RADANT ANALYSIS STUDIES

Interim Report No. 3
1 February through 31 May 1966

C.T. Tai

June 1966

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Project Engineer, S. Pitts AVWE

Prepared for

Air Force Avionics Laboratory, AVWE
Research and Technology Division, AFSC
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by The University of Michigan under Contract No. AF 33(615)2811, Task 416103, Project 4161. The work was administered under the direction of theAir Force Avionics Laboratory, Research and Technology Division, Air Force Systems Command: E. M. Turner, Technical Monitor; S. Pitts, Project Engineer.

This report covers the work conducted from February through May 1966.

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ABSTRACT

In this third interim report, the theory of the scattering property of two crossed dipoles is briefly outlined. It is shown that the two components of the scattered field should be of the same order of magnitude when the transmission line is matched to the dipoles.

The impedance of a dipole placed on a dielectric panel has been measured. A significant shift of the resonant frequency has been observed. The result of a preliminary experimental study of twenty pairs of dipoles mounted on a conical surface is also included in this report.

I

INTRODUCTION

During this period (1 February - 31 May) our main activity involves a theoretical study of the scattering property of two perpendicular dipoles linked by a pair of transmission lines. This investigation is considered to be a necessary step prior to the study of a panel made of such units. An outline of the treatment for a single unit is included in this report.

Experimental work on the dipole panel is on the way and the design is described here. In order to choose the proper frequency band for the experiment, an investigation is made to determine the effect of a dielectric panel on the impedance of a dipole. The data is presented here.

Previous work on broadband antennas* indicated that a combination of dipoles with various lengths exhibits certain broadband characteristics. A preliminary investigation was conducted to apply the technique to a conical dielectric surface. Although the problem is not the main topic of this project, it is felt that information concerning this structure would be of general interest to radant study. The result, which is decribed below, indicates that twenty pairs are not sufficient. Like the manipole case, the minimum number of pairs to cover a 6:1 band presumably should be doubled.

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*Broadband Antenna Techniques Study, Technical Report ECOM-01263-3, Radiation Laboratory, University of Michigan, February 1966.

II

SCATTERING BY TWO PERPENDICULAR DIPOLES LINKED BY A PAIR OF TRANSMISSION LINES

The problem under consideration is illustrated in Fig. 1.

Following the theory of receiving antennas, it can be shown that the short-circuit current induced at the terminals of antenna No. 1 is given by

$$I_1^{(s)} = Y_{11}\,\bar{h}_1 \cdot \bar{E}_i \tag{1}$$

where

Y_{11} = self-admittance of antenna No. 1, defined in the presence of antenna No. 2

$\bar{h}_1$ = effective height of antenna No. 1

$\bar{E}_1$ = incident E-field evaluated at the terminals of antenna No. 1.

We assume here that the incident E-field is parallel to the axis of antenna No. 1. Since the mutual impedance for two perpendicular dipoles is zero, h_1 is the same as the effective height of an isolated dipole. For a half-wave dipole, the value of h_1 measured in the broadside direction is given by

$$\bar{h}_1 = \frac{\lambda}{\pi}\,\hat{z} \tag{2}$$

Since the incidence wave is perpendicular to antenna No. 2, $I_2^{(s)} = 0$.

Denoting the terminal currents and voltages by I_1 , I_2 and V_1 , V_2 , one finds, by the application of the superposition theorem, that

$$I_1 = Y_{11}\,\bar{h}_1 \cdot \bar{E}_1 + Y_{11} V_1 \tag{3}$$

$$I_2 = Y_{22}\,V_2 \tag{4}$$

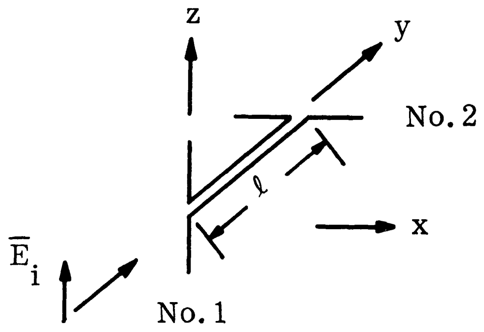

FIG. 1: SCATTERING OF A PLANE WAVE BY TWO PERPENDICULAR DIPOLES LINKED BY A PAIR OF TRANSMISSION LINES

Because of the constraint due to the transmission line, the terminal currents and voltages must satisfy the following equations:

$$\begin{pmatrix} V_1 \\ V_2 \end{pmatrix} = \begin{pmatrix} Z_a & Z_b \\ Z_b & Z_a \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \end{pmatrix} \tag{5}$$

where $Z_a = j\, Z_0 \cot k\ell$

$Z_b = j\, Z_0 \csc k\ell$

Z_0 = characteristic impedance of the line

ℓ = length of the line

$k = 2\pi/\lambda$ = wave number

By eliminating V_1 and V_2 in (3) and (5) we can determine I_1 and I_2. The results are

$$I_1 = Y_{11}\, \bar{h}_1 \cdot \bar{E}_1 \left[1 - Y_{11} Z_a - Y_{11} Z_b \frac{Y_{22} Z_b}{1 - Y_{11} Z_a} \right]^{-1} \tag{6}$$

$$I_2 = \left(\frac{Y_{22} Z_b}{1 - Y_{22} Z_a} \right) I_1 \tag{7}$$

Once the terminal currents are known the scattered field can be determined. Assuming again a sinnsoidal current distribution for half-wave dipoles, one obtains

$$\bar{E}_n^{(s)} = \frac{j \eta_0 I_n}{2\pi} \frac{\cos\left(\frac{\pi}{2} \cos\theta_n\right)}{\sin\theta_n} \frac{e^{-jkR_n}}{R_n} \hat{\theta}_n \tag{8}$$

where n = 1, or 2: and θ_1 and θ_2 denote, respectively, the angle between the direction of observation and the axis of the dipole.

It is interesting to observe that if one considers the ideal case such that

$$Y_{11} Z_0 = Y_{22} Z_0 = 1 \tag{9}$$

then

$$I_1 = \frac{1}{2 Z_{11}} h_1 E_1 \tag{10}$$

$$I_2 = - E^{-jk\ell} I_1 \tag{11}$$

This is an expected result for a matched system, when there is no exterior coupling between the antennas, as for the case of two perpendicular dipoles.

