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An experimental investigation of a small volume sandwich antenna in the 400 megacycle frequency range

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AN EXPERIMENTAL INVESTIGATION OF A SMALL VOLUME SANDWICH ANTENNA IN THE 400 MEGACYCLE FREQUENCY RANGE

BY

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A

THESIS

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1959

Approved by - ________________________________

Professor of Electrical Engineering

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LIST OF SYMBOLS

Symbol	Description
f	Frequency
λ	Wavelength
W	Width of antenna
L	Length of antenna
T	Thickness of antenna
D	Distance of feed probe position from rear of the antenna
VSWR	Voltage standing wave ratio
R	Resistive component of the input impedance of the antenna
X	Reactive component of the input impedance of the antenna. Positive values of reactance indicate inductive reactance while negative values indicate capacitive reactance.
mc	Megacycles
c	Speed of light
Z_o	Characteristic impedance of a transmission line
Q	2π times the maximum energy stored per cycle divided by the energy dissipated per cycle

INTRODUCTION

Since the recent increased interest in the field of missiles, attention has been focused upon special hardware such as antennas for these missiles. The problem dealt with in this thesis originated because of the special requirements placed upon missile antenna design.

The problem originally proposed was to set forth a specific set of requirements for a missile antenna, and then to find the type of antenna which would fulfill these requirements. After a suitable paper solution had been obtained, the antenna was to be designed, built, and tested. However, after the specific antenna had been chosen, the problem was modified to that of determining the antenna's characteristics with the ultimate goal of adapting these characteristics to a specific set of requirements. Detailed requirements are given in the following paragraph.

The general characteristics desired were that the antenna (1) have low wind resistance, (2) be of small volume in comparison with conventional antennas of the same frequency range now known to exist, (3) have a pattern that would be adaptable for use as an omnidirectional antenna, either used alone or in conjunction with other antennas identical to it, (4) be efficient over the desired frequency range, and (5) be of sufficient bandwidth. Pictorially, the pattern characteristics in the plane of the axis of the missile would be as shown in Figure 1. In the plane

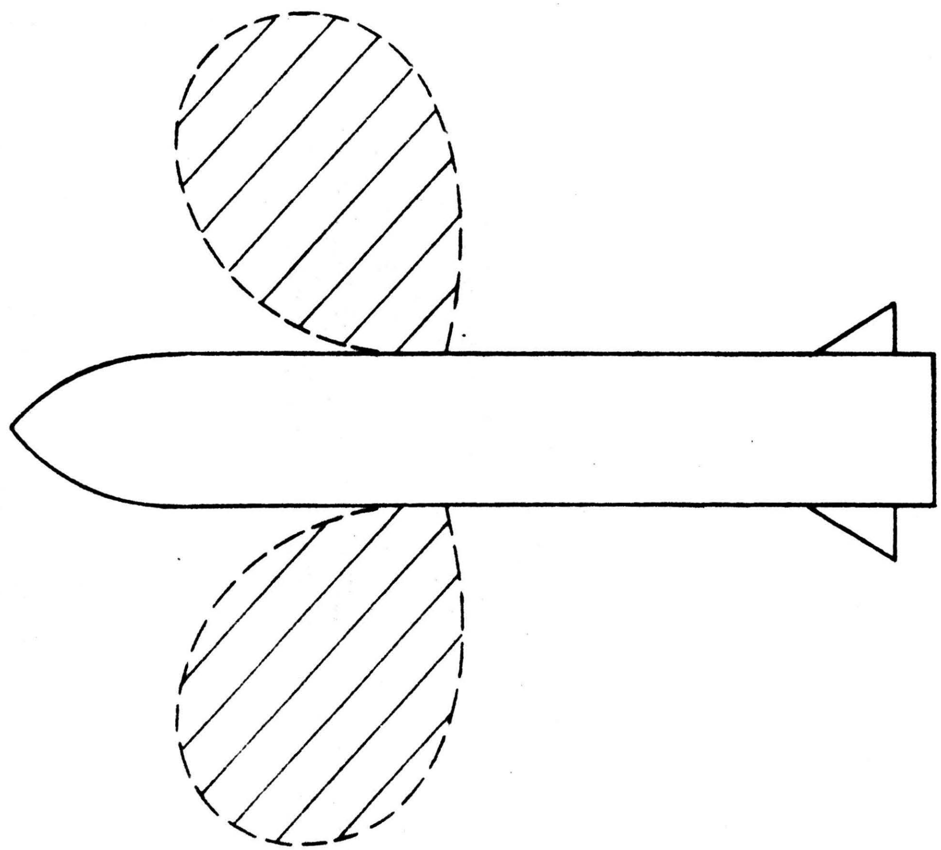


FIGURE 1

OMNIDIRECTIONAL PATTERN OF REVOLUTION
ABOUT THE LONGITUDINAL AXIS
OF THE MISSILE

perpendicular to the missile axis the pattern would be a circle.

For design purposes, the frequency of operation was set at 400 megacycles. The matching characteristics were designated to be such that the voltage standing wave ratio (VSWR) be less than 2 over a frequency range of plus or minus five percent of the operating frequency.

With the above requirements as a guide, several antenna configurations were investigated to determine which would do the job most satisfactorily. Three possibilities were considered. Each of the three configurations considered was of the flush-mounted variety.

The first antenna considered was the resonant slot antenna. This antenna has been treated extensively in literature. Included in the literature is an article describing the resonant slot antenna which was mounted on a missile to give a radiation pattern similar to that shown in Figure 1. The article was written by W. E. Barrik and D. L. Brannon.[1]

Another possibility considered was that of a Vee type slot excited by a dipole. This possibility evolved from the idea of wrapping a corner reflector about the missile so that it appears as a Vee shaped indention filled with dielectric. The sides of the corner reflector appear as the sides of the Vee-shaped slot. However, the lengths of the sides of the corner reflector are effectively extended by joining them to the outer surface of the missile. This

1. All references are in bibliography.

extension should improve the impedance characteristics over the characteristics of the same corner reflector located in free space without the extension. A starting point on the design of an antenna utilizing the Vee-shaped slot, which was suggested here, would be a very comprehensive set of contour graphs describing the characteristics of the corner reflector antenna. Such a set of experimental graphs illustrating impedance as a function of the variables, position of dipole, angle of aperature, width and length of the reflector was presented recently for the first time by H. V. Cottony and A. C. Wilson.[4]

The third possibility considered was that of a very thin sandwich antenna, which is illustrated in Figure 4 on page 12, mounted in such a way as to reduce wind resistance. This antenna was selected for the experimental investigation described in this thesis. The antenna is fully described in the next section.

Any one of the three possibilities appeared feasible from the preliminary investigation. The resonant slot, which has already been tested experimentally, was eliminated because it takes up a fairly large amount of inside volume of the missile. The dipole-fed Vee-slot was eliminated because rough preliminary calculations indicated that the volume taken up by the Vee-slot would exceed the volume of the resonant slot. Thus, the small volume sandwich antenna was chosen because it appeared to have good possibilities for application and because the experimental work would be original insofar as any available literature was concerned.

Scope of the Investigation

The small volume sandwich antenna was patterned after that of F. D. Clapp's which appears in an unpublished report[3] written for the United States Navy. Clapp's antenna is shown in Figure 2. The antenna described in this report was investigated at approximately one-thousandth of the volume of the original Clapp antenna. Clapp's antenna was designed for the 225-400 megacycle range; while the author's model was designed for operation at 400 megacycles.

The objective of this investigation was to build a small volume sandwich antenna which could be adapted to satisfy the characteristics listed on page 1. Since there was no information available in literature on the sandwich antenna at very small volumes, the experimental work described in this report was directed toward determining the antenna's characteristics at these very small volumes. In essence the experimental work described here was a feasibility study of the small volume sandwich antenna.

REVIEW OF LITERATURE

The antenna investigated in this thesis was based upon the work done by Clapp.[3] Figure 2 shows the end result of Clapp's work. Clapp's antenna was designed for a band of frequencies between 225 and 400 megacycles.

The radiation characteristics of the clapp antenna are investigated theoretically by H. E. Shanks.[8] By considering the electromagnetic waves to propagate between the top and bottom plates of the antenna in the manner of an infinite parallel plane transmission line, Shanks develops approximate equations for the radiation patterns. Neither Clapp nor Shanks attempted to develop theoretical equations for the impedance characteristics because of the complicated geometry and finite size of the antenna.

Clapp's antenna had a VSWR of less than 2 for frequencies varying from 225 megacycles up to 900 megacycles. Thus, it was a broad band antenna at these frequencies. However, decreasing frequency resulted in a high VSWR, beginning at 200 megacycles where the VSWR rose sharply to approximately 7 continuing to increase.

The radiation pattern was approximately a cardioid in the plane of the antenna. In the vertical plane the antenna had a radiation pattern as shown in Figure 3 which also illustrates the azimuthal pattern. In investigating the pattern at much lower frequencies, Clapp found that the pattern approached the shape of that of a vertical dipole.

