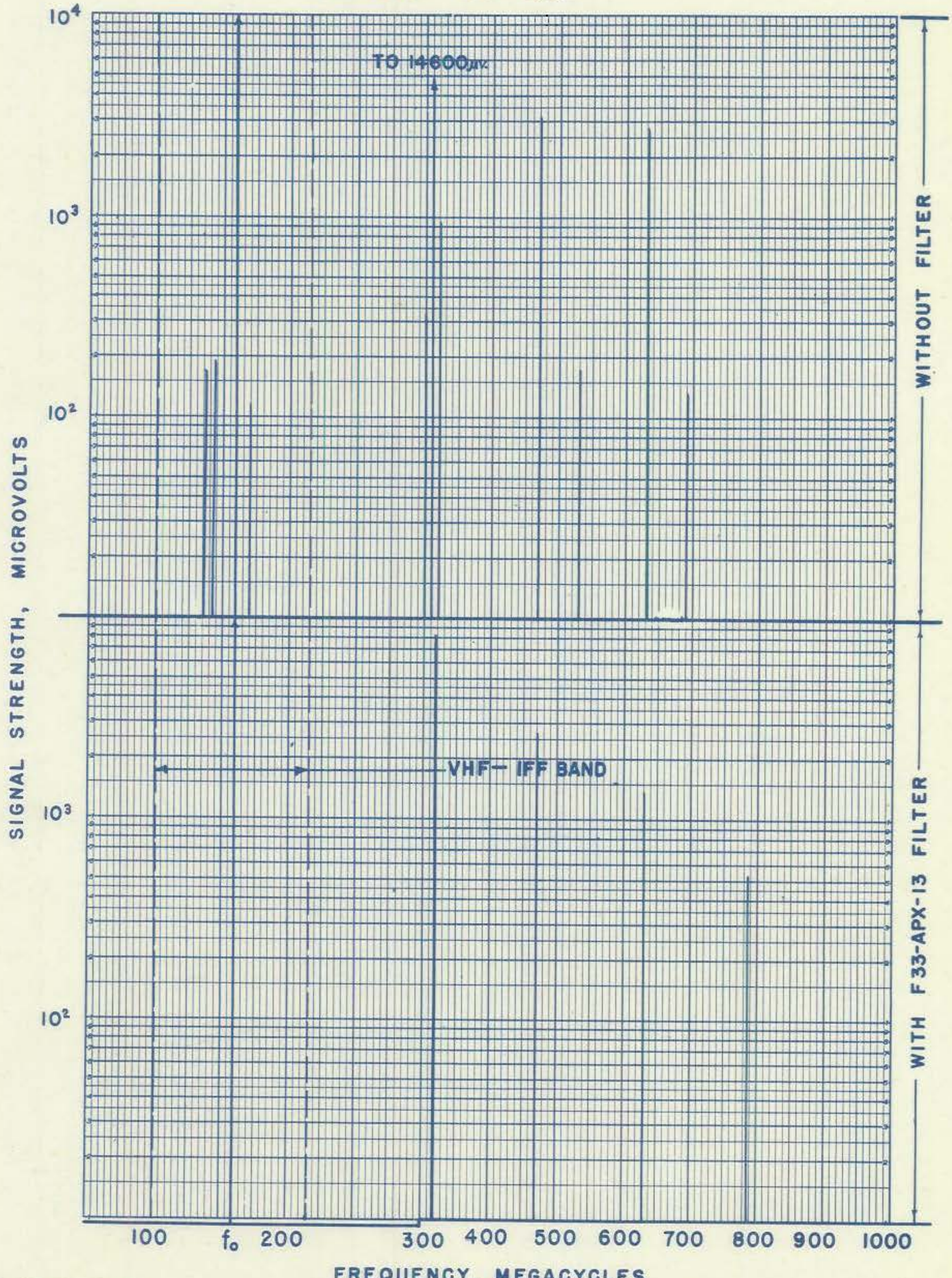

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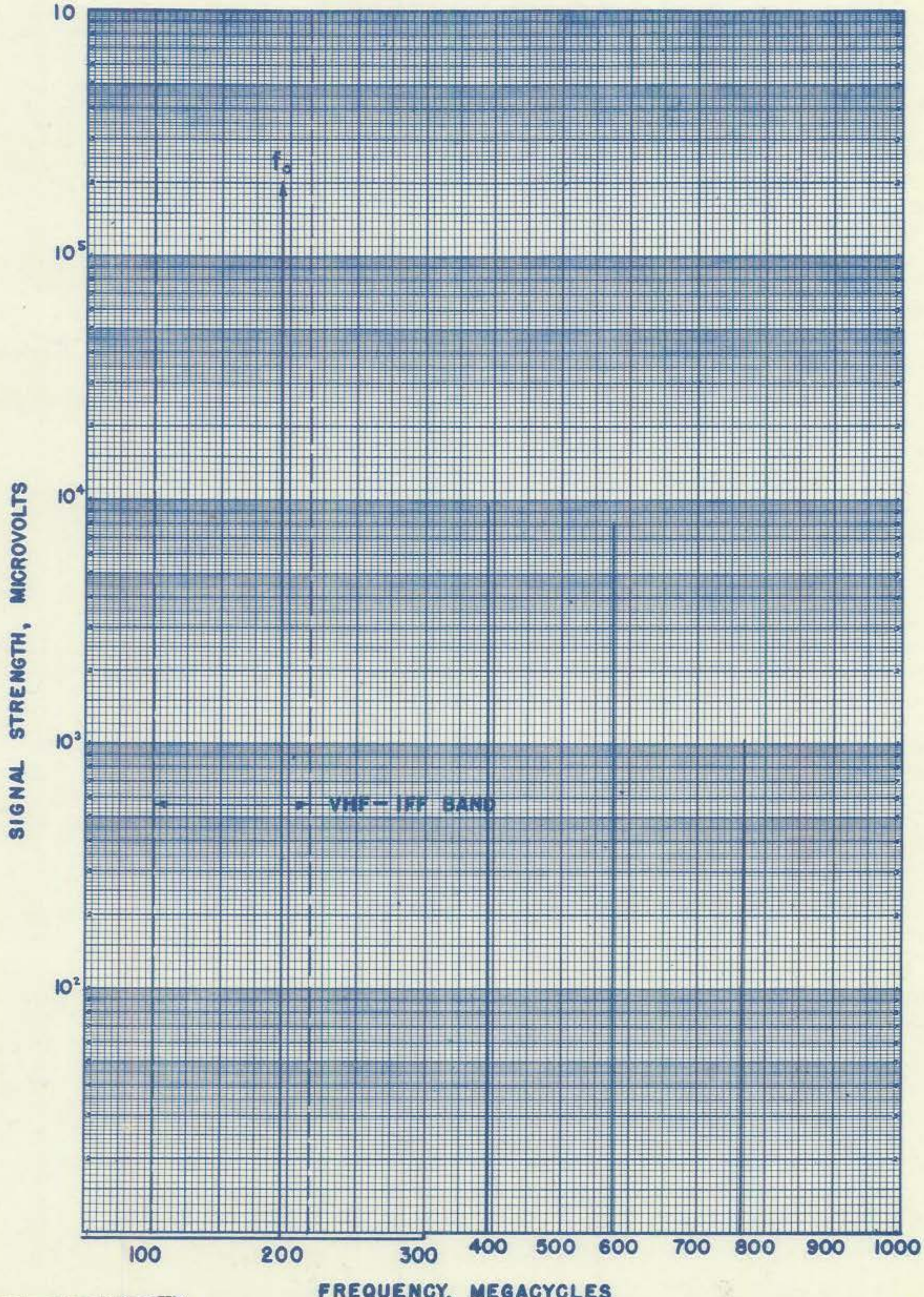
PLATE 5

INTERFERENCE SURVEY OF AN/APX-2 I.F.F. EQUIPMENT

"G" BAND 194 MC.