It is seen from the above simple analysis that the scattering field due to the two dipoles would be of comparable strength. The unit, therefore, may be considered as a polarization transformer as far as the scattered field is concerned. One expects that a similar property will prevail when a number of these units is arranged in the form of an array. An experiment involving two dipole arrays, one perpendicular to the other has, therefore, been designed to determine the effectiveness of the polarization transform as a function of the line separation under the actual condition that the line is not matched to the antennas.

III

DESIGN OF THE DIPOLE PANEL

The proposed structure will consist of two half-wave dipole arrays. The two arrays will be cross-polarized and separated by a variable electrical length. Initial trial separations will be $\lambda/4$, and $\lambda/2$ and $3\lambda/4$. A two-wire transmission line will connect each pair of cross-polarized dipoles.

Each array will be fabricated from a fiberglass panel copper-clad on one side. The fiberglass panel will be approximately 36" square and 1/16" thick. Excess copper will be chemically removed from the panel leaving approximately 400 small copper strips imprinted on the fiberglass. These strips will then form 200 half wave dipoles. The approximate size and spacing of the dipole elements is shown in Figure 2. A preliminary experimental investigation has indicated that this dipole configuration is resonant at approximately 3 GHz.

Two panels will comprise the structure. The fiberglass panels are connected physically and the dipoles electrically by the 200 transmission lines. The orientation of the panels is shown in Figure 3.

As noted above, an experimental investigation was conducted to determine the impedance of a single dipole imprinted on the fiberglass board. This study was needed to obtain a better feeling for the characteristic impedance of the transmission line that is to inter-connect the two panels of the radant structure. Initially, a thin cylindrical half-wave dipole was constructed and attached to a balun as shown in Figure 4. Impedance data was collected for this configuration to confirm correct adjustment of the balun for approximately 3 GHz. The final impedance plot for this configuration is shown in Figure 5. The balun was then connected to a single copper-strip dipole imprinted on a 4 inch square fiberglass panel as shown in Figure 6. The length of the dipole was adjusted until the configuration was resonant at approximately 3 GHz. The resulting dipole length

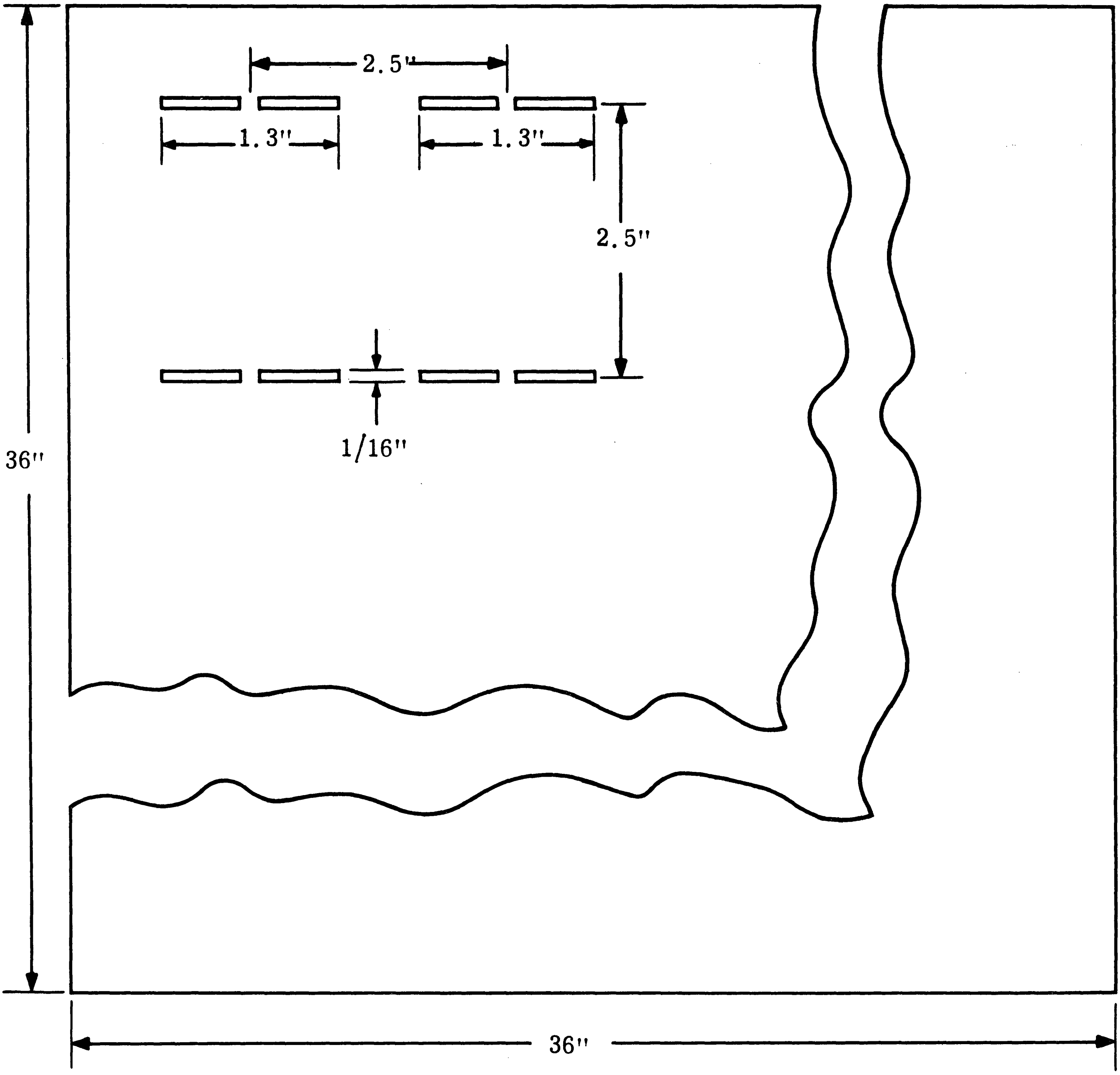

FIG. 2: ARRANGEMENT OF DIPOLE ELEMENTS OF FIBERGLASS PANEL.