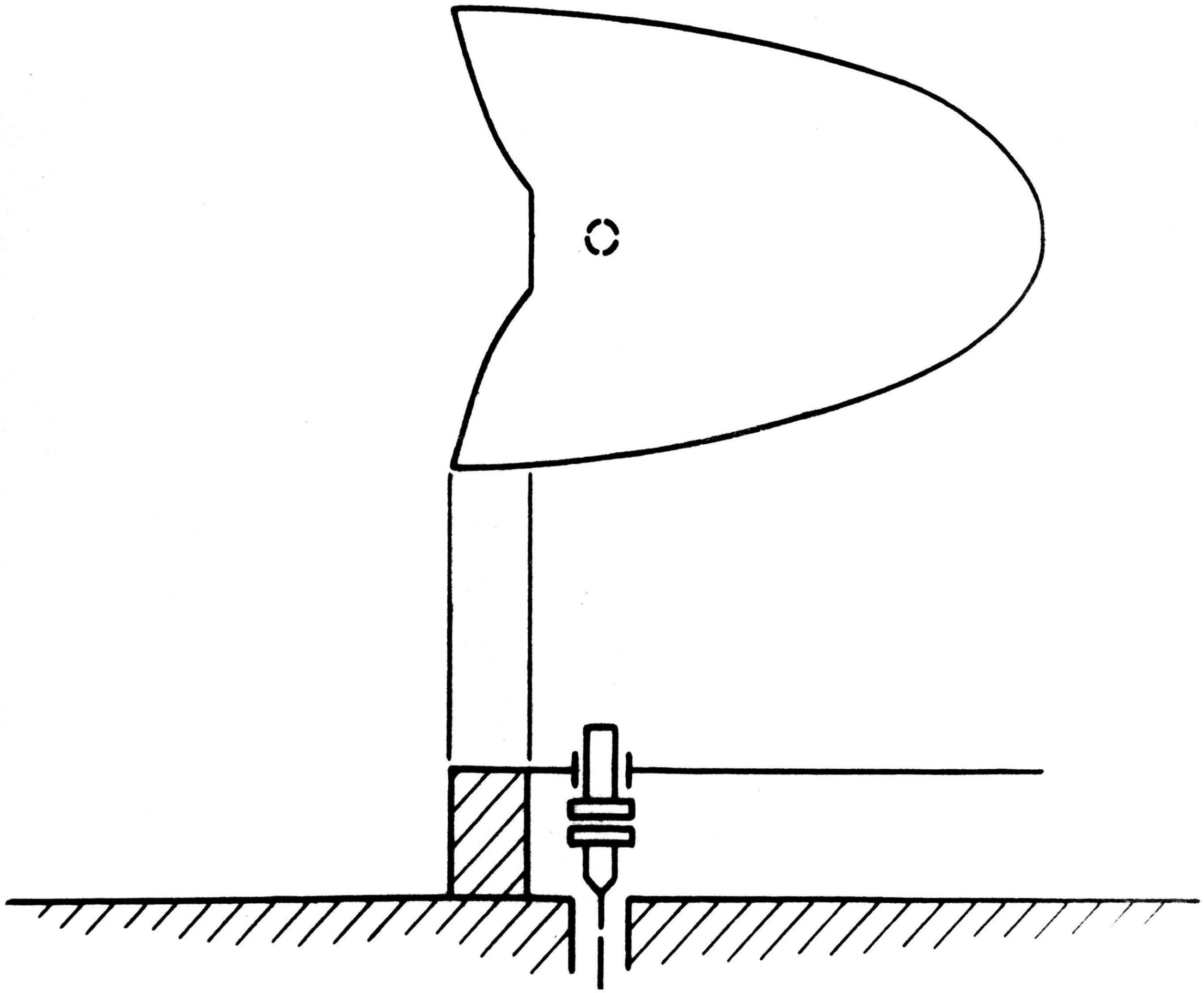
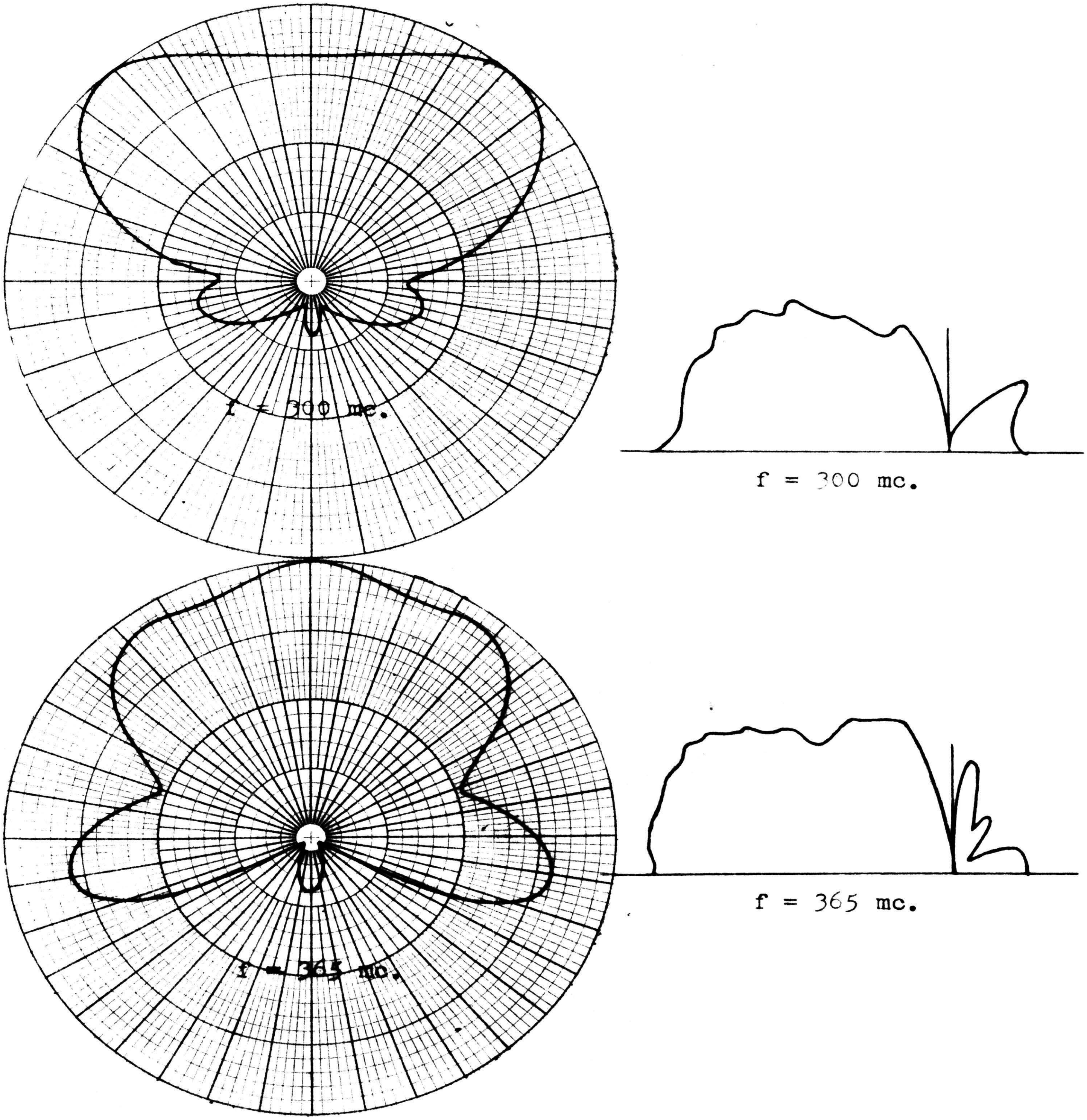


FIGURE 2

CLAPP'S SEMI-FLUSH-MOUNTED ANTENNA



AZIMUTH PATTERNS VERTICAL PATTERNS

FIGURE 3

APPROXIMATE RELATIVE PATTERNS OF CLAPP'S ANTENNA

For a dielectric filler Clapp used a material formed from epoxy resins and glass cloth known as "Hexcel". The antenna was fed with a standard RG9/U coaxial cable fastened to a type "n" connector serving as the antenna terminal. The capacitor shown in Figure 2 was used to tune out any inductive reactance.

There are several other antennas in existence which provide some insight into the operation of the small volume sandwich antenna. For example, the small volume sandwich antenna resembles the E-plane sectorial horn[2,6] in some respects. However, the location of the feed point of the sandwich antenna does not permit a usable definition of a flare angle upon which the theory of the sectorial horn is based. Also, the sectorial horn theory neglects currents flowing on the outside walls of the horn. For a sandwich antenna of dimensions much less than a wavelength these currents are prominent and cannot be neglected. As the dimensions of the small volume sandwich antenna increases, the characteristics do approach, to some extent, that of the sectorial horn with very large flare angles.

Another antenna found in literature is the flush disc antenna[5,7] which has characteristics similar to that of the small volume sandwich antenna. The flush disc antenna evolves from a top-loaded stub antenna. There is one major difference between the sandwich antenna and the flush disc antenna. The flush disc antenna is symmetrical about the feed, with the edges of the top plate at the same potential;

while the sandwich antenna may be unsymmetrical about the feed with one edge of the top plate at ground potential.

Dr. Robert Hansen of Hughes Aircraft Company was contacted to determine whether or not any other publications exist which pertain to the small volume sandwich antenna. He suggested the investigation of a partial sleeve antenna developed at the University of Illinois. Subsequent correspondence with the University of Illinois revealed the fact that the work on the partial sleeve antenna was done under government contract and was classified. Consequently, this possible source of information was not available to the author. This source is included here because the information is available to persons with security clearance and the need to know. There is also the possibility that the work may become declassified at a later date.

THE EXPERIMENTAL ANTENNA AND TEST EQUIPMENT

The experimental sandwich antenna used in this investigation was of rectangular shape with the width and length dimensions variable. The width was varied between 8 and 9 inches, the length from 3 to 7 inches, and the depth from a constant 1/4 inch to a tapering depth between 1/4 inch and 3/8 inch. The experimental antenna is shown in Figure 4, Figure 5, and Figure 6.

The length and width dimensions were decreased by simply sawing the antenna with a bandsaw to its new dimensions. This required that the antenna first be built to its maximum size and then systematically reduced by sawing off measured amounts. Obtaining the data presented here necessitated the building of four separate antennas.

The antenna was mounted on a rectangular ground plane of width approximately 3.5 wavelengths by length of 4 wavelengths. A photograph of the antenna shown mounted on the ground plane is presented in Figure 6. The ground plane was fabricated from copper-plated steel and copper wire mesh.

The antenna was mounted on the ground plane in such a way that the feed probe could be moved along a four inch slot to vary its position in the antenna. This was accomplished by soldering two copper plates on to the ground plane leaving a secondary slot just large enough to accomodate a type "n" chassis connector which served as the antenna terminals. This arrangement is shown in Figure 7.