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INTERFERENCE SURVEY OF AN/APX-2 I.F.F. EQUIPMENT

"G" BAND 172 MC. (ROOSTER)

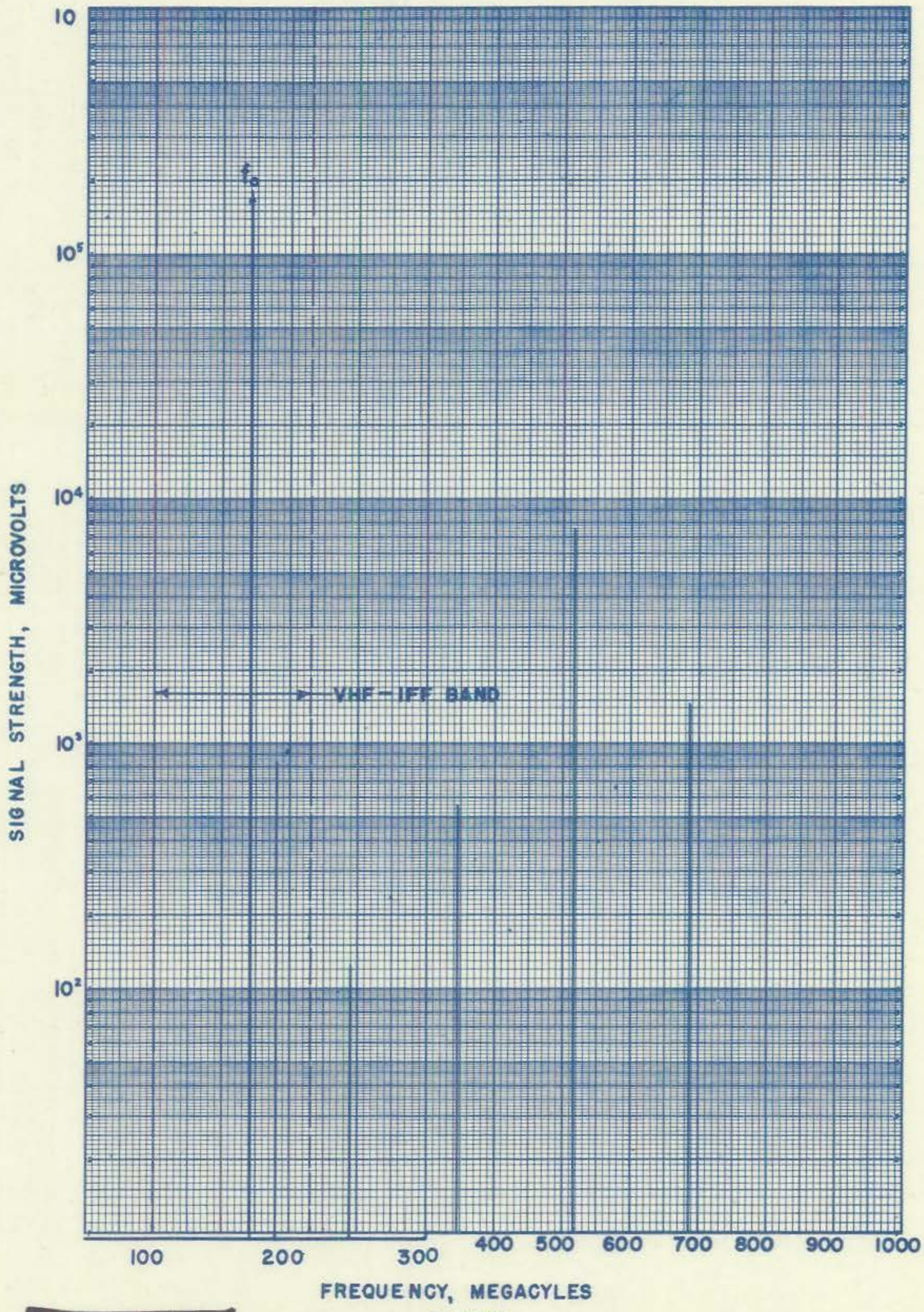

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PLATE 7

INTERFERENCE SURVEY OF AN/APX-2 I.F.F. EQUIPMENT

INTERROGATOR-RESPONSOR 160 MC.