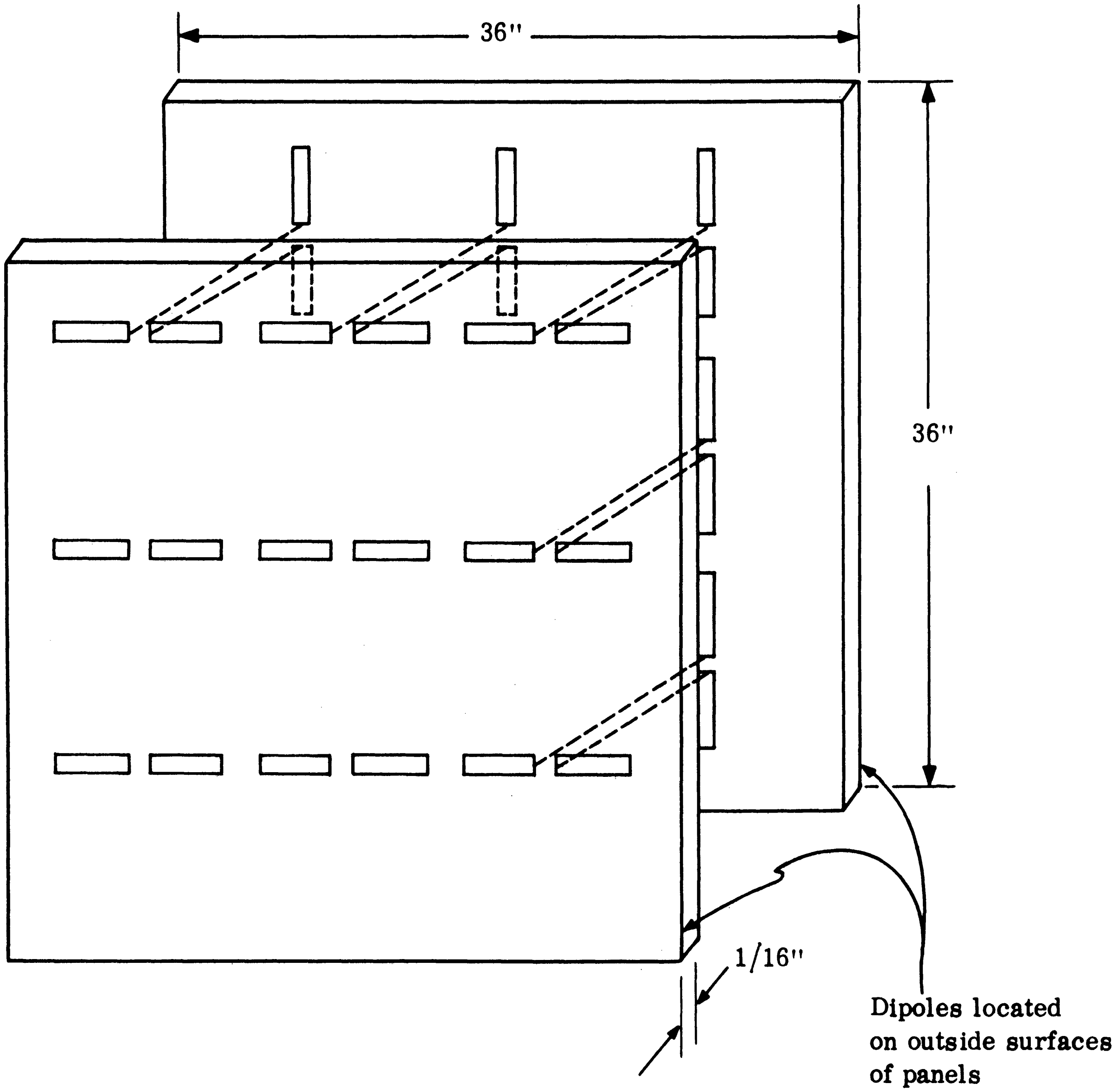

FIG. 3: ORIENTATION OF DIPOLE ARRAYS
(only 9 dipole pairs shown for clarity)