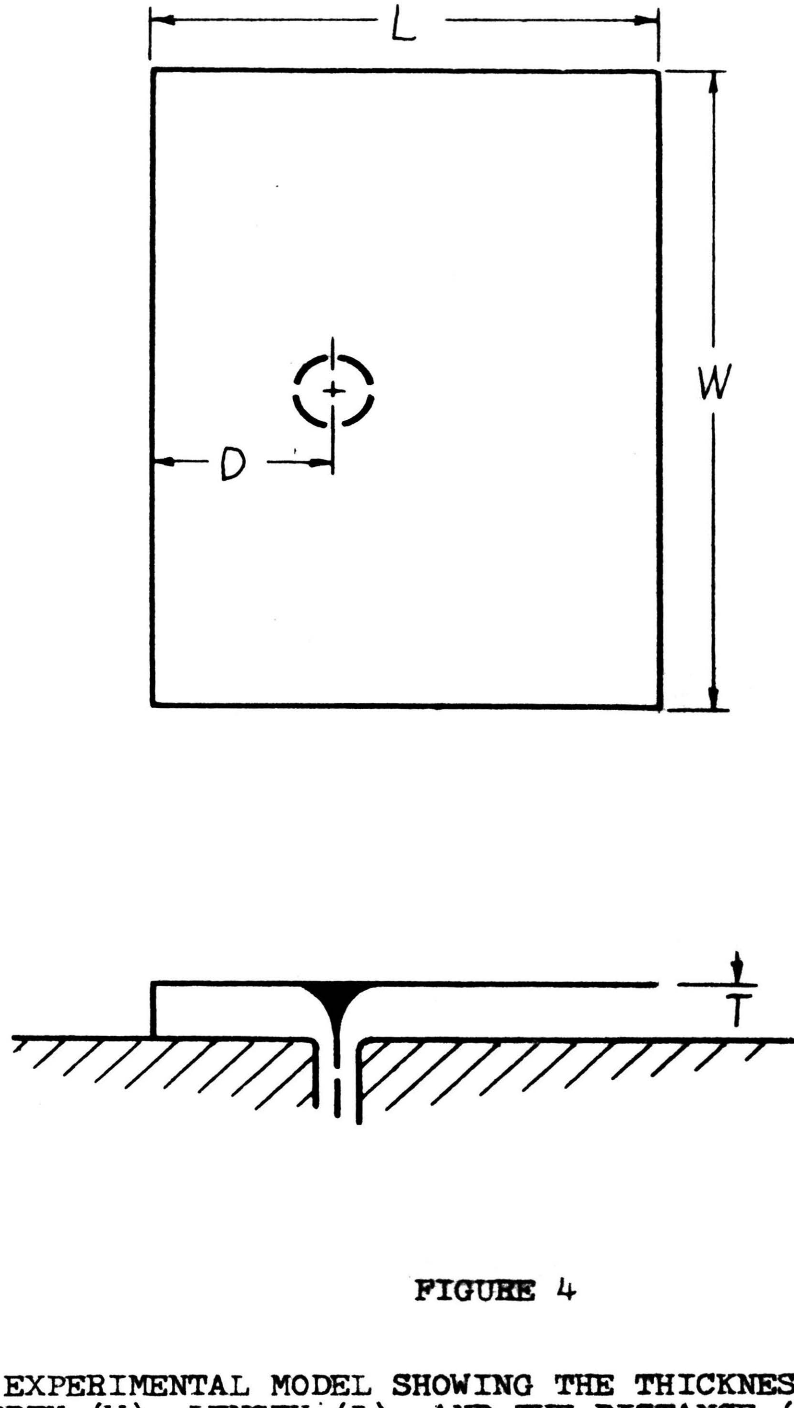


FIGURE 4

THE EXPERIMENTAL MODEL SHOWING THE THICKNESS (T), WIDTH (W), LENGTH (L), AND THE DISTANCE (D) OF THE FEED POINT FROM THE REAR OF THE ANTENNA

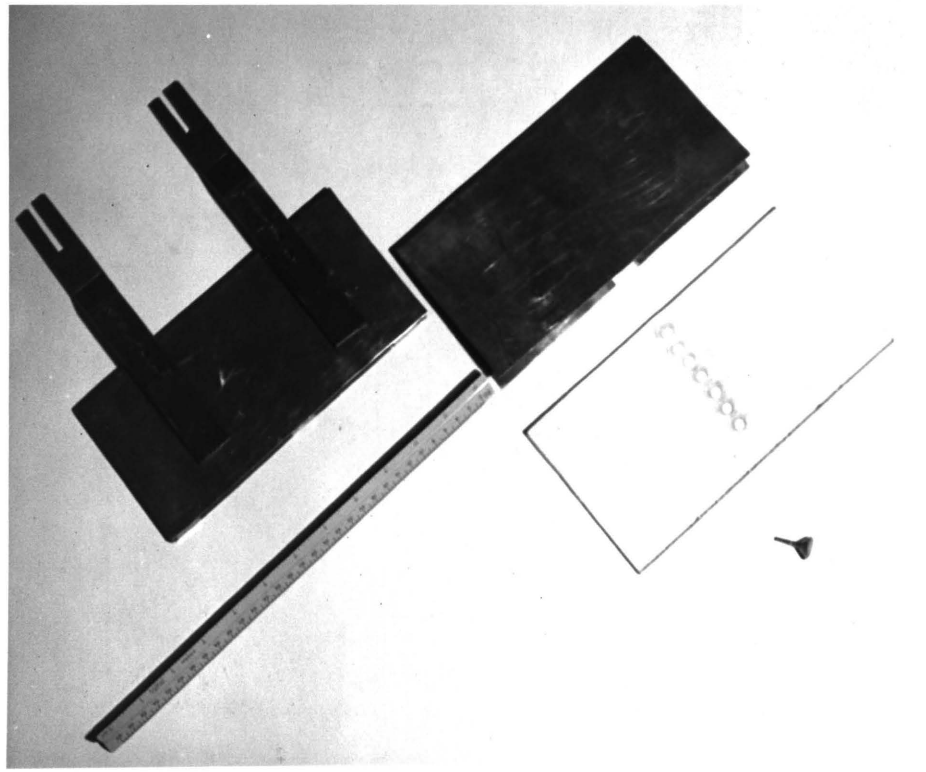


FIGURE 5

THE SMALL VOLUME SANDWICH ANTENNA ASSEMBLED (AT LEFT) WITH HOLDING CLAMPS AND DISASSEMBLED (AT RIGHT) SHOWING THE COPPER PLATES, THE DIELECTRIC FILLER AND THE TAPERED FEED PROBE