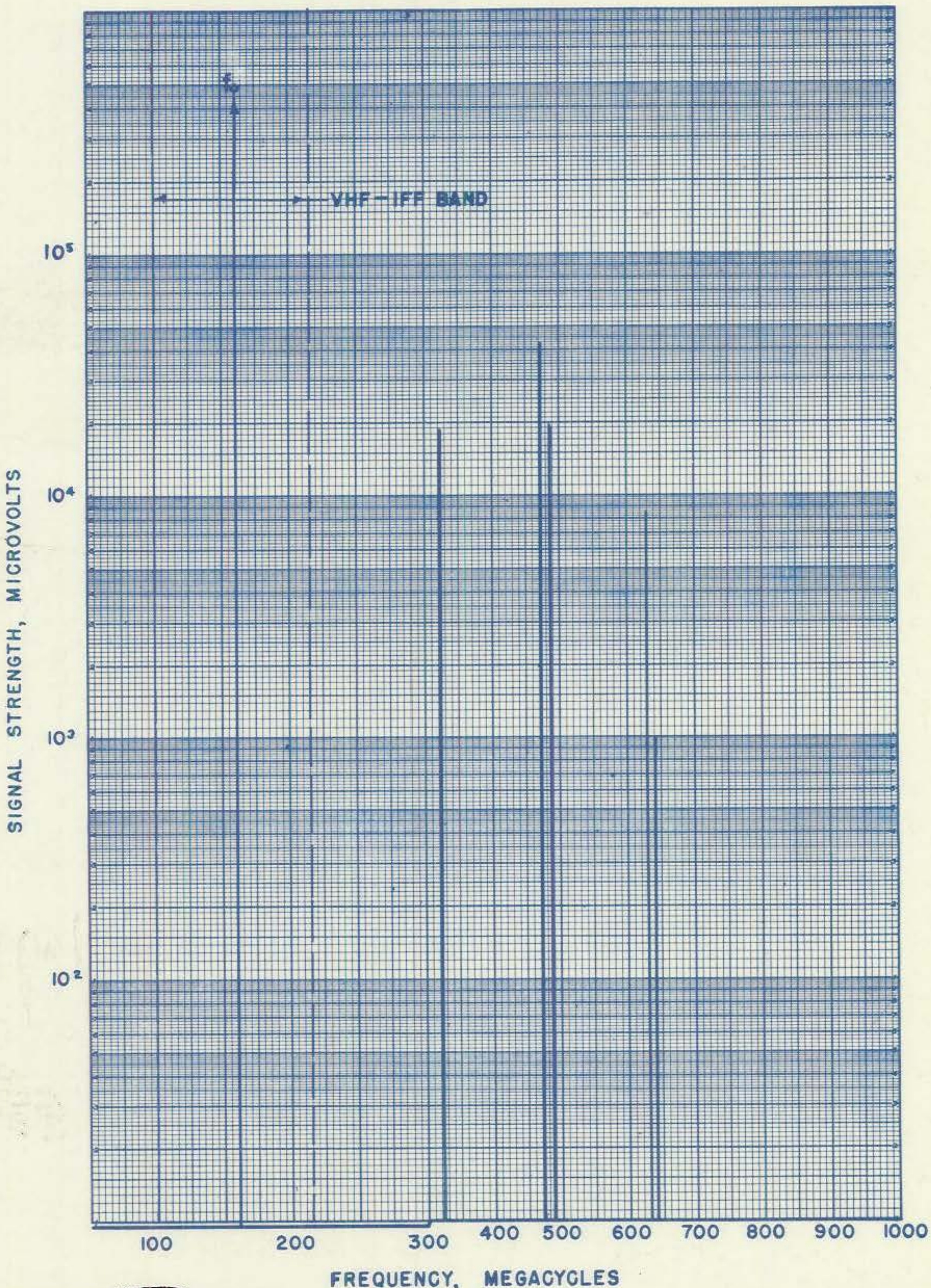

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PLATE 8

INTERFERENCE SURVEY AN/ARC-1 AIRCRAFT EQUIPMENT*

CHANNEL 1 116.1 MC

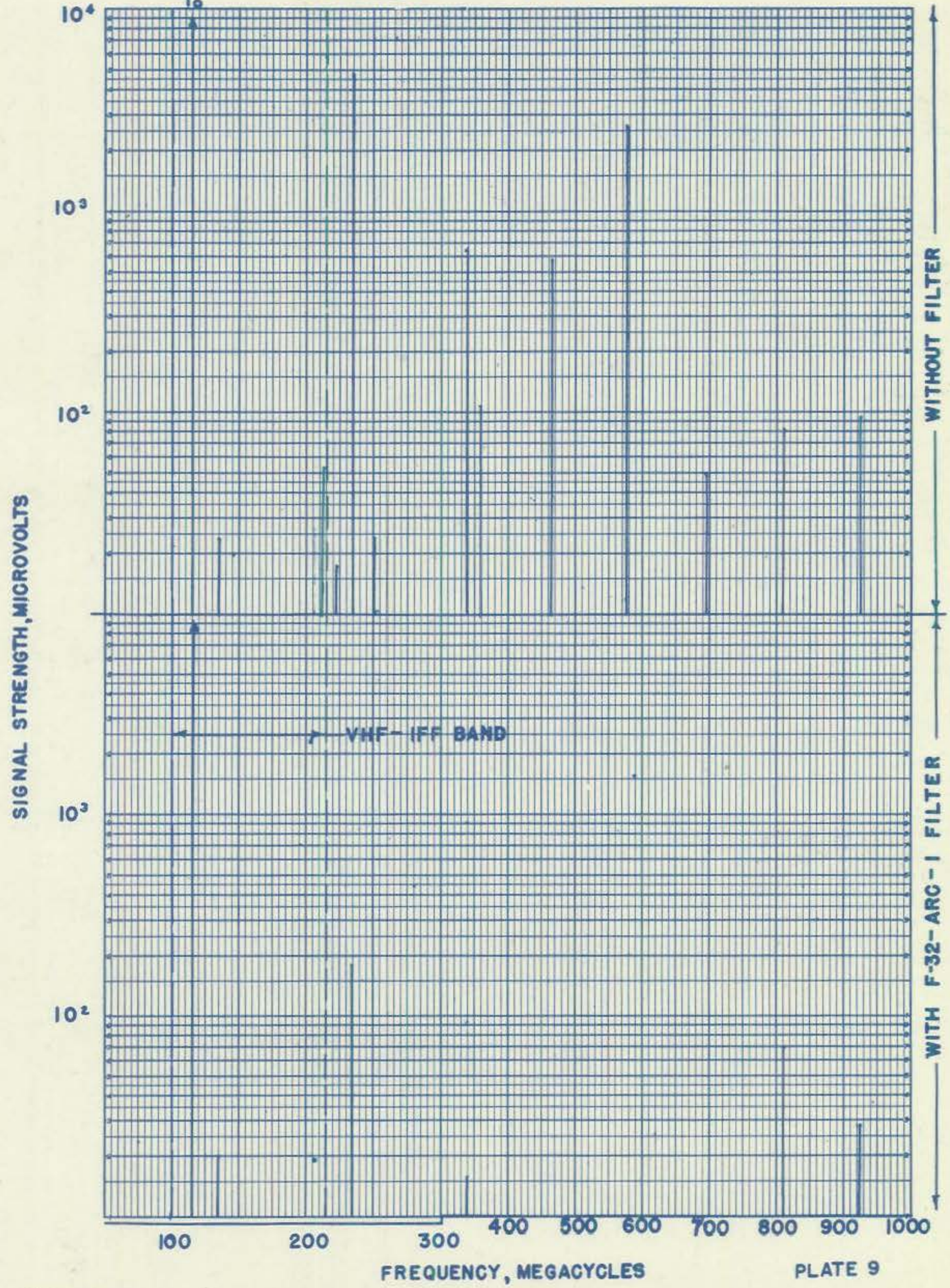

PLATE 9

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INTERFERENCE SURVEY AN/ARC-1 AIRCRAFT EQUIPMENT

CHANNEL 4 128.7 MC

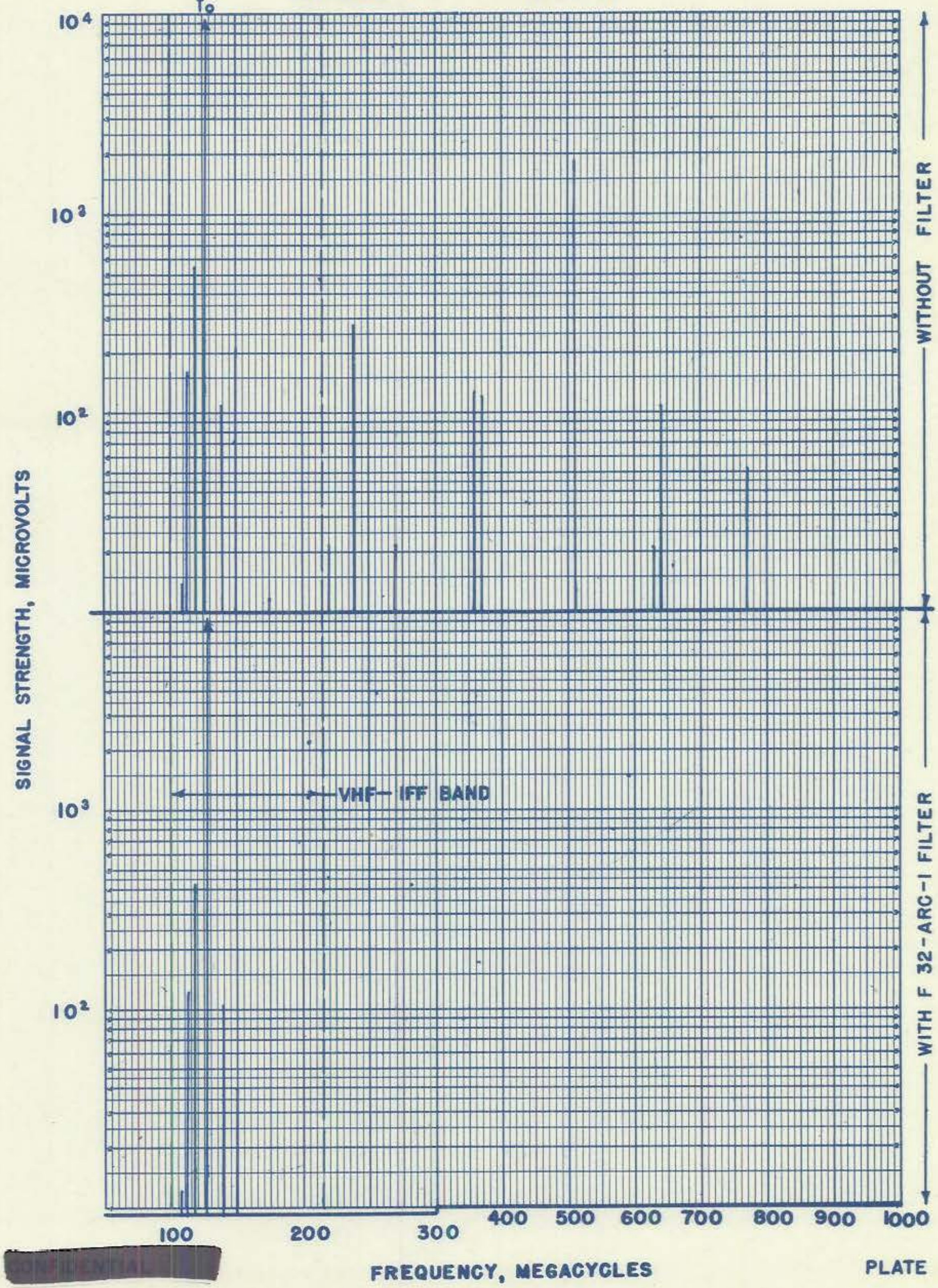

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PLATE 10

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INTERFERENCE SURVEY AN/ARC-1 AIRCRAFT EQUIPMENT *