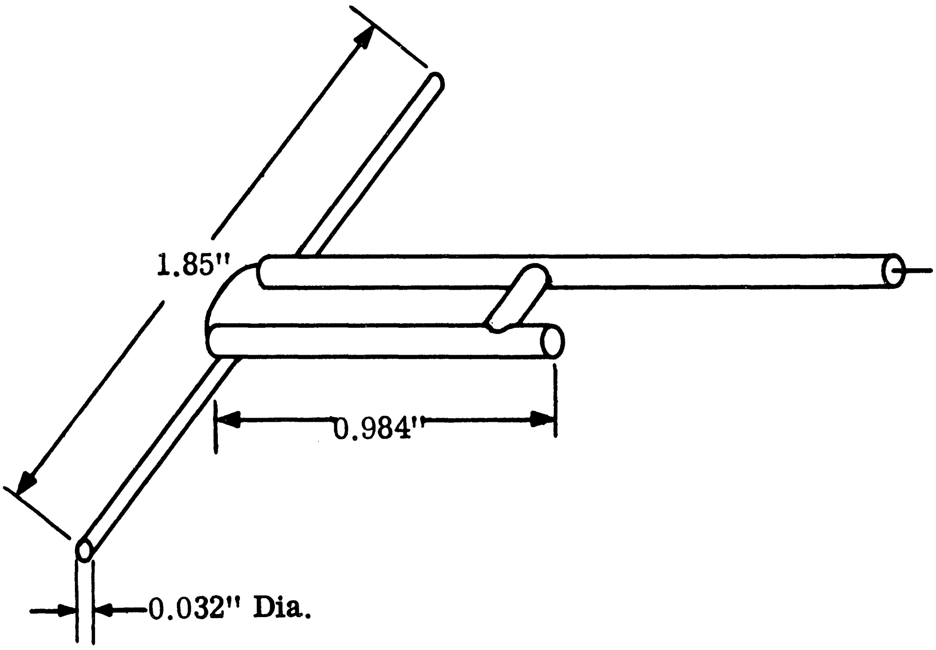

FIG. 4: CYLINDRICAL λ/2 DIPOLE AND BALUN

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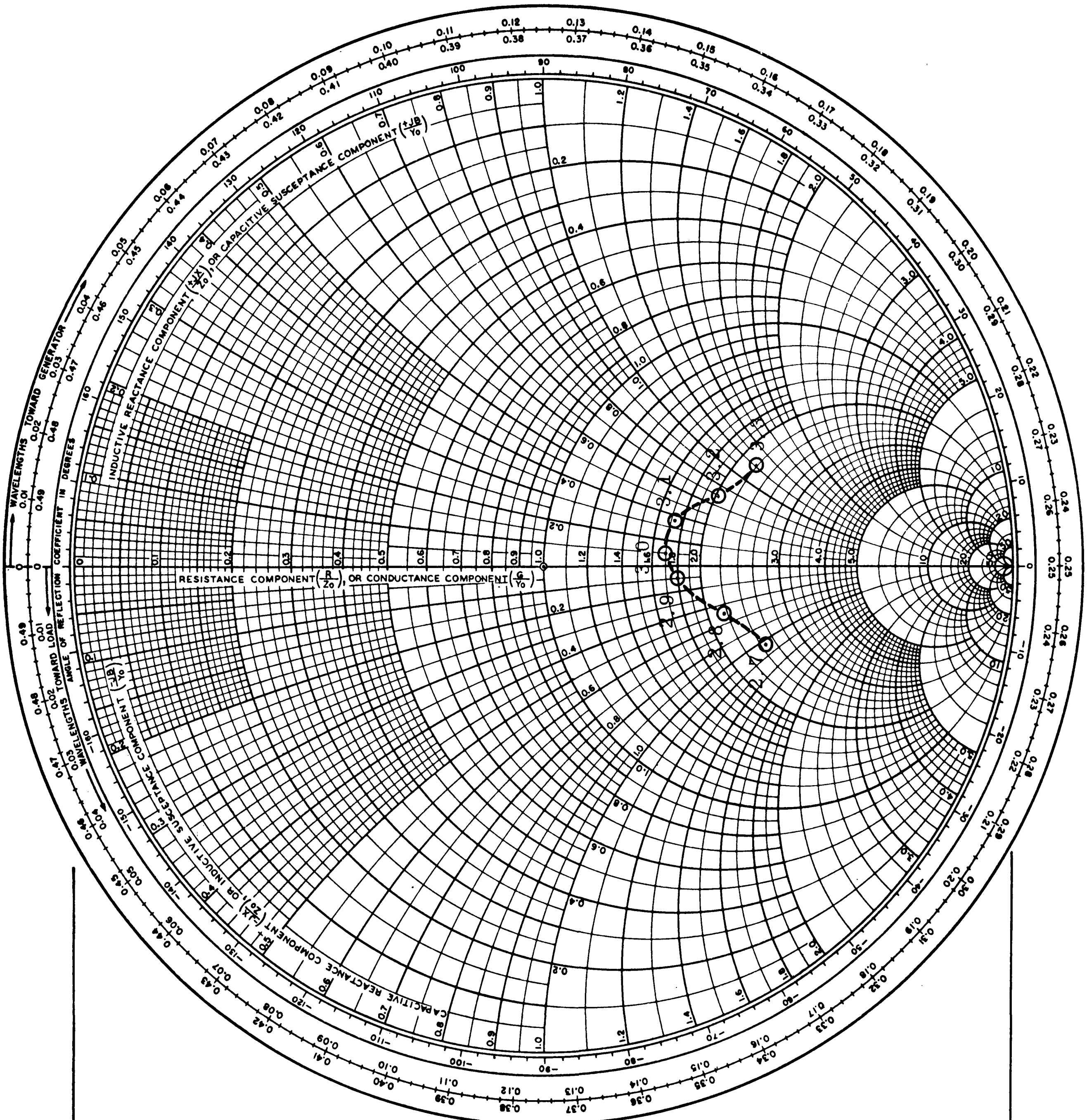
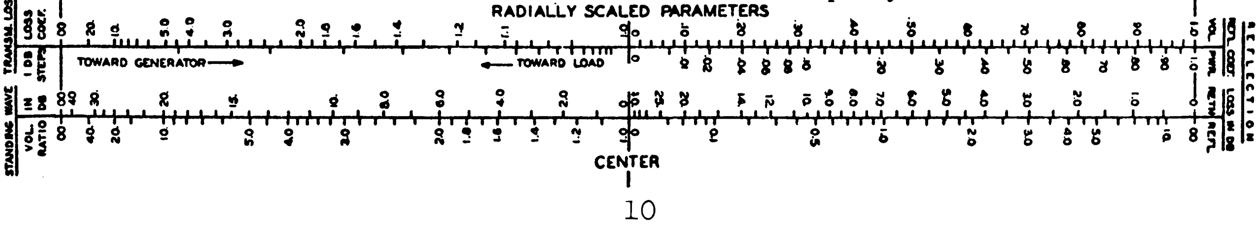


FIG. 5: CYLINDRICAL DIPOLE AND BALUN (Frequency in GHz)