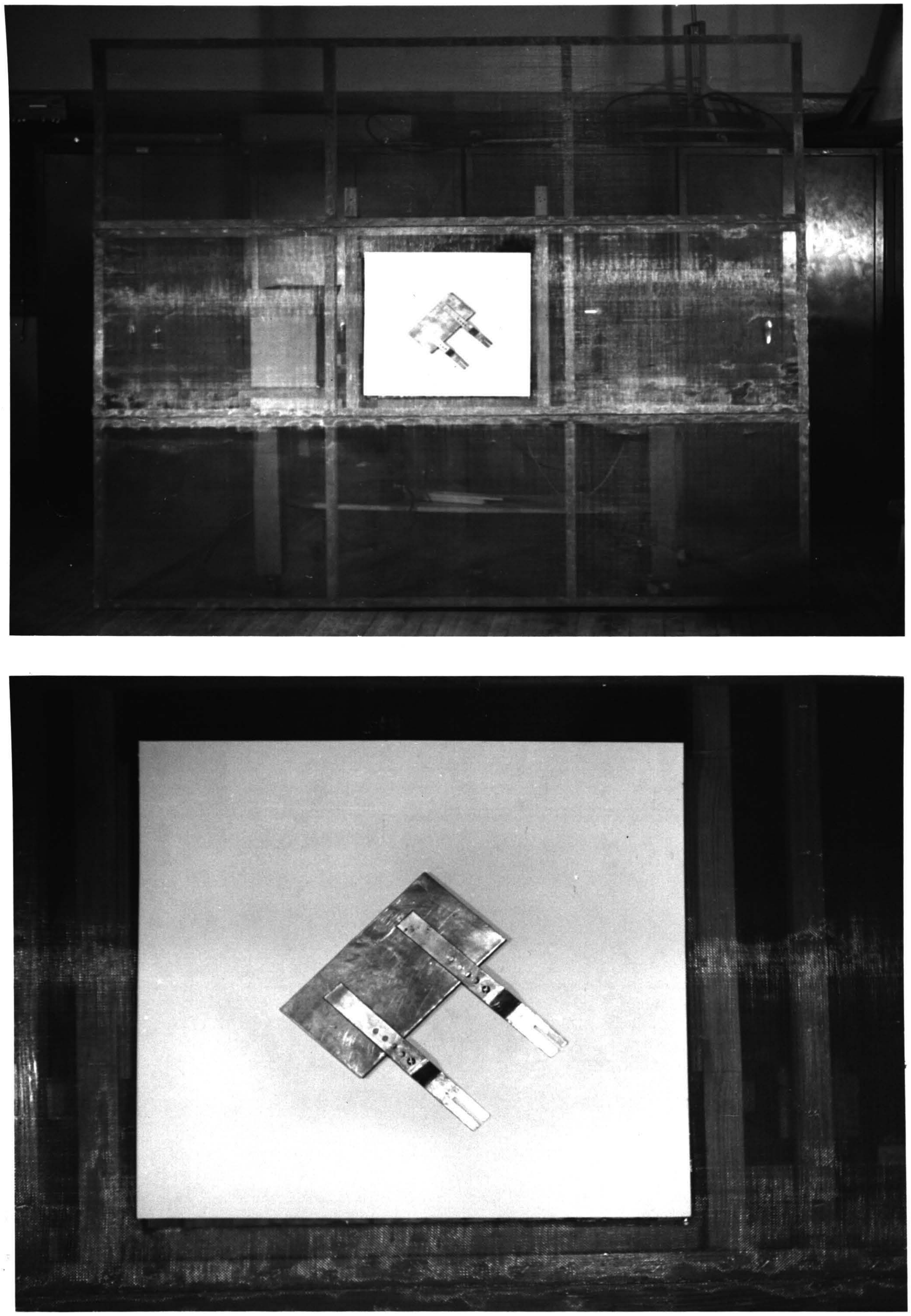


FIGURE 6

SMALL VOLUME SANDWICH ANTENNA SHOWN
MOUNTED ON GROUND PLANE

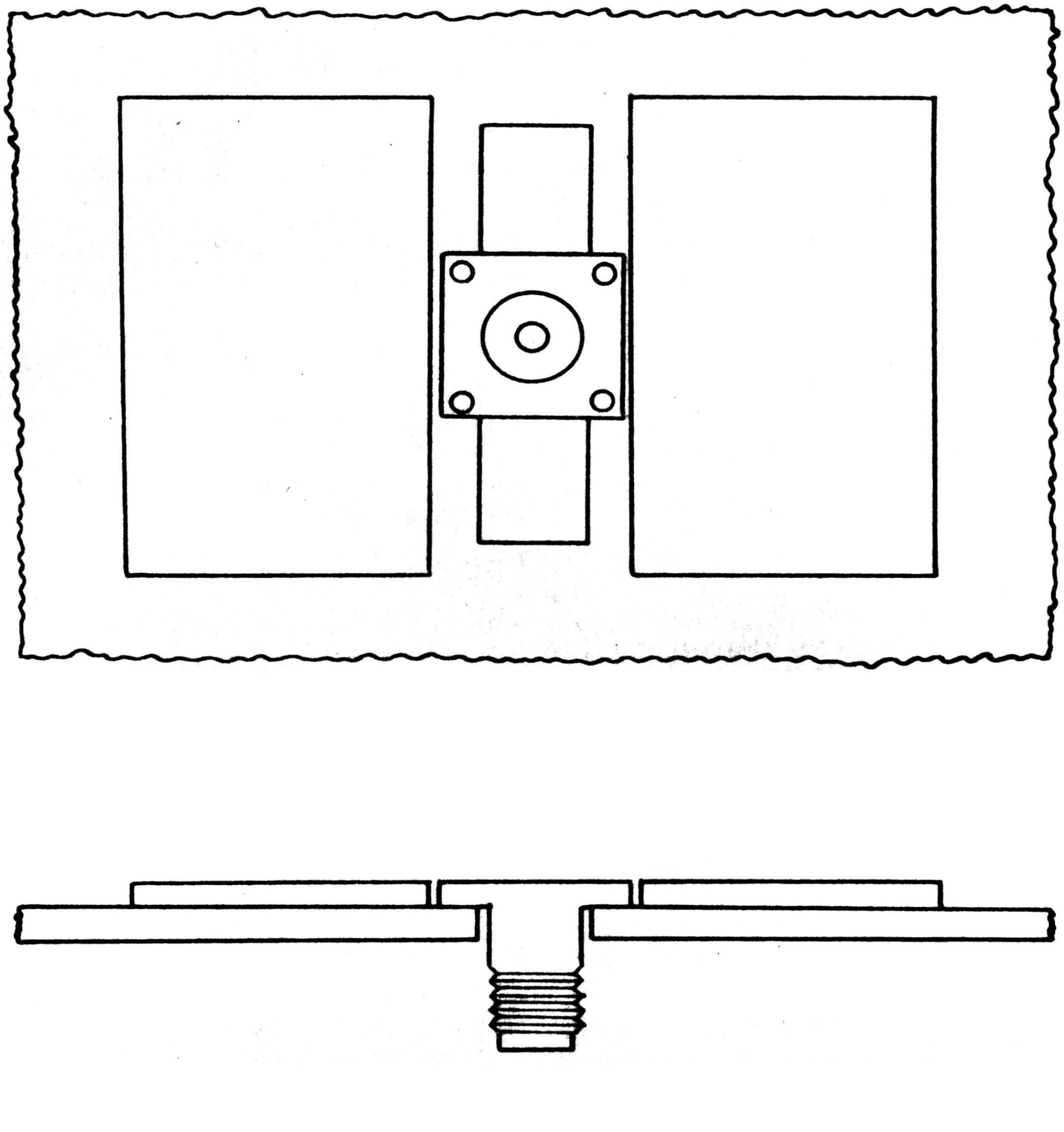


FIGURE 7

SKETCH ILLUSTRATING THE METHOD OF FLUSH-MOUNTING THE MOVABLE FEED PROBE

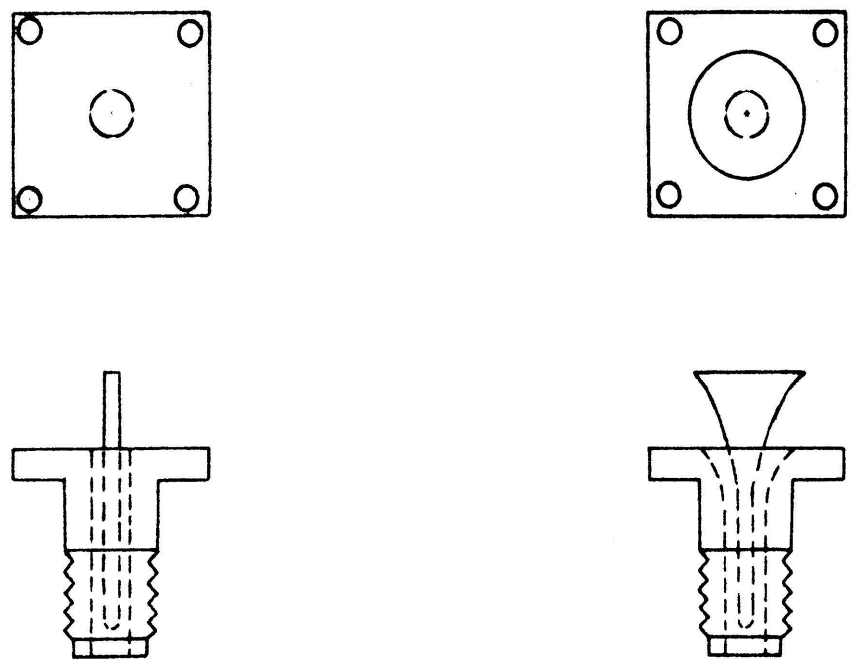
The space not taken up by the type "n" chassis connector was filled with metal. Thus, the bottom plate of the antenna lay on a flat surface with the terminals of the antenna being essentially a part of the ground plane.

The model was held securely to the ground plane by clamps. These clamps are shown in Figure 5 and Figure 6. Note that in Figure 6 the antenna is mounted with its axis along a diagonal of the ground plane. This was done so that reflection from the discontinuity at the edge of the finite ground plane would not return to the antenna in phase.

Two feed probes were tried during this investigation. The first was a standard type "n" chassis connector with the second being a type "n" connector modified to have a taper such that the diameter of the outer conductor increased with the increase in the diameter of the inner conductor. In both cases the inner conductor served as the feed probe. Both are shown in Figure 8.

The dielectric used in the model was polystyrene which has a relative dielectric constant of 2.53. The 1/4 inch thick sheet of polystyrene had tapered feed holes located every 1/4 inch along the center line of the longitudinal axis. These holes are shown in Figure 5 with the feed probe which fits into the holes.

The experimental setup was located within a first floor room with metal lath located in both the ceiling and the floor. Thus, there was some mutual coupling between these metal objects and the antenna.



STANDARD CONNECTOR MODIFIED CONNECTOR

FIGURE 8

The test circuit diagram is shown in Figure 9. The variable frequency carrier wave transmitter was a T-9/APQ-2 modulated by a Hewlett-Packard Model 200 AB audio oscillator. The modulating frequency was 1000 cycles per second. A Model 360A Hewlett-Packard low-pass filter with a cutoff frequency of 700 megacycles was used to eliminate harmonics. With the antenna input impedance of any value other than the characteristic impedance of the line, a standing wave of voltage existed everywhere along the line. The Hewlett-Packard Model 415A standing wave indicator was used in conjunction with the Model 805A Hewlett-Packard slotted line to measure directly the voltage standing wave ratio. The position of the null was measured with a vernier located on the slotted line. The frequency was measured with a cavity type TS 69(XA)/AP frequency meter.

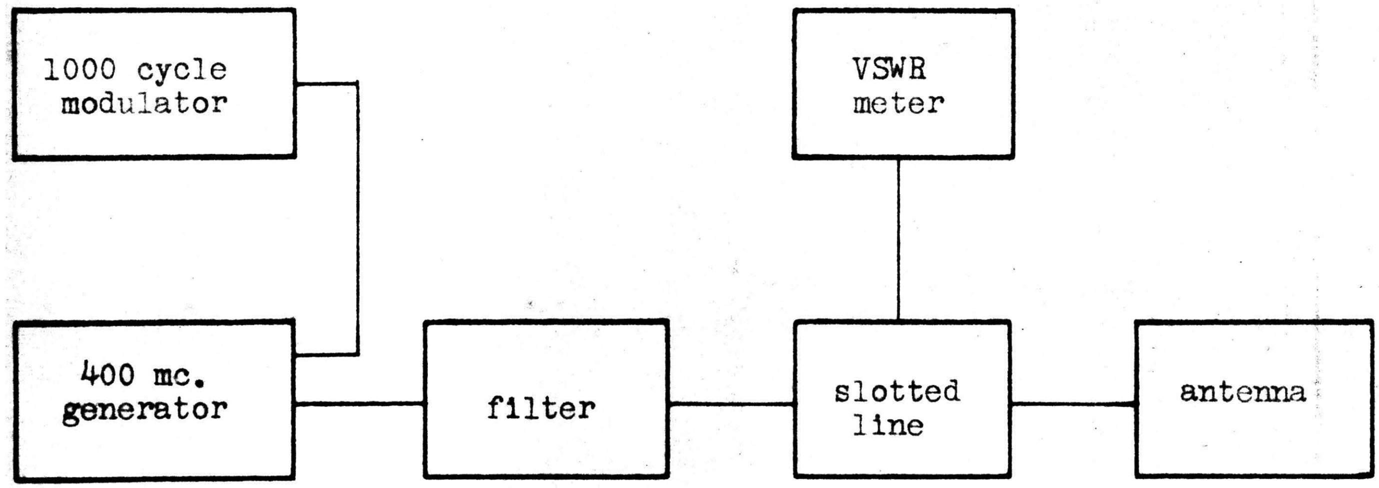


FIGURE 9

BLOCK DIAGRAM OF THE CIRCUIT
USED IN THE EXPERIMENT

EXPERIMENTAL RESULTS

I. Results of Early Work

The first phase of the experimental work was an attempt to obtain a match in the region of length variable between 3 and 4 inches, width variable between 8 and 10 inches thickness equal to 1/4 inch constant. All VSWR's obtained were greater than 18. However, several observations of note were recorded. First, varying the width from 8 to 10 inches had little effect on the VSWR or the position of the null. Thus, in this region the width was not a determining factor. Second, inconsistent readings were obtained because the top plate made of copper sheet had a tendency to wrinkle. This indicated that the thickness of the antenna was important in determining the impedance. Because of the original inconsistency, later models were made of 22 gauge copper plate. Third, in an attempt to speed up the rate of taking data by adding a plate between the top plate of the antenna and the fastening clamps, a good match was obtained when the top plate was extended to a length of about 7 inches. Fourth, the time required to obtain one reading was approximately 20 minutes resulting from the necessity of disassembling and reassembling the antenna for each reading.

Because of the observations recorded in the foregoing paragraph, the objectives of the investigation were altered slightly. The combination of the effect of negligible change in impedance with width between 8 and 10 inches and the time consuming method of obtaining readings led to the restricting of the width to a constant value of 8.5 inches. Because of the good match obtained with the added top plate, the maximum length was extended to 8 inches.

The second model built had dimensions of width and thickness constant at 8.5 and 0.25 inches respectively. The length was systematically reduced from 8 to 4 inches with the resulting VSWR remaining above 4:1. These data did not bear out the conclusion that added length was the only change necessary. Subsequent investigation proved that a slight increase in depth toward the front of the antenna was necessary for matching.

At this point of the investigation, the feed probe was modified in such a way that the inner conductor increased gradually as the outer conductor was faired into the bottom plate of the antenna. This gave an improved VSWR reading over that of the unmodified feed. At the point tested, the VSWR improved from 10 to 4.6. No attempt was made to optimize this improvement because of the precision machine work required and the time involved in building and testing each feed.

From the results of the early work done, the requirements for the final two models were established. As mentioned above, the length was increased, the width held constant; an improved feed probe was made; and the copper plate was made heavier. One other improvement was made for the final data taking runs. Heavier and longer mounting straps with holes for varying positions were made and tested. These straps allowed a more uniform pressure to be exerted on the antenna top plate and, thus, reduce error due to slight variations in the antenna depth, which was very critical. Tests revealed no noticeable effect on impedance due to increasing the size of the holding straps.