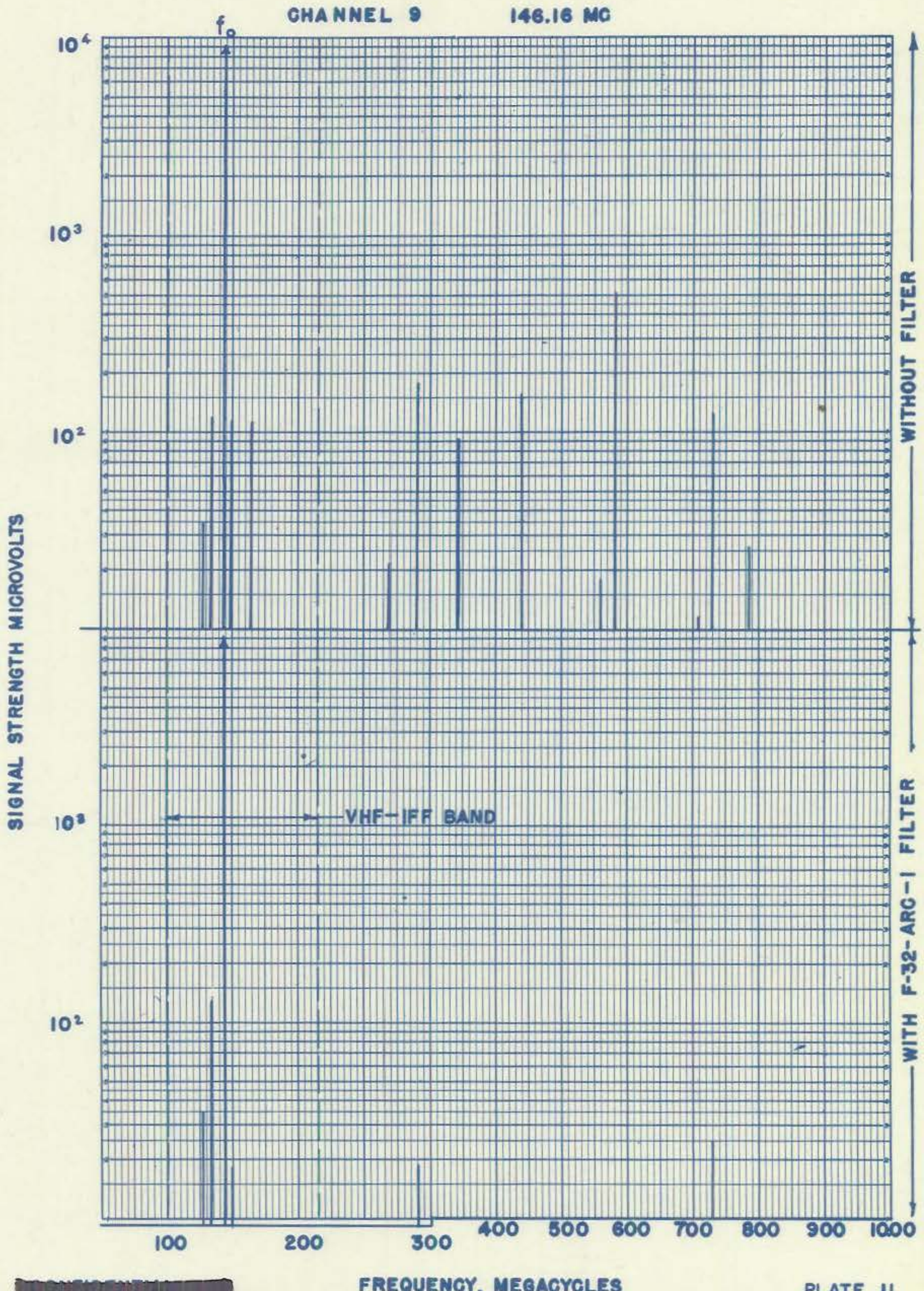

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PLATE II

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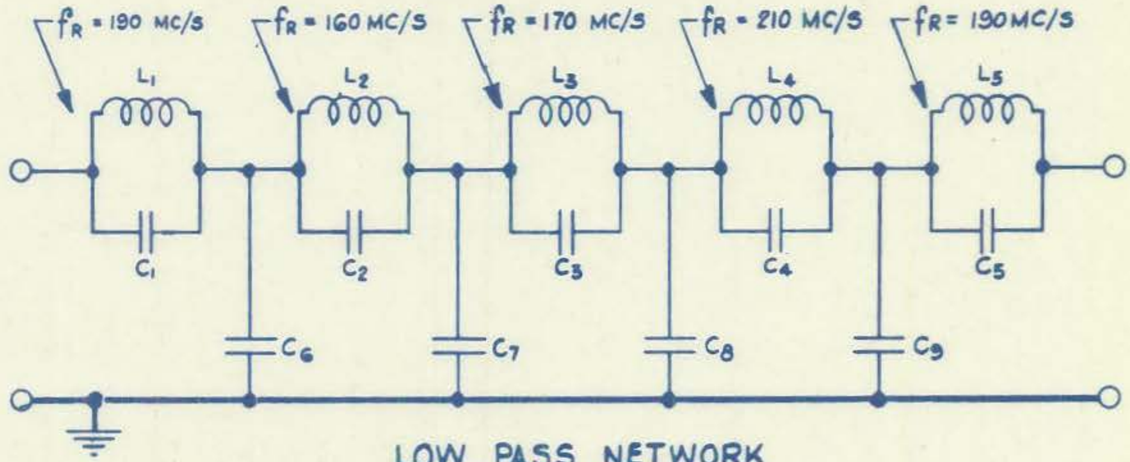
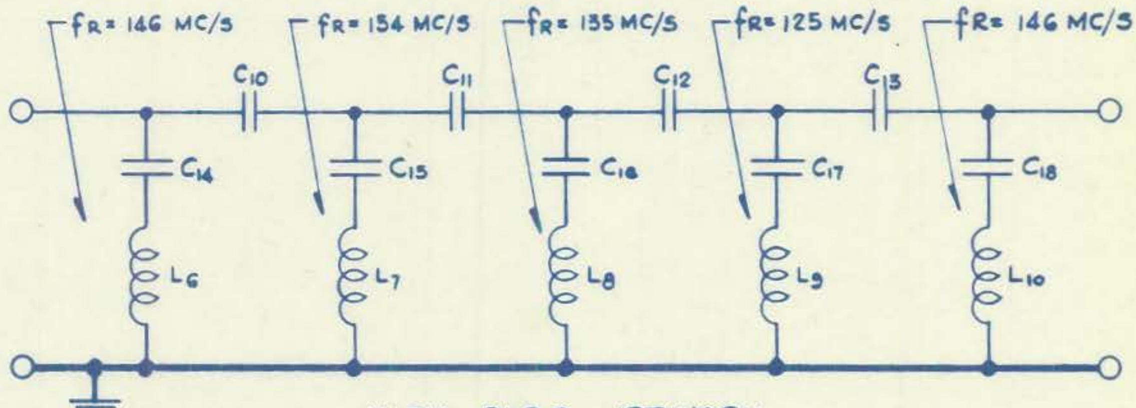
SCHEMATIC CIRCUIT DIAGRAMS OF ANTENNA NETWORKS



LOW PASS NETWORK
F-32/ARC-1



HIGH PASS NETWORK
F-33/APX-13

	DESIGN VALUE	*VALUE USING KOBAR SEALS
C_1 =	18.3 μμf	18.3 μμf
C_2 =	24.6 "	24.6 "
C_3 =	15.4 "	15.4 "
C_4 =	6.7 "	6.7 "
C_5 =	18.3 "	18.3 "
C_6 =	15.7 "	14.2 "
C_7 =	13.1 "	11.6 "
C_8 =	19.6 "	18.1 "