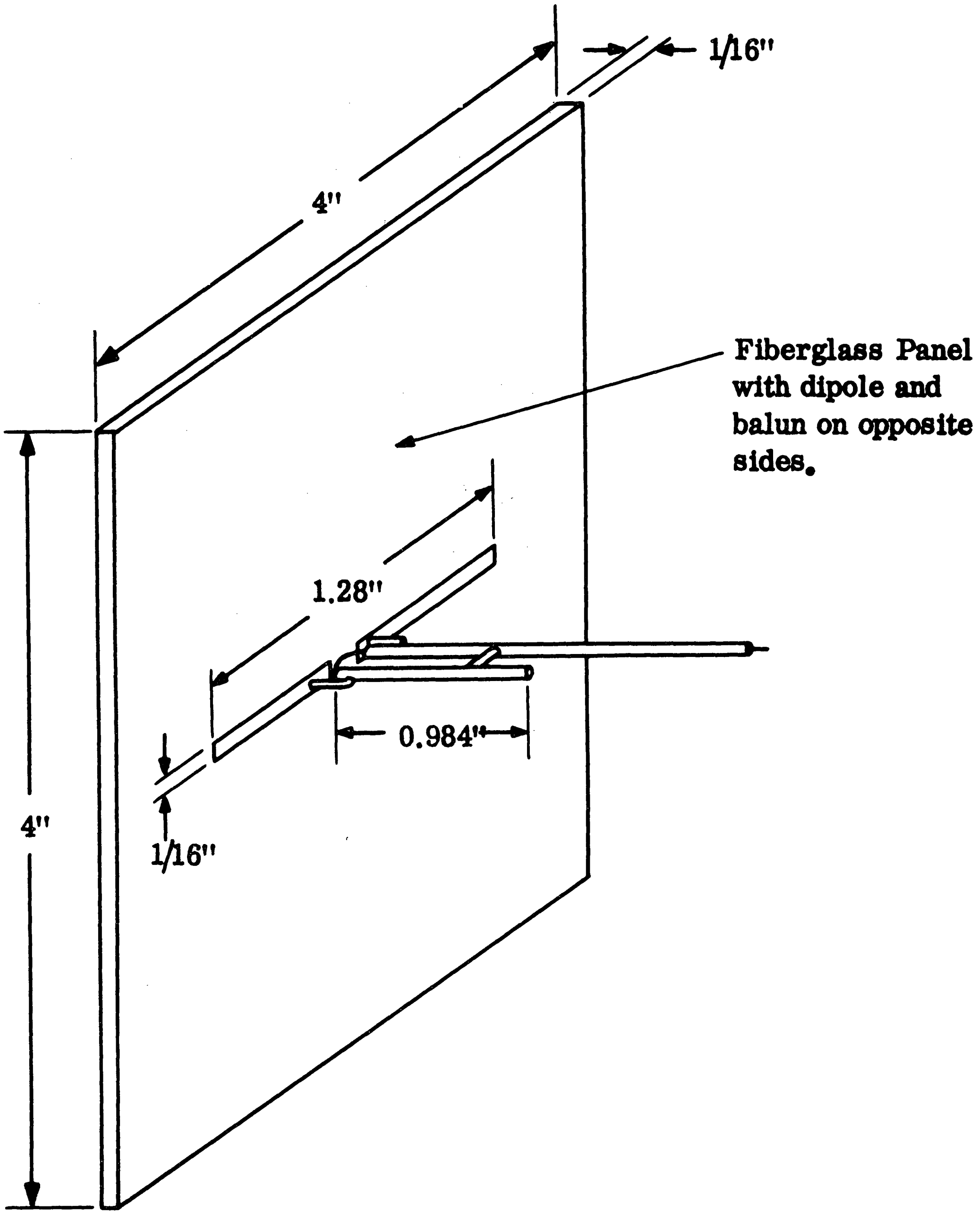


FIG. 6: COPPER STRIP λ/2 DIPOLE AND BALUN

was approximately 1.3". Impedance measurements of this configuration indicate the impedance to be approximately 50 ohms at resonance as can be seen from Figure 7. To substantiate the above result, a second copper-strip dipole was constructed on a second piece of 4" square fiberglass. This half-wave dipole had a length of 1.95" and was connected to a length of coax cable as shown in Figure 8. Data collected for this configuration, Figure 9, indicated the impedance at resonance to be approximately 50 ohms and it shared also a reduction in resonant frequency from that of an equal length free space half-wave dipole.

It should be remarked that there is so far no theoretical treatment about the effect of a dielectric panel on the impedance of dipole. The drastic shift of the resonant frequency is, rather unexpected.