II. Impedance Results

Effect of Varying Length of Antenna

The effect of varying the length of the antenna was established at the same time as that of varying the probe position. The antenna impedance was measured at each size of antenna for 1/4 inch changes of the feed probe position. The antenna was then cut down to a shorter length and the measurements repeated. After all measurements had been completed, the impedances were calculated with the aid of a Smith Impedance Chart. Table I, Figure 10, and Figure 11 exhibit the characteristic of varying the length of the antenna for a constant width of 8.5 inches, a constant thickness of 0.25 inches, and for various constant values of probe position.

For the width of 8.5 inches, the thickness 0.25 inches, and the length variable between 4.25 inches and 5.75 inches, and any constant probe position, the input resistance of the

TABLE I

EXPERIMENTAL IMPEDANCE RESULTS WITH LENGTH OF THE ANTENNA AS THE VARIABLE

W = 8.5 in., T = 0.25 in., f = 400 mc.

(1) D = 1.0 in.

L (in.)	R (ohms)	X (ohms)
4.25	1.0	+13.2
4.50	5.0	+34.0
4.75	17.5	+33.5
5.00		- 4.5
5.25		0.0
5.50		+ 5.0
5.75		+ 5.0

(2) D = 1.5 in.

L (in.)	R (ohms)	X (ohms)
4.25	1.9	+18.1
4.50	7.0	+35.0
4.75	30.5	+65.3
5.00	3.00	-17.0
5.25	0.75	- 2.5
5.50	0.05	+ 1.5
5.75		+ 4.5

TABLE I (continued)

(3) D = 2.0 in.

L (in.)	R (ohms)	X (ohms)
4.25	2.5	+23.8
4.50	8.1	+46.5
4.75	85.5	+108.0
5.00	4.80	-26.5
5.25	1.50	- 8.2
5.50	0.25	- 3.1
5.75		+ 0.3

(4) D = 2.5 in.

L (in.)	R (ohms)	X (ohms)
4.25	4.5	+ 35.8
4.50	11.3	+ 61.5
4.75	170.0	+160.0
5.00	5.00	- 34.5
5.25	1.60	- 15.0
5.50	0.50	- 5.5
5.75		- 0.3

TABLE I (continued)

(5) D = 3.0 in.

L (in.)	R (ohms)	X (ohms)
4.25	6.0	+ 41.5
4.50	12.5	+ 71.0
4.75	165.0	+200.0
5.00	6.50	- 48.5
5.25	1.60	- 21.3
5.50	0.90	- 11.7
5.75		- 5.0

(6) D = 3.5 in.

L (in.)	R (ohms)	X (ohms)
4.25	8.0	+ 49.0
4.50	12.5	+ 77.0
4.75	72.0	+175.0
5.00	21.50	- 84.0
5.25	1.60	- 25.0
5.50	1.60	- 16.5
5.75	0.50	- 9.0

INPUT REACTANCE OF ANTENNA VERSUS LENGTH OF THE ANTENNA
FOR CONSTANT VALUES OF FEED PROBE POSITION

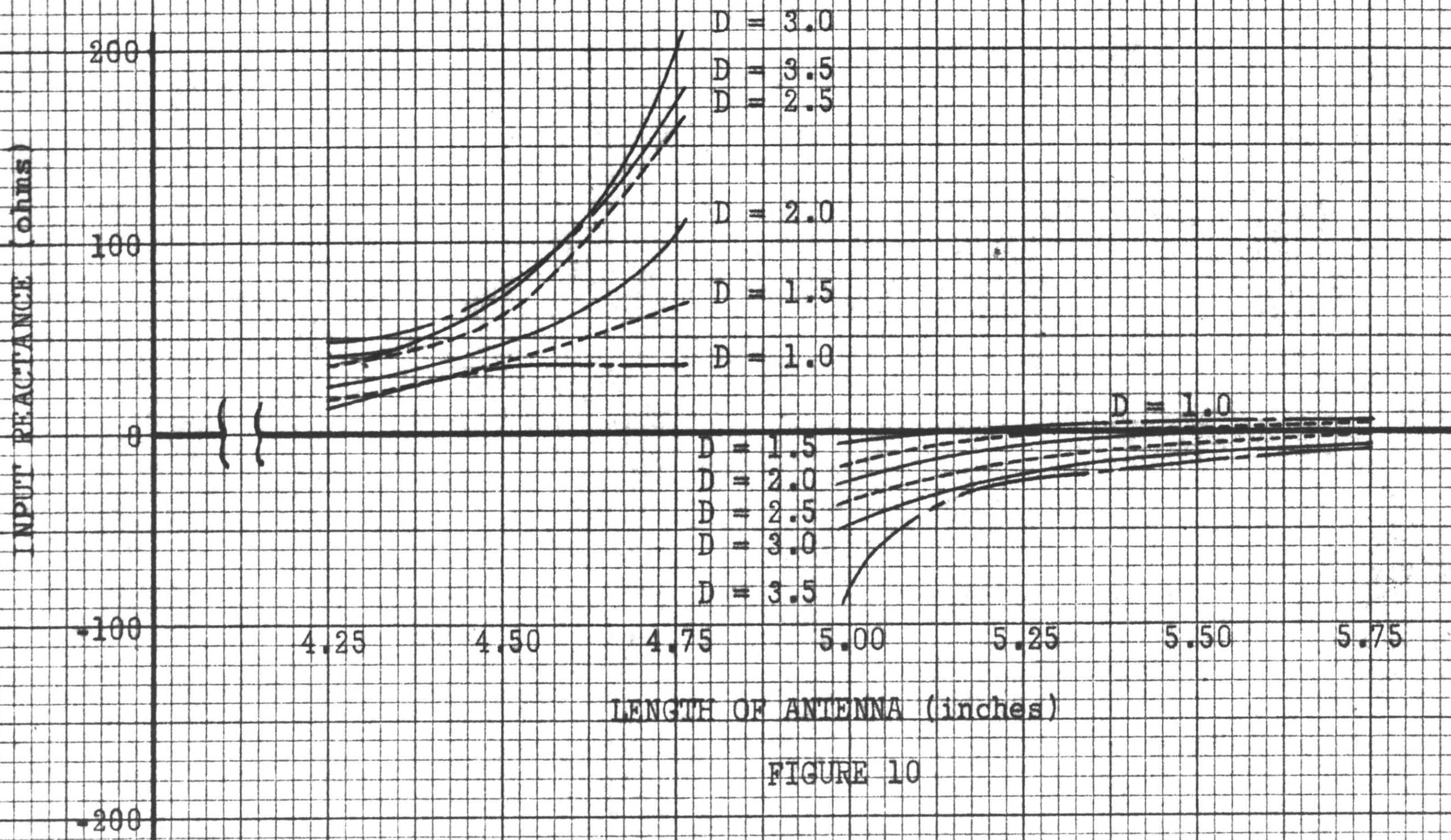


FIGURE 10

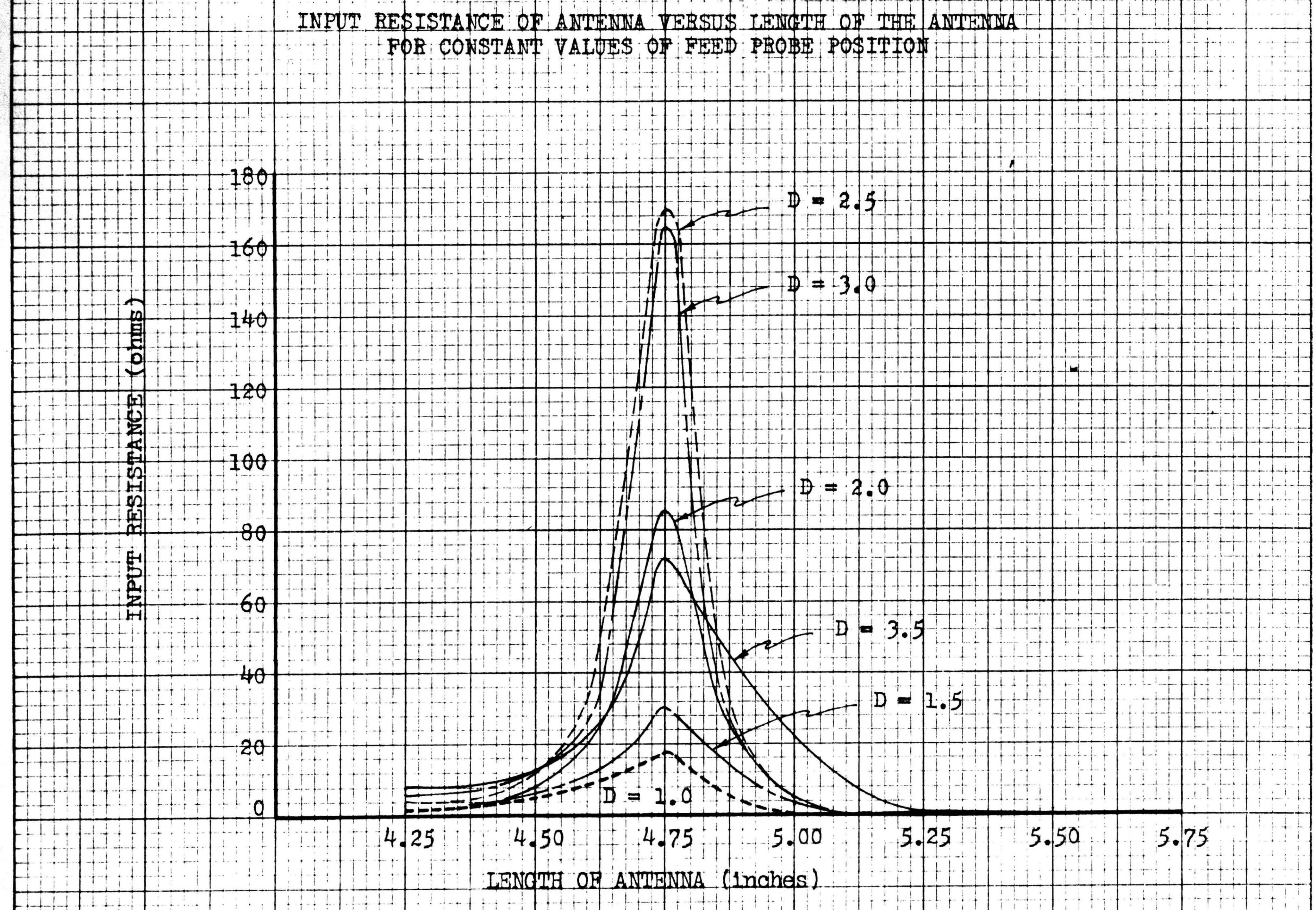

INPUT RESISTANCE OF ANTENNA VERSUS LENGTH OF THE ANTENNA
FOR CONSTANT VALUES OF FEED PROBE POSITION
INPUT RESISTANCE (ohms)
180
160
140
120
100
80
60
40
20
0
D = 2.5
D = 3.0
D = 2.0
D = 3.5
D = 1.5
D = 1.0
4.25
4.50
4.75
5.00
5.25
5.50
5.75
LENGTH OF ANTENNA (inches)

FIGURE 11

antenna reached a sharp maximum at a length of approximately 4.75 inches. This peak is illustrated in Figure 11 and Table I. On both sides of the maximum the resistance fell off toward zero. The sharp peak in resistance occurred at the point of high energy storage in the inductive field, as can be seen in Figure 10 and Table I. At a slightly increased length the reactance changed abruptly from a high inductive reactance to capacitive reactance. Both figures indicate a resonating effect in this region.