C_9 =	22.2 "	20.7 "
C_{10} =	23.7 "	23.7 "
C_{11} =	20.3 "	20.3 "
C_{12} =	14.6 "	14.6 "
C_{13} =	16.4 "	16.4 "
C_{14} =	7.9 "	7.9 "
C_{15} =	11.0 "	11.0 "
C_{16} =	23.6 "	23.6 "
C_{17} =	32.6 "	32.6 "
C_{18} =	7.9 "	7.9 "

L_1 =	.038 μH
L_2 =	.040 "
L_3 =	.057 "
L_4 =	.088 "
L_5 =	.038 "
L_6 =	.166 "
L_7 =	.111 "
L_8 =	.064 "
L_9 =	.054 "
L_{10} =	.166 "

* THESE VALUES ALLOW FOR 1.5 μμf CAPACITY TO GROUND OF KOBAR SEALS.

[redacted]

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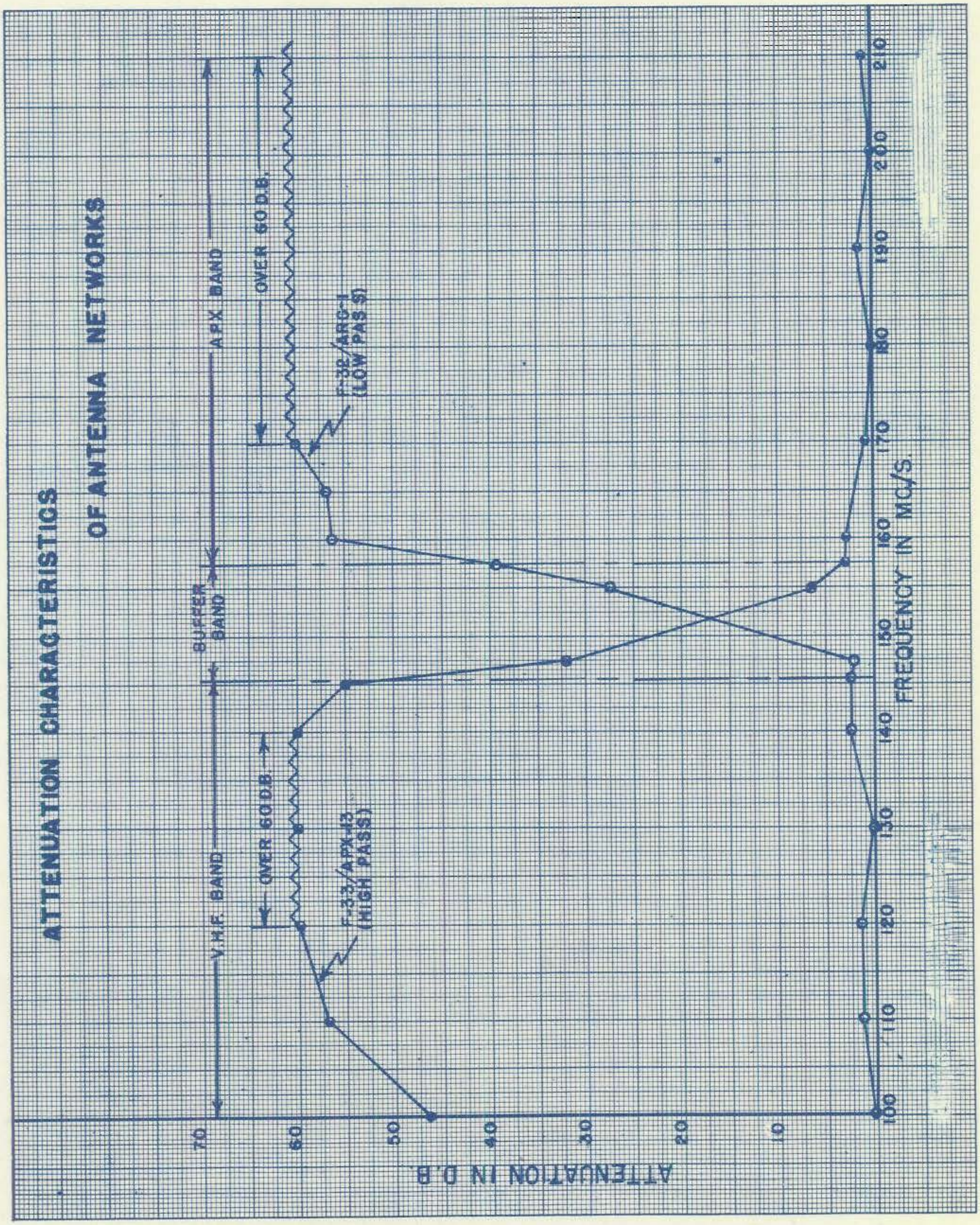
PLATE 12