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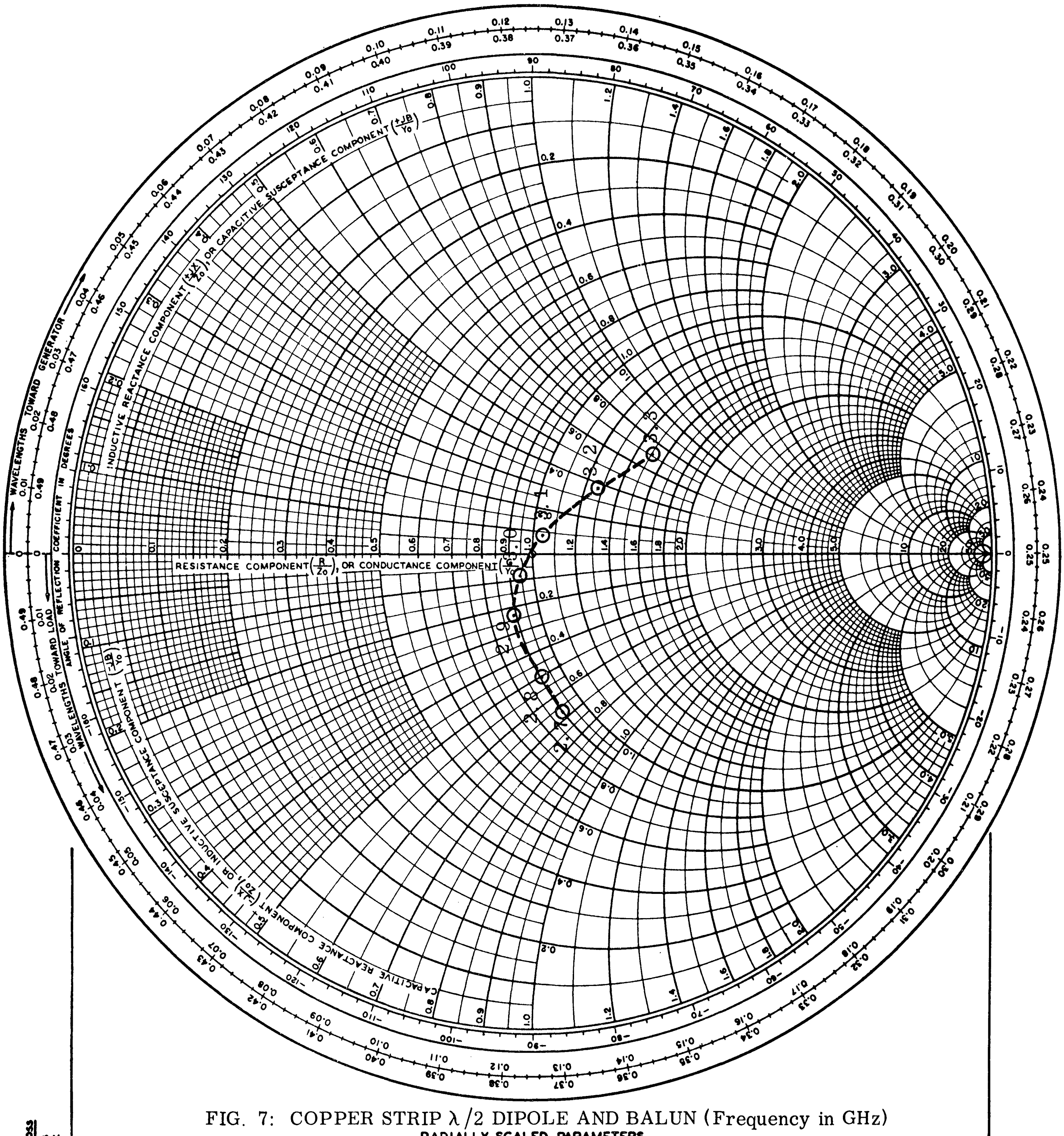
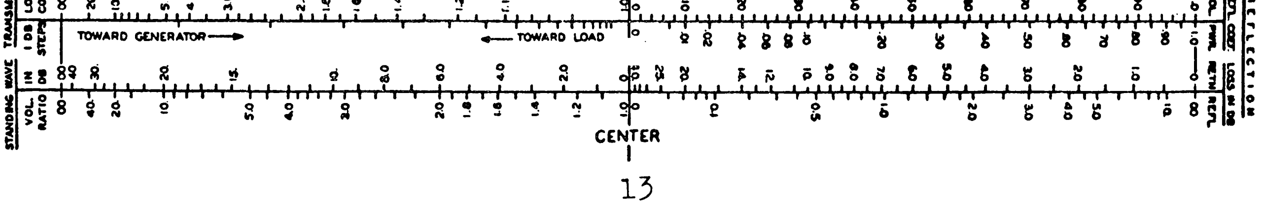


FIG. 7: COPPER STRIP λ/2 DIPOLE AND BALUN (Frequency in GHz)