Effect of Varying Probe Position

The effect of varying the feed probe position is interrelated with the length dimension. Figure 12, Figure 13, and Table II show that for the longer lengths there is very little change in reactance with change in feed position. For the shorter lengths, however, there is a fairly large change in reactance with a change in feed position. At lengths above 4.75 inches the reactance becomes more capacitive when increasing the feed distance from the rear of the antenna. At lengths 4.75 inches and shorter the reactance becomes more inductive with an increase in the distance of the feed point from the rear of the antenna.

Table II and Figure 13 display very well one noteworthy fact concerning the resistive component of the input impedance. The resistance tends to increase with an increase in feed distance for all lengths. However, the magnitude of the increase is dependent upon the length of the antenna.

TABLE II

EXPERIMENTAL IMPEDANCE RESULTS WITH FEED PROBE POSITION AS THE VARIABLE

W = 8.5 in., T = 0.25 in., f = 400 mc.

(1) L = 4.25 in.

D (in.)	R (ohms)	X (ohms)
1.0	1.0	+13.2
1.5	1.9	+18.1
2.0	2.5	+23.8
2.5	4.5	+35.8
3.0	6.0	+41.5
3.5	8.0	+49.0

(2) L = 4.50 in.

D (in.)	R (ohms)	X (ohms)
1.0	5.0	+34.0
1.5	7.0	+35.0
2.0	8.1	+46.5
2.5	11.3	+61.5
3.0	12.5	+71.0
3.5	12.5	+77.0

TABLE II (continued)

(3) L = 4.75 in.

D (in.)	R (ohms)	X (ohms)
1.0	17.5	+ 33.5
1.5	30.5	+ 65.3
2.0	85.5	+108.0
2.5	170.0	+160.0
3.0	165.0	+200.0
3.5	72.0	+175.0

(4) L = 5.0 in.

D (in.)	R (ohms)	X (ohms)
1.0	0	- 4.5
1.5	3.0	-17.0
2.0	4.8	-26.5
2.5	5.0	-34.5
3.0	6.5	-48.5
3.5	21.5	-84.0

TABLE II (continued)

(5) L = 5.25 in.

D (in.)	R (ohms)	X (ohms)
1.0	0.25	0
1.5	0.75	- 2.5
2.0	1.50	- 8.2
2.5	1.60	-15.0
3.0	1.60	-21.3
3.5	1.60	-25.0

(6) L = 5.5 in.

D (in.)	R (ohms)	X (ohms)
1.0	0	+ 5.0
1.5	0.05	+ 1.5
2.0	0.25	- 3.1
2.5	0.50	- 5.5
3.0	0.90	-11.7
3.5	1.60	-16.5

TABLE II (continued)

(7) L = 5.75 in.

D (in.)	R (ohms)	X (ohms)
1.0	0	+5.0
1.5		+4.5
2.0		+0.3
2.5		-0.3
3.0		-5.0
3.5	0.5	-9.0

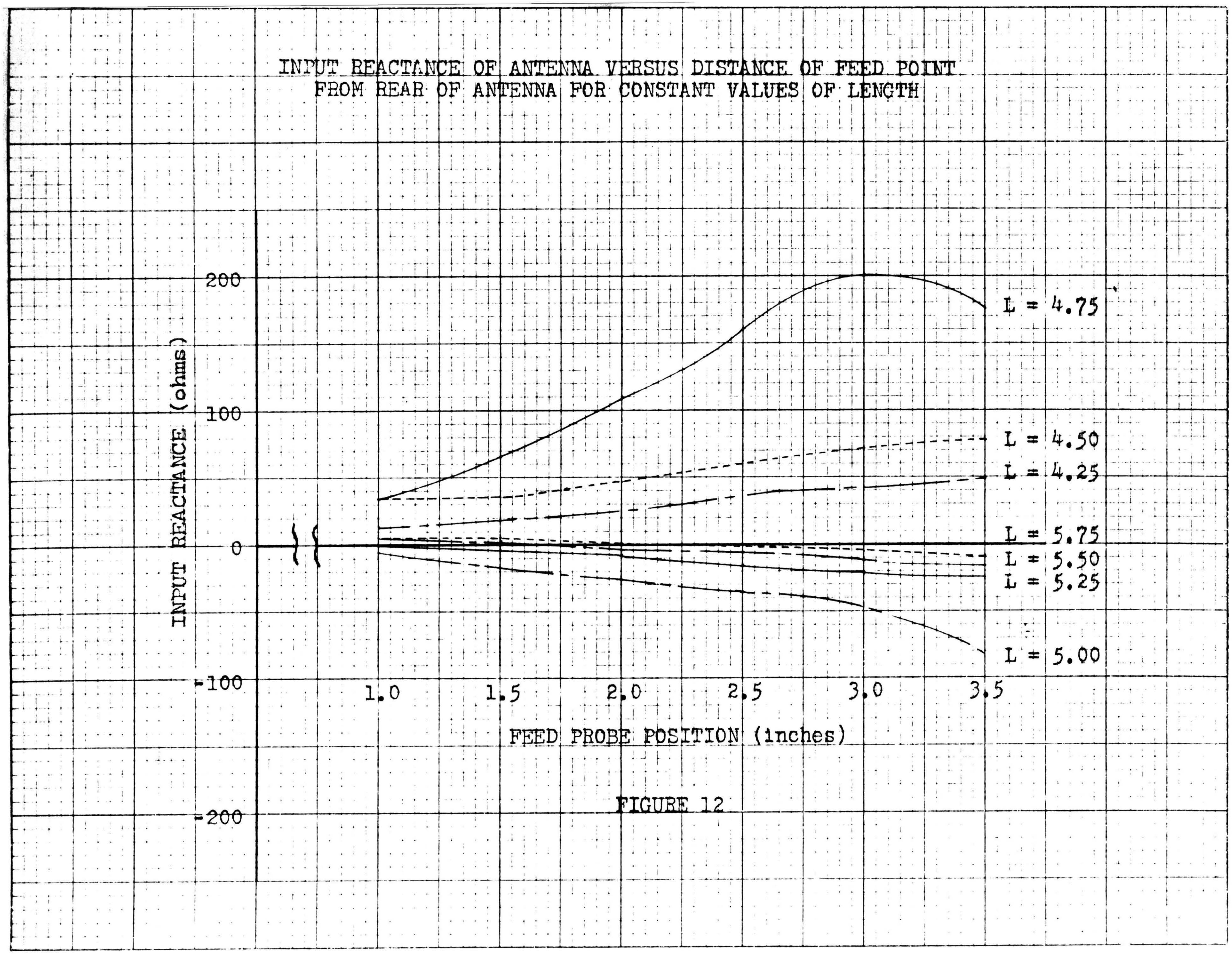

INPUT REACTANCE OF ANTENNA VERSUS DISTANCE OF FEED POINT FROM REAR OF ANTENNA FOR CONSTANT VALUES OF LENGTH
INPUT REACTANCE (ohms)
200
100
0
-100
-200
1.0
1.5
2.0
2.5
3.0
3.5
FEED PROBE POSITION (inches)
L = 4.75
L = 4.50
L = 4.25
L = 5.75
L = 5.50
L = 5.25
L = 5.00