ATTENUATION CHARACTERISTICS
OF ANTENNA NETWORKS
V.H.F. BAND
BUFFER BAND
APX BAND
OVER 60 D.B.
OVER 60 D.B.
F-33/APX-13 (HIGH PASS)
F-32/ARC-1 (LOW PASS)
ATTENUATION IN D.B.
FREQUENCY IN MC/S.
70
60
50
40
30
20
10
100
110
120
130
140
150
160
170
180
190
200
210

[redacted]

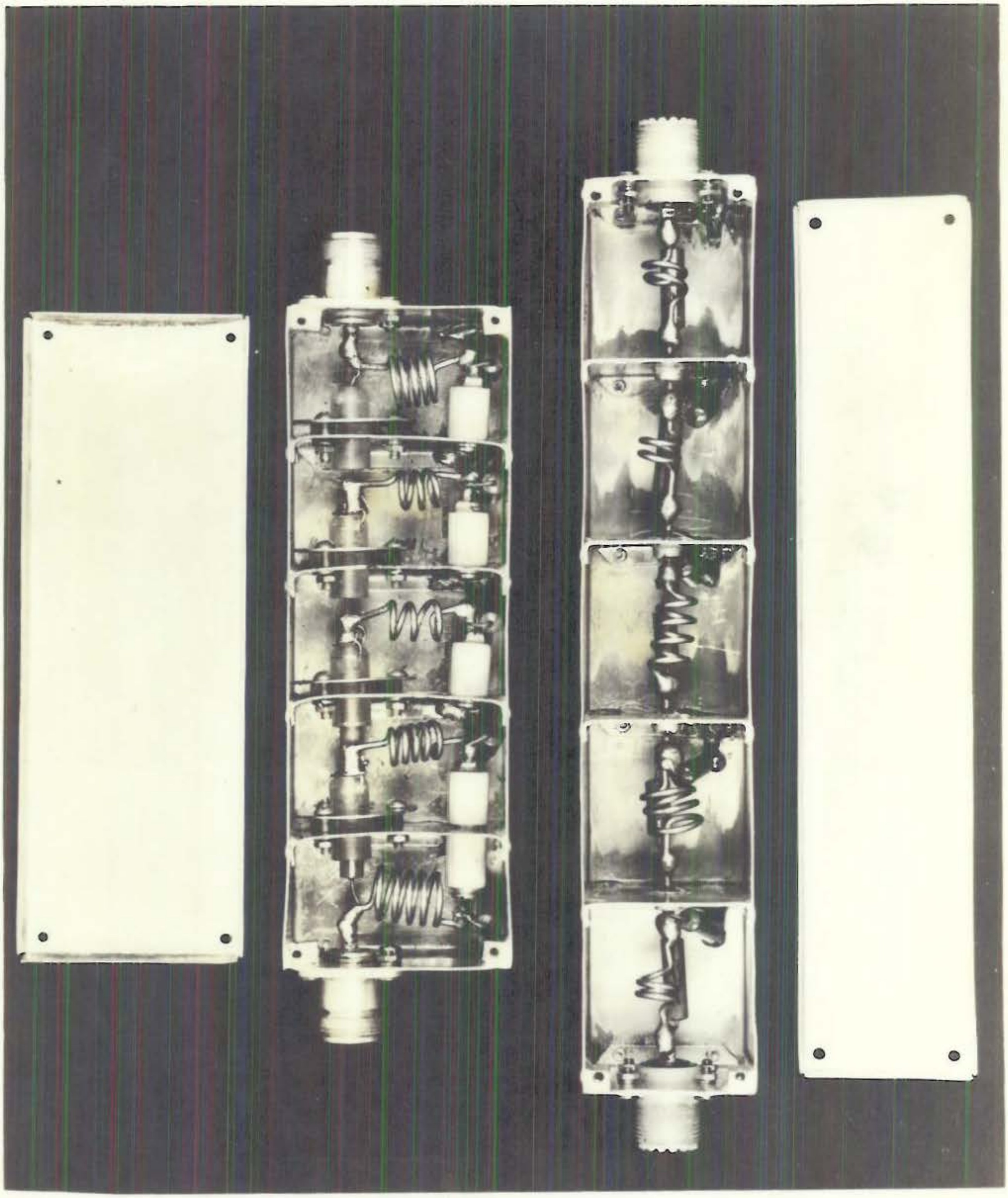


PLATE 14

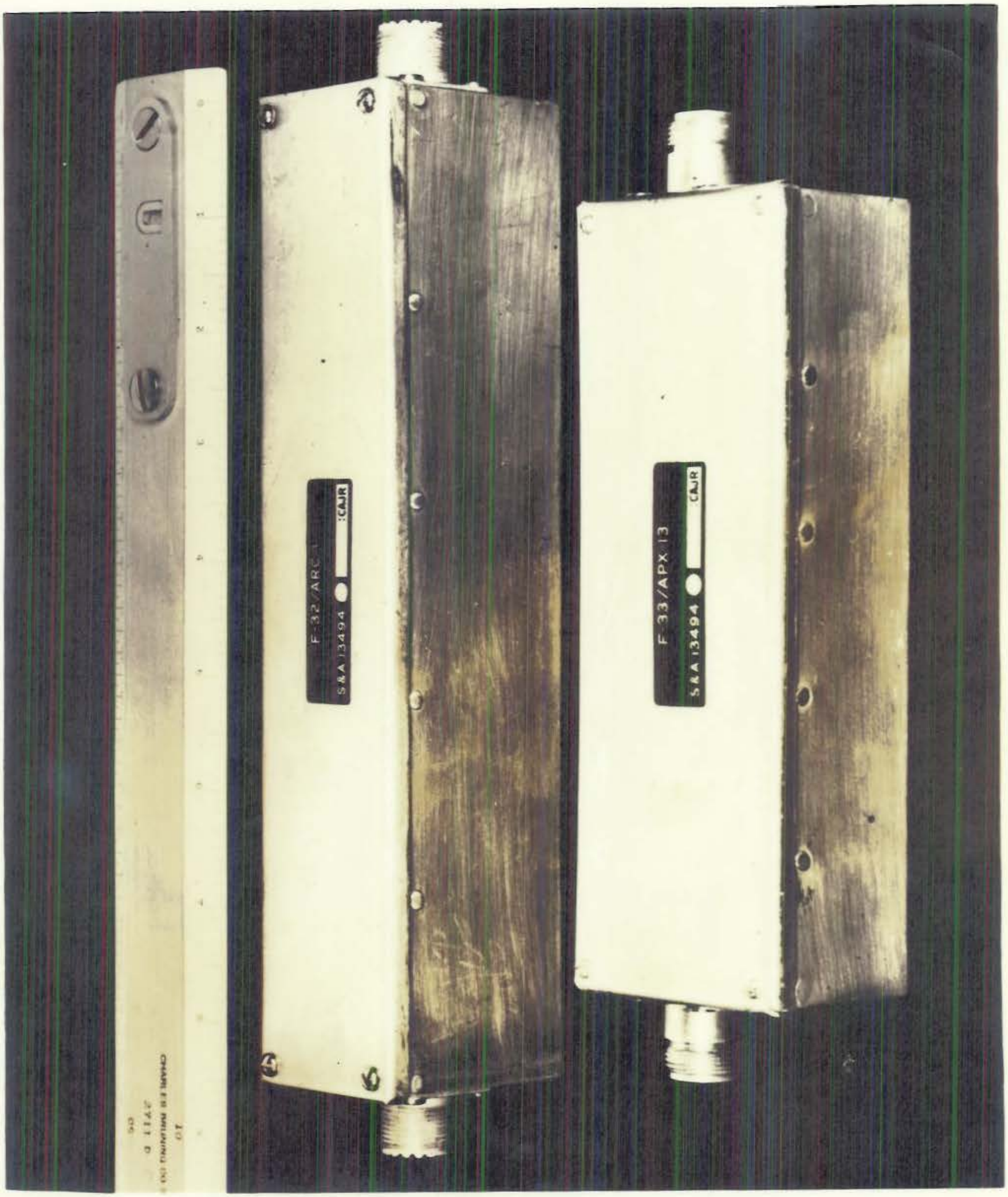