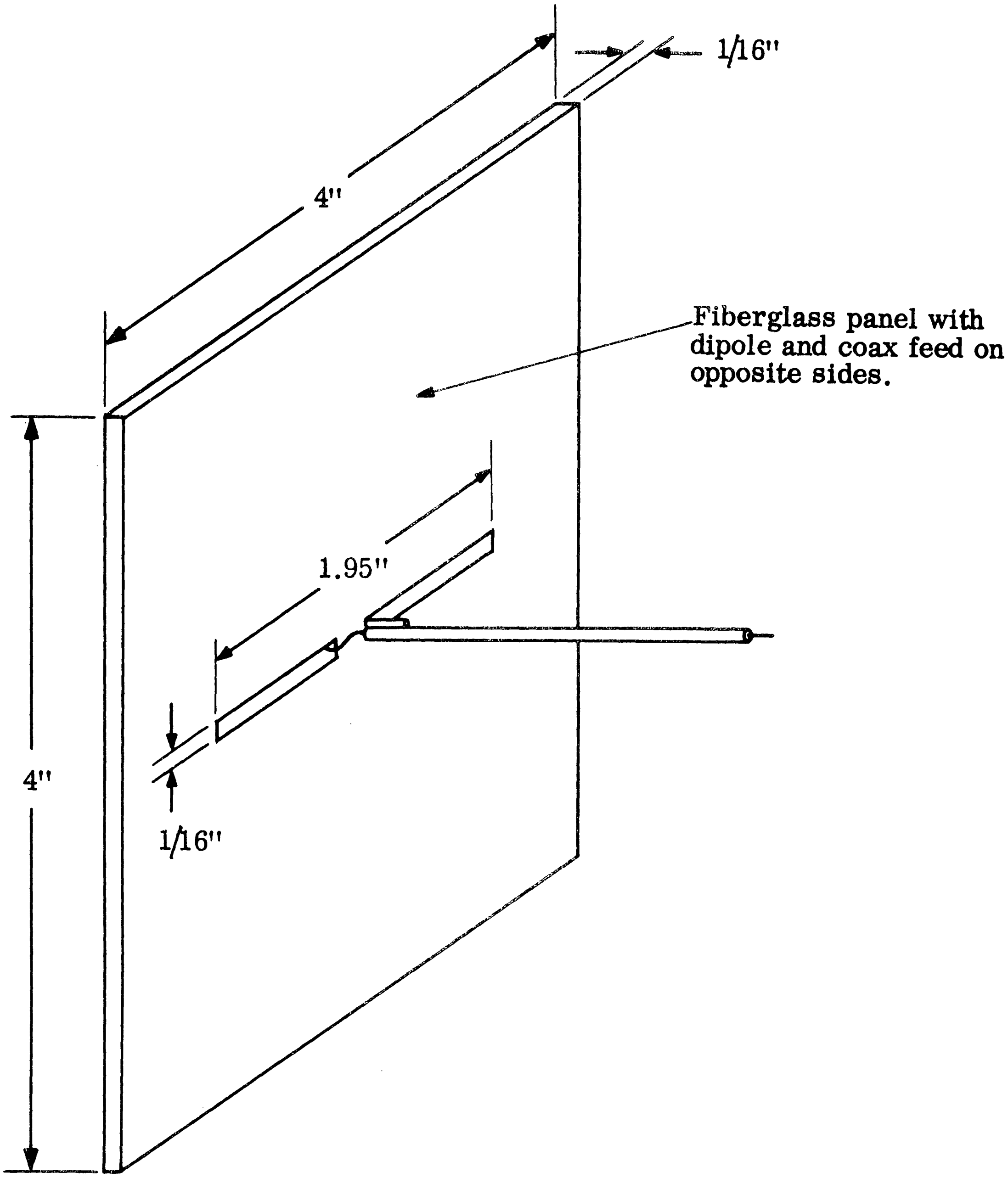


FIG. 8: COPPER STRIP λ/2 DIPOLE AND UNBALANCED FEED

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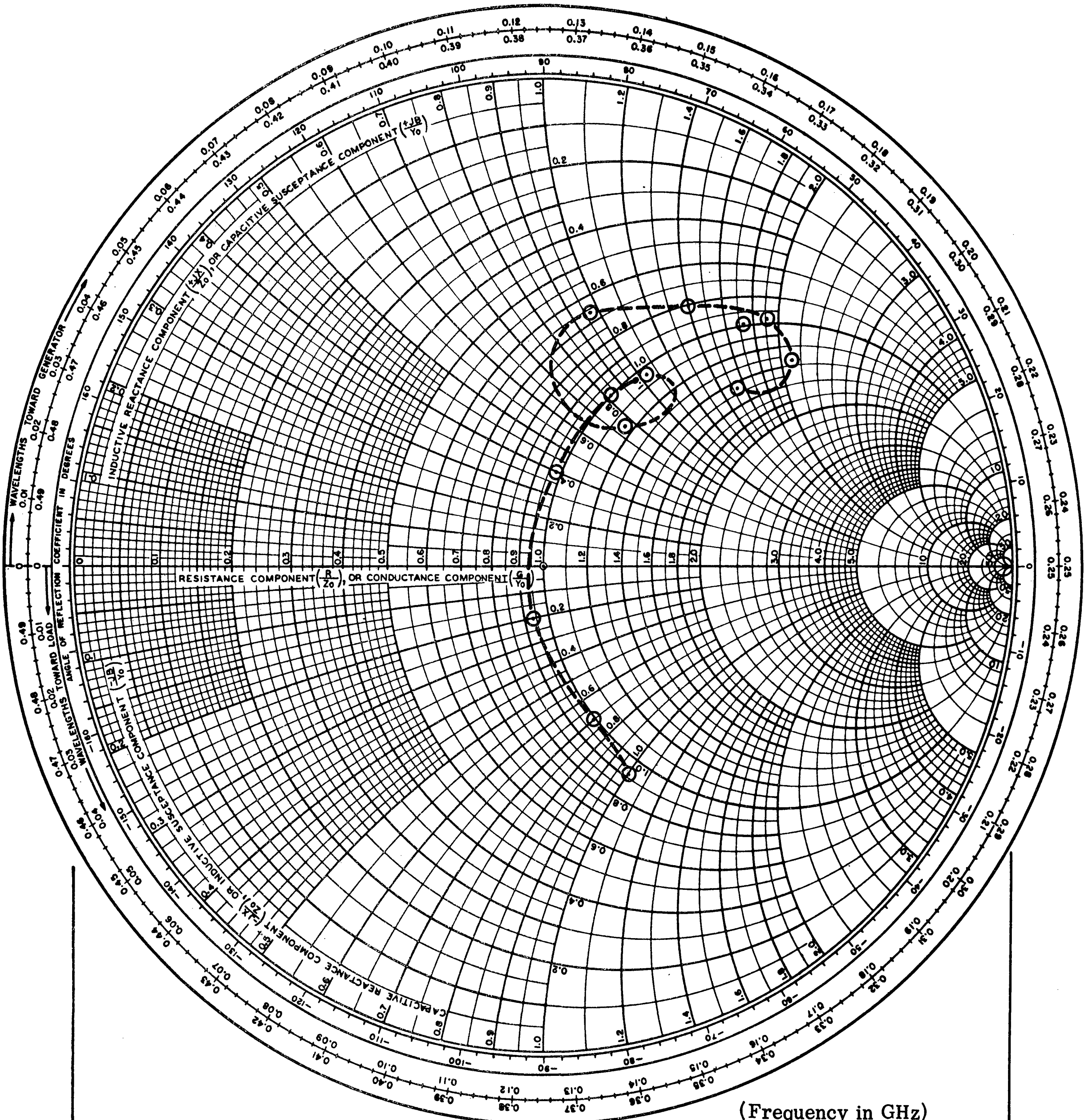
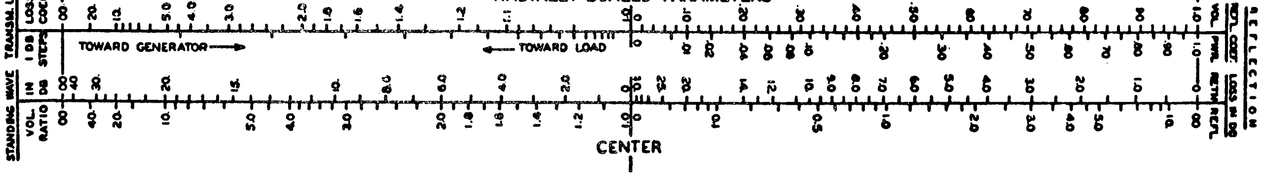


(Frequency in GHz)

FIG. 9: COPPER STRIP λ/2 DIPOLE AND UNBALANCED FEED



IV

CONICAL MANIPOLE

As mentioned in the Introduction, a preliminary study has been conducted to investigate the impedance characteristics of a conical manipole. The manipole previously investigated under another contract was designed to give an omni-directional azimuth pattern over a very broad frequency range. The manipole antenna may be compared to a monopole over a ground plane where the single element is replaced by many elements. The elements may vary in length by a factor of 10 to 1 with the longest being $\lambda/4$ for the lowest frequency and others being $\lambda/4$ long for selected frequencies up to the highest frequency of interest.