FIGURE 12

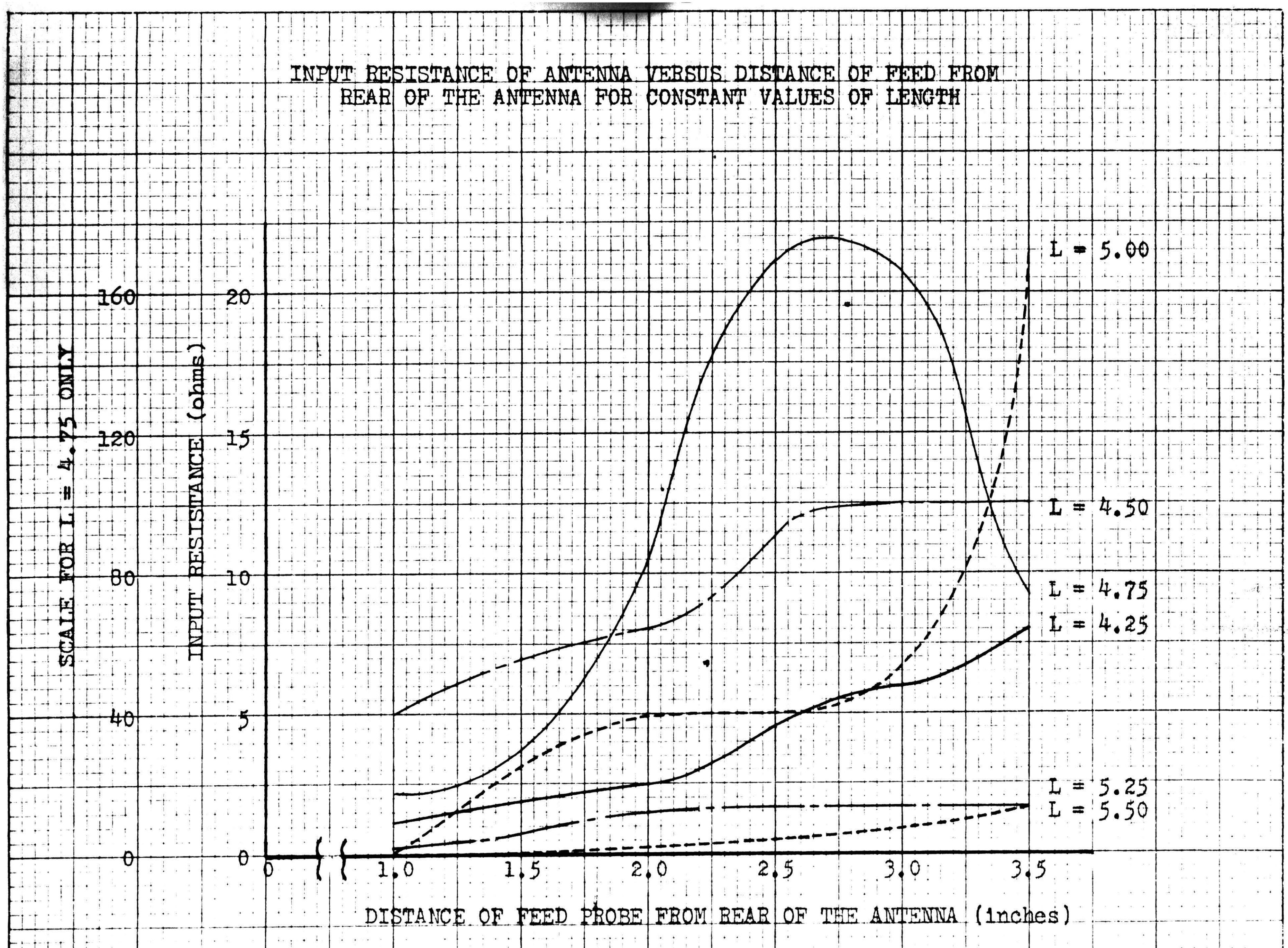

INPUT RESISTANCE OF ANTENNA VERSUS DISTANCE OF FEED FROM
REAR OF THE ANTENNA FOR CONSTANT VALUES OF LENGTH
SCALE FOR L = 4.75 ONLY
INPUT RESISTANCE (ohms)
160
120
80
40
0
20
15
10
5
0
0
1.0
1.5
2.0
2.5
3.0
3.5
L = 5.00
L = 4.50
L = 4.75
L = 4.25
L = 5.25
L = 5.50
DISTANCE OF FEED PROBE FROM REAR OF THE ANTENNA (inches)

FIGURE 13

Effect of Tapering Top Plate

When the length of the antenna was greater than 4.75 inches, a slight increase in the thickness of the antenna toward the front brought about a condition of good match. In other words, the VSWR approached 1 with a slight taper in thickness of the top plate. Greater length of the antenna required a correspondingly larger increase in the taper to obtain a good match.

Figure 14 and Figure 15 illustrate the extent of matching obtained by the slight taper. Table III, which lists the change in impedance with frequency, may be used as a guide for scaling the antenna to a slightly larger or smaller size. The effect of tapering gave no improvement for lengths of 4.75 inches and shorter.

Bandwidth

Figure 14, Figure 15, and Table III illustrate the bandwidth of the small volume sandwich antenna. The bandwidth proved to be quite narrow with a total expected bandwidth of about ten megacycles for a VSWR of 1.10 at the center frequency. This is using the original specification of VSWR less than 2.0 as the bandwidth limit.

Pattern

The radiation pattern was not recorded because of the amount of time required to set up the equipment out of doors. A check was made inside the laboratory in an attempt to determine the general shape of the pattern. A crystal

TABLE III

BANDWIDTH DATA

(1) W = 8.5 in., L = 5.0 in., D = 1.0 in., T = 0.25 for L less than 3.5 in., tapering from T = 0.25 at L = 3.5 to T = 0.281 at L = 5.0

VSWR	f (mc.)	R (ohms)	X (ohms)
9.10	416	5.0	0
6.70	414	7.7	- 1.5
4.50	412	11.2	- 5.7
3.30	410	15.5	- 7.9
3.15	409	16.7	-10.3
2.70	408	19.4	-11.0
2.40	407	26.5	-24.0
1.85	406	31.5	-17.5
1.58	405	39.0	-17.0
1.44	404	42.0	-15.0
1.30	403	47.5	-13.0
1.15	402	57.0	- 1.5
1.18	401	59.0	0
1.34	400	60.0	+12.5
1.52	399	54.0	+21.0
1.80	398	46.0	+27.5
2.25	397	36.0	+32.0
2.60	396	29.0	+31.5
4.00	395	18.8	+32.0
5.00	394	13.5	+27.5
6.80	393	10.0	+27.0
8.40	392	7.9	+25.5
15.00	390	4.0	+18.2
18.50	388	3.5	+15.0

TABLE III (continued)

BANDWIDTH DATA

(2) W = 8.5, L = 5.75 in., D = 2.0 in., T = 0.25 for L less than 4 in., tapering from T = 0.25 at L = 4.0 in. to T = 0.438 at L = 5.75 in.

VSWR	f (mc.)	R (ohms)	X (ohms)
8.00	412	22.5	- 84.0
5.90	410	44.0	- 95.0
4.40	408	100.0	-105.0
3.00	406	140.0	- 32.0
2.70	405	130.0	+ 25.0
2.30	404	109.0	+ 25.0
2.00	403	75.0	+ 35.0
1.80	402	53.5	+ 30.5
1.50	401	43.0	+ 17.0
1.40	400	42.5	+ 13.5
1.80	399	31.0	+ 13.0
2.30	398	23.0	+ 10.5
2.80	397	18.0	0
3.80	396	13.5	+ 2.0
4.10	395	13.0	- 2.0
4.50	394	12.5	- 5.0
5.00	393	10.0	- 5.4
5.60	392	9.3	- 9.5
6.60	390	8.0	- 12.3
7.80	388	7.0	- 17.0

BANDWIDTH CHARACTERISTIC OF ANTENNA FOR

(1) W = 8.5 in., L = 5.0 in., D = 1.0 in., T = 0.25 for L less than 3.5 in., tapering from T = 0.25 at L = 3.5 to T = 0.281 at L = 5.0 in.

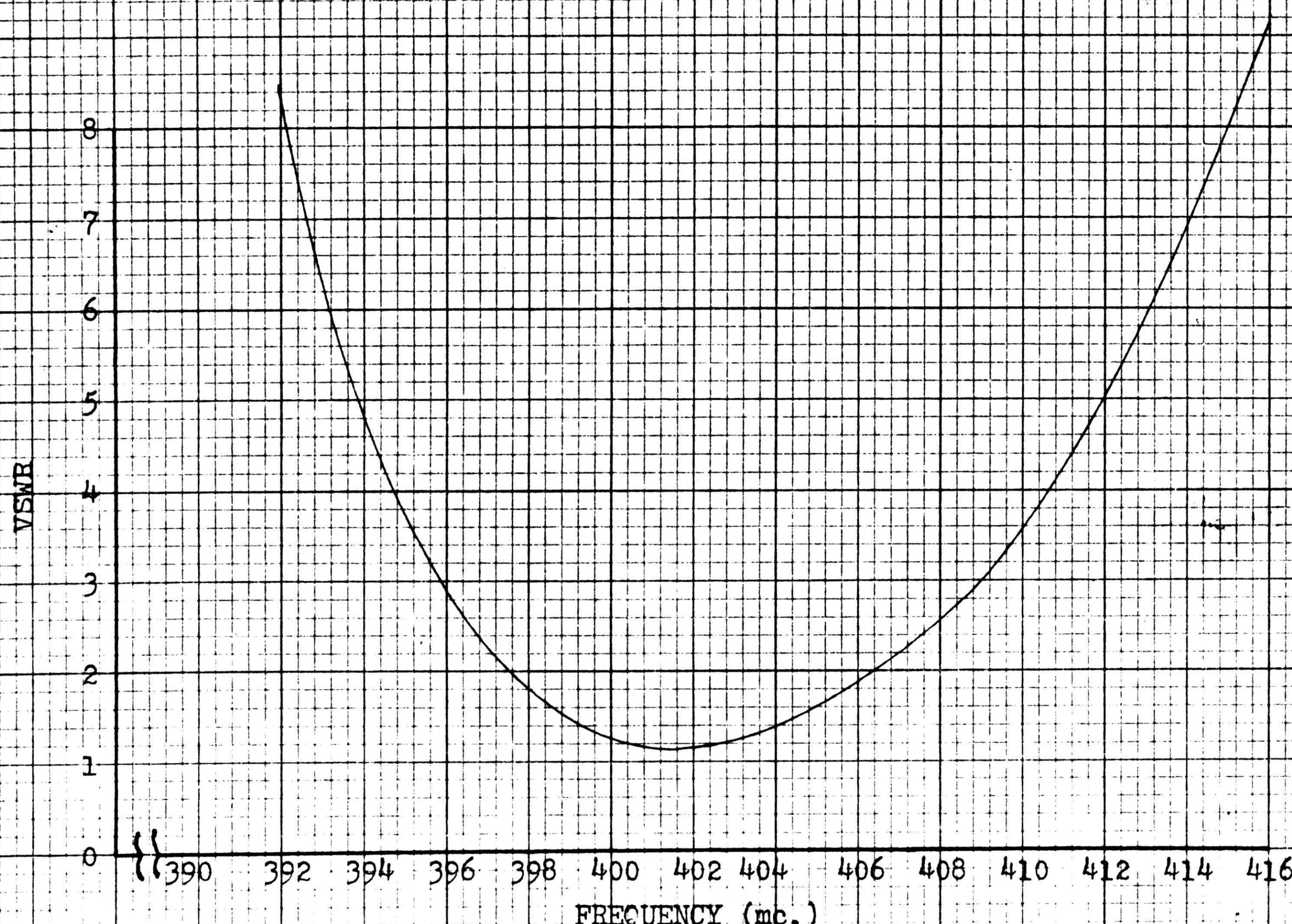


FIGURE 14

BANDWIDTH CHARACTERISTIC OF ANTENNA FOR

(2) W = 8.5 in., L = 5.75 in., D = 2.0 in., T = 0.25 for L less than 4 in., tapering from T = 0.25 at L = 4.0 in. to T = 0.438 at L = 5.75 in.