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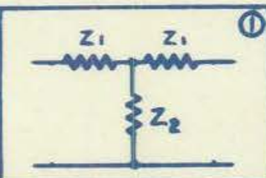
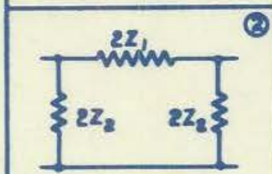
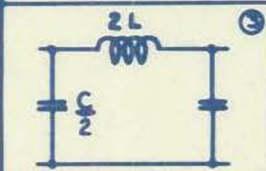
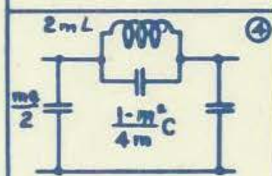
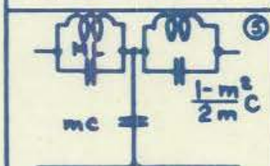
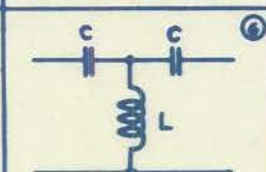
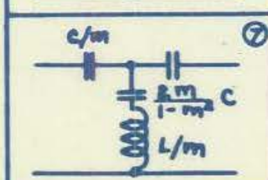
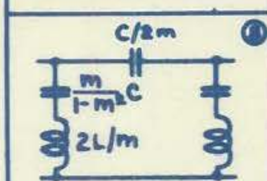
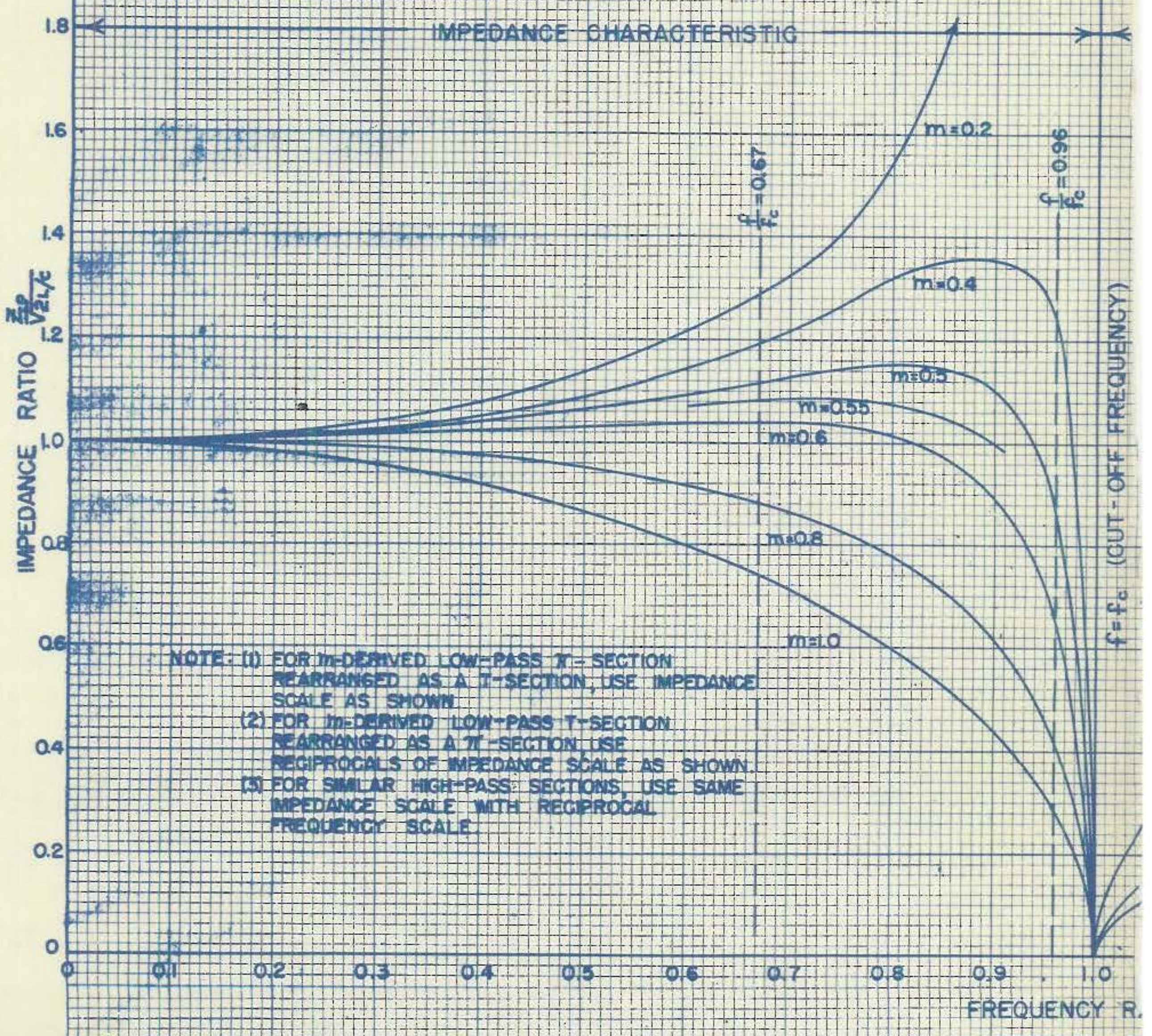
PLATE 15