The present antenna consists of 20 pairs of elements supported by a fiber-glass cone. There is, of course no ground plane present and the cone is chosen as representative of the tip of a radome. The elements were trimmed such that they differ in length by 10 percent, i.e., the longest element is resonant at 300 MHz, the second longest at 330 MHz, the third longest at 363 MHz, etc. Each pair of equal length elements was oriented in a dipole configuration as shown in Figure 10. The distribution of pairs is random with an approximate spacing of 9^o . VSWR data has been collected for the frequency range of 300 to 2100 MHz. This data is shown in Table I.

This is obvious from this data that in order to increase the band width the number of pairs must be increased considerably. Since a 6:1 band antenna has successfully been designed using 43 monopoles[*] it is very likely that at least 40 pairs are needed for the conical structure too.

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[*] See reference quoted in Introduction.

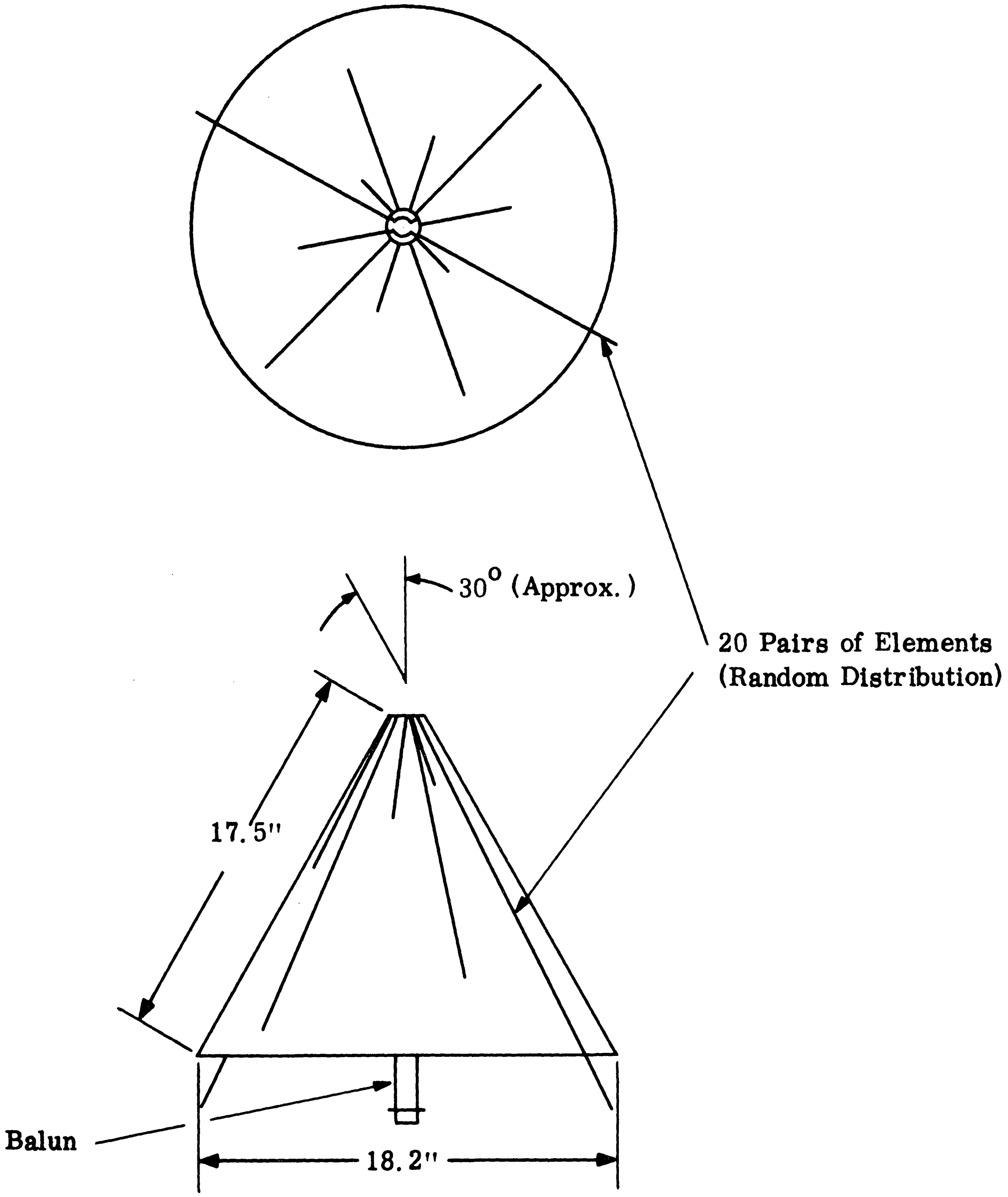

FIG. 10: CONICAL MANIPOLE CONFIGURATION

TABLE I

Frequency (MHz)	VSWR	Frequency (MHz)	VSWR	Frequency (MHz)	VSWR	Frequency (MHz)	VSWR
300	3.9						
350	7.8	800	3.8	1250	1.9	1700	3.0
400	2.5	850	2.3	1300	1.2	1750	3.6
450	2.3	900	1.4	1350	1.2	1800	5.1
500	1.6	950	2.7	1400	1.5	1850	3.7
550	2.3	1000	4.9	1450	1.3	1900	1.8
600	3.4	1050	2.8	1500	2.2	1950	2.9
650	9.3	1100	2.8	1550	3.9	2000	3.4
700	5.1	1150	2.9	1600	2.5	2050	4.9
750	4.8	1200	2.7	1650	3.3	2100	3.3

V

FUTURE WORK

During the next period, we shall concentrate on the experimental part of the dipole panel. In particular, the polarization transform characteristics of the panel will be investigated. The effect of the length and the characteristic impedance of the transmission line connecting the dipoles will be studied.

For the conical manipoles, more pairs will be inserted into the structure. It is hoped that the result, both on impedance and pattern, will be comparable to what we have found for the manipoles. If desirable, the effect of a dielectric coating on the conical antennas will also be investigated experimentally. Finally, the apex angle to yield the best omnidirectional pattern will be determined.

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13. ABSTRACT

The theory of scattering properties of two crossed dipoles is briefly described in this third interim report. It is shown that the two components of the scattered field should be of the same order of magnitude when the transmission line is matched to the dipoles.

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