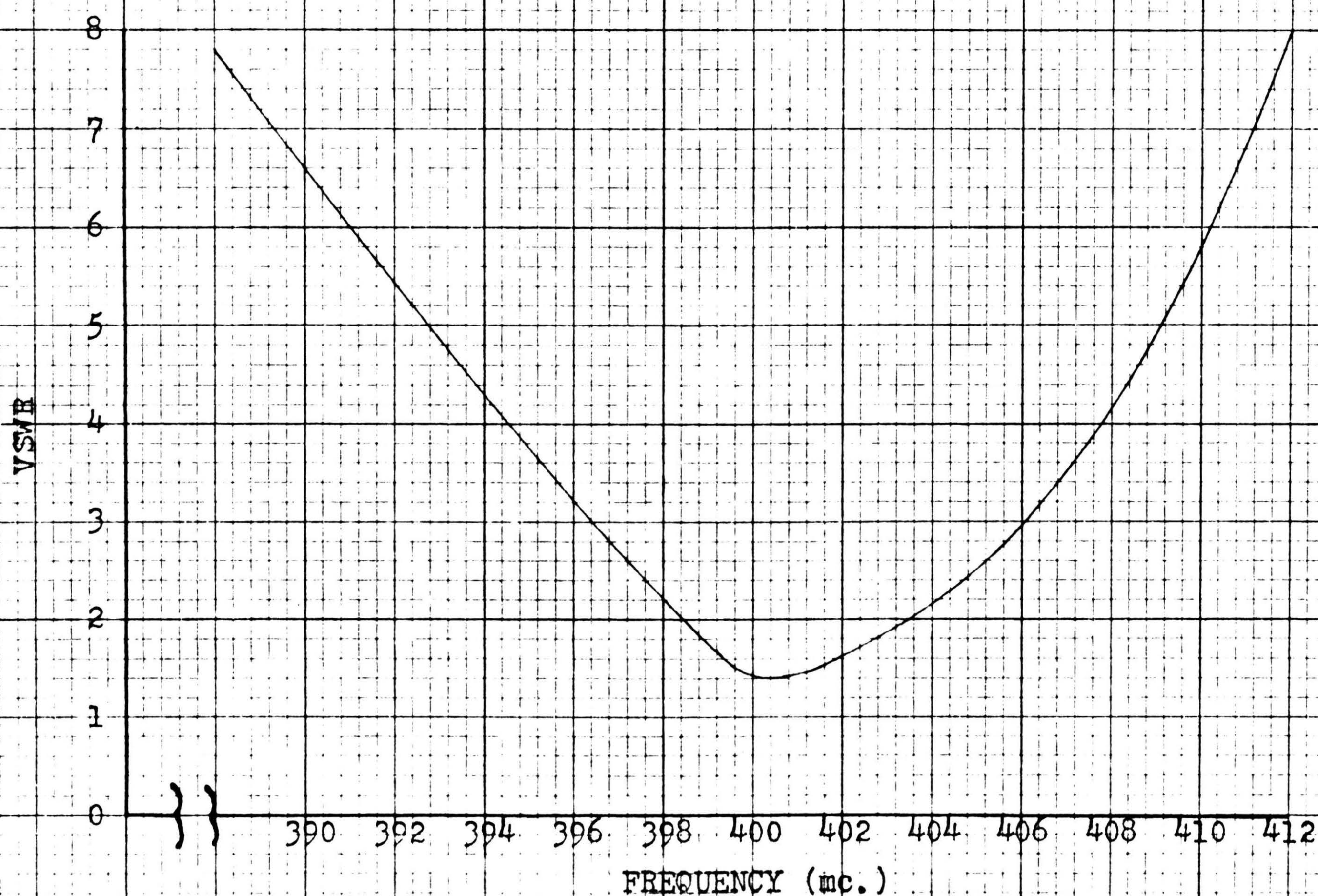


FIGURE 15

diode in conjunction with a micro-ammeter was used to test the relative field strength. The readings indicated an omnidirectional pattern was present rather than a cardioid shaped pattern. No defined nulls were detected. Because of the effect of re-radiation from surrounding metal objects, however, no definite statement can be made concerning the radiation pattern.

III. Sources of Error and Effect of Errors on Result

Any experimental result must be qualified by stating the errors present. There are several errors which must be considered when evaluating the results of this experiment. These errors and their effect upon the results are discussed in the following paragraphs.

Since all impedance measurements were obtained inside a room which contained steel lath in both the walls and ceiling, the effect of mutual or reflected impedance must be considered. The nearest metal reflector was at least one and one half wavelengths distant from the antenna. Although this distance was not completely negligible, the effect on the shape of the curves should have been small. This follows from the fact that the mutual impedance is a function of the geometry only, for any given frequency, and that any constant value added to a curve does not change the shape of the curve.

Another error of consequence for individual readings was the inability of the experimenter to reassemble the antenna in exactly the same manner for each reading. This applies particularly to the force exerted on the antenna by the holding straps. Any small deviation in thickness of the antenna caused by change in pressure exerted by the straps results in a slightly erroneous impedance reading. This type of error manifests itself in a point on the experimental curve deviating from a smooth curve drawn through all points. The percentage of points in obvious error was small.

The errors accumulated in calculations and readings of null positions should be small in comparison with the errors discussed in the foregoing paragraphs.

Although not an error, one other qualification of the results should be noted. The ground plane was of finite size. Therefore, the results apply to the finite sized ground plane used in this experiment. Use of a ground plane of different dimensions should be expected to yield slightly different results.

SAMPLE CALCULATIONS USING EXPERIMENTAL DATA AND SMITH CHART

Experimental Data

Frequency = 400 mc.

VSWR = 2.0

Reading of null on slotted line with terminals of the antenna shorted = 37.0 cm.

Reading of null with the antenna as the termination = 29.5 cm.

Calculation of Impedance

At f = 400 mc. = c/f = $\frac{3 \times 10^8}{4 \times 10^8}$ = 0.75 meters

The null with the antenna as the termination is 7.5/75 = 0.1λ from the shorted null, and is on the generator side of the line.

To find the impedance at the antenna terminals, enter the Smith Chart at point A which is on the VSWR = 2.0 circle. Follow the VSWR = 2.0 circle counterclockwise 0.1λ toward the load. Point B is then read directly as the relative impedance with respect to Z_o = 50 ohms. The reading at B is (0.67 - j 0.48) 50 ohms. Thus, the antenna impedance at the terminals is (33.5 - j 24) ohms. The negative sign indicates capacitive reactance.

NAME	TITLE	DWG. NO.
SMITH CHART Form 756-N	GENERAL RADIO COMPANY, CAMBRIDGE, MASSACHUSETTS	DATE

IMPEDANCE OR ADMITTANCE COORDINATES

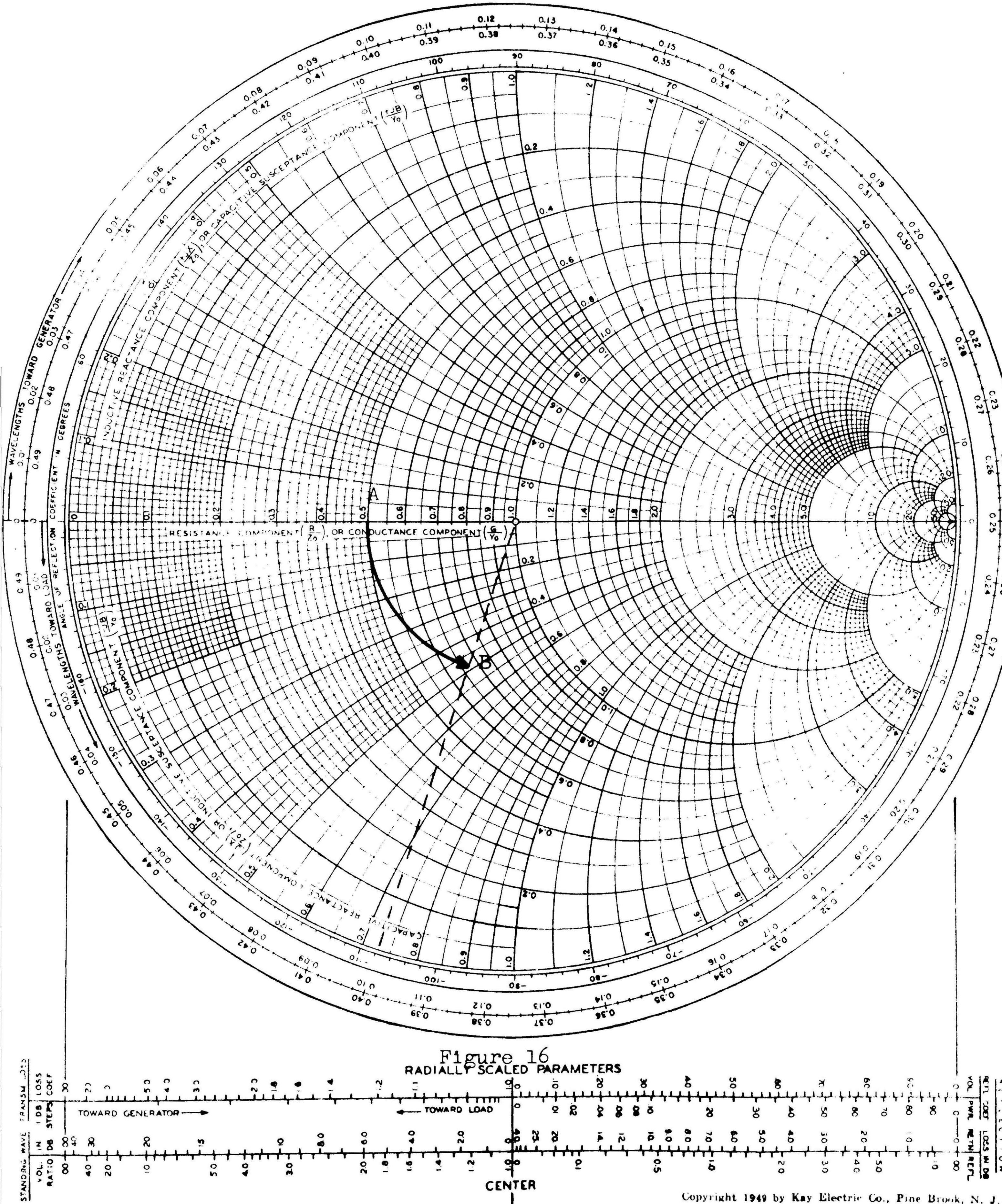


Figure 16

Electronics VOL 17, NO 1, PP 130-133, 318-325, JAN 1944

CONCLUSIONS

The small volume sandwich antenna can be matched for the dimensions of length approximately 0.17λ (5.0 inches), the width approximately 0.29λ (8.5 inches), and the thickness approximately 0.0085λ (0.25 inches). However, for a VSWR less than 2, the bandwidth is less than 10 megacycles for a carrier frequency of 400 megacycles. The sharpness with which the radiation resistance changes with feed probe position, length, and thickness indicates that the antenna resonates in much the same manner as a high "Q" parallel resonant circuit. At the dimensions investigated in this experiment, the applications of the antenna would necessarily be restricted to narrow band transmission or reception about a single center frequency.

The measurements of relative field strength indicated that the antenna pattern approaches an omnidirectional radiation pattern. An omnidirectional radiation pattern indicates negligible gain in the forward direction of the antenna in comparison with any other direction of radiation. This omnidirectional character of the pattern is probably due to currents on the top and rear plates of the antenna being of sufficient magnitude to mask the effect of the fields radiating from the front and side openings. Thus, at the small dimensions described here, the approximate equations derived for this type of antenna by Shanks do not apply. Shanks' work neglected these currents.

In conclusion, the usefulness of the sandwich antenna would be restricted to narrow band, low gain applications. These antenna characteristics would be particularly desirable for an application where very high selectivity (high "Q") of the antenna circuit is desired in conjunction with omnidirectional reception or transmission.

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