NETWORK DESIGN EQUATIONS

	CIRCUIT	DESCRIPTION	EQUATIONS
GENERAL		GENERAL T-SECTION Z_0 = CHARACTERISTIC SECTION X = ATTENUATION IN NEPERS	$Z_0 = \sqrt{Z_1^2 + 2Z_1 Z_2}$ $\cosh x = \left\| 1 + \frac{Z_1}{Z_2} \right\|$
GENERAL		GENERAL PI-SECTION Z_0 = CHARACTERISTIC SECTION X = ATTENUATION IN NEPERS	$Z_0 = \frac{2Z_1 Z_2}{\sqrt{Z_1^2 + 2Z_1 Z_2}}$ $\cosh x = \left\| 1 + \frac{Z_1}{Z_2} \right\|$
LOW PASS		PROTOTYPE LOW PASS PI - SECTION	$Z_0 = \sqrt{\frac{2L}{C}} \Big/ \sqrt{1-\left(\frac{f}{f_c}\right)^2}$ (1) $f_c = 1/\pi\sqrt{2LC}$ $\cosh x = \left\| 1 - 2\left(\frac{f^2}{f_c}\right)^2 \right\|$ (2)
LOW PASS		M-DERIVED LOW PASS PI- SECTION $0 < m < 1.0$	Z_0 = SAME AS (1) $\cosh' x = \left\| \frac{(1+m^2)\left(\frac{f}{f_c}\right)^2 - 1}{(1-m^2)\left(\frac{f}{f_c}\right)^2 - 1} \right\|$ (3)
LOW PASS		M-DERIVED LOW-PASS PI-SECTION REARRANGED AS A T-SECTION	$Z_0' = \sqrt{\frac{2L}{C}} \frac{\sqrt{1-\left(\frac{f}{f_c}\right)^2}}{\left[1-(1-m^2)\left(\frac{f}{f_c}\right)^2\right]}$ (4) COSH' X - SAME AS (3)
HIGH PASS		PROTOTYPE HIGH PASS T- SECTION	$Z_0 = \sqrt{\frac{2L}{C}} \sqrt{1-\left(\frac{f_c}{f}\right)^2}$ (5) $f_c = 1/2\pi\sqrt{2LC}$ $\cosh x = \left\| 1 - 2\left(\frac{f_c}{f}\right)^2 \right\|$ (6)
HIGH PASS		M-DERIVED HIGH PASS T-SECTION $0 < m < 1.0$	Z_0 = SAME AS (5) $\cosh' x = \left\| \frac{\left(\frac{f_c}{f}\right)^2 - (1+m^2)}{\left(\frac{f_c}{f}\right)^2 - (1-m^2)} \right\|$ (7)
HIGH PASS		M-DERIVED HIGH PASS T-SECTION REARRANGED AS A PI-SECTION	$Z_0' = \sqrt{\frac{2L}{C}} \frac{\left[1-(1-m^2)\left(\frac{f_c}{f}\right)^2\right]}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$ (8) COSH' X = SAME AS (7)



THEORETICAL C
FOR
IMPEDANCE AND A
OF
FILTER NETWORK

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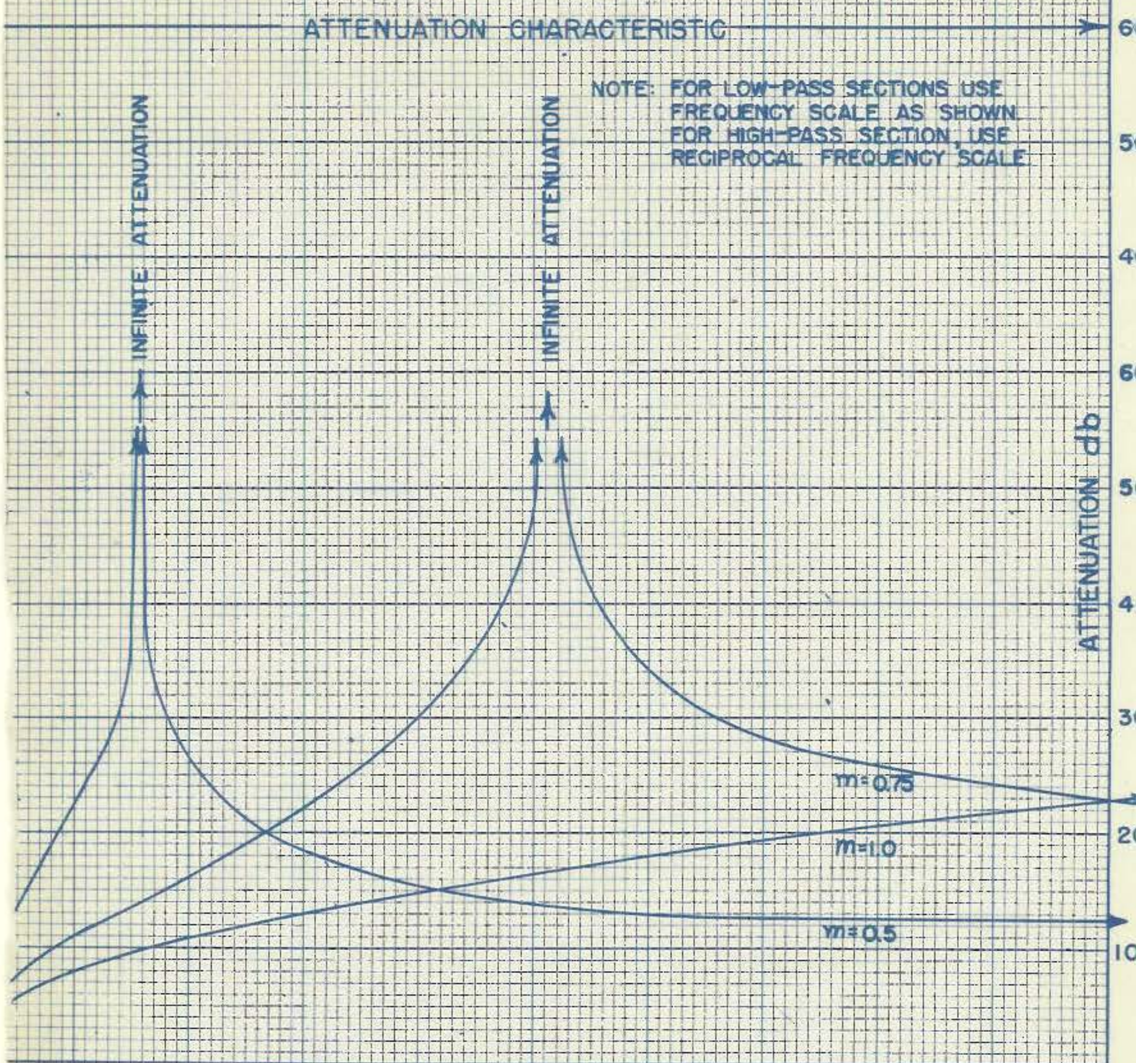

ATIO $\frac{f}{f_c}$

URVES

TTENUATION

SECTIONS.

PLATE 17