EXPERIMENTAL STUDIES ON A 13-ELEMENT INTERDIGITAL ARRAY ANTENNA

John A. M. Lyon and William W. Parker

FOREWORD

This report, 1770-7-T, was prepared by the Radiation Laboratory of The University of Michigan, Department of Electrical Engineering, 2216 Space Research Building, 2455 Hayward Street, Ann Arbor, Michigan 48105, under the direction of Professor Ralph E. Hiatt and Professor John A. M. Lyon on Air Force Contract Number F33615-68-C-1381, Task 627801 of Project 6278, "Study and Investigation of UHF-VHF Antennas". This report is the last in a series of seven technical reports issued under this contract. The work was administered under the direction of the Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio 45433. The Task Engineer was Mr. Olin E. Horton and the Project Engineer, Mr. E. M. Turner, AFAL/WRE. This report was submitted by the authors in May 1971.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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ABSTRACT

Experimental studies on a 13-element center-fed interdigital array antenna are described. In a previous report (1770-3-T) a theoretical analysis was presented for this type of antenna. The antenna consists of 13 finger-like elements lying in a plane with the elements parallel to one another. The single driven element can be considered to be a toppled monopole with six parasitic toppled monopoles on either side of the driven element.

At the lower range of frequencies the antenna provides a broadside plum-shaped pattern. At higher frequencies there is some end-fire radiation and a split-beam pattern is ultimately observed. Numerous radiation patterns and data on the relative gain are presented. The range of gain is 6 to 16 dB below a half wave resonant dipole. Arguments are presented which indicate that the reported gain is very conservative because of a number of factors; it is expected that the actual gain is higher than recorded. The VSWR is less than 2 over a frequency range from 400 to 650 MHz, the recommended range for broadside operation. The radiation patterns also show a very low side lobe and back lobe level for the frequency range.

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I

INTRODUCTION

This report summarizes the results of experimental studies on a 13-element center fed interdigital array. A theoretical analysis of this array has been presented previously*. The present study is primarily concerned with the impedance and radiation characteristics of the antenna. In this study the antenna has been modified for flush mounting and it is tested with a dielectric cover plate. Relative gain measurements were also made.

No attempt is made in this report to justify by theory any of the results obtained since a detailed analysis was given earlier*. That report showed that both Smith chart impedance plots and radiation patterns were consistent with the mathematical analysis. However, because of the excessively high computer cost for interdigital arrays having many elements, it was not deemed feasible at that time to make computer calculations for interdigital arrays of more than three elements. Because of this fact the 13-element interdigital array was presented there purely on the basis of observed experimental data. For the above reasons the study of the 13-element array is studied here only experimentally.

The interdigital array antenna offers a moderate amount of broadside directivity. The finger-like elements lie in a plane denoted by X-Y (see Fig. 1-2). Each element is parallel to the Y axis. The most descriptive radiation patterns are those taken as X-Z cuts. Here the dominant polarization is with E parallel to the Y-axis. Patterns taken in this way show a directivity comparable to that for a single dipole with a reflector behind it. The array consists of a toppled monopole with several parasitic toppled monopoles on each side. The parasitically fed elements have obviously added to the directivity.

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* Parker, Wm.W. (July 1970), "The Interdigital Array as a Boundary Value Problem," AFAL-TR-70-94, AD 871265. Hereinafter referred to in the text as Report 1770-3-T.

The interdigital array antenna is of physically small size, being approximately 0.17 by 0.31 wavelengths in area by 0.02 high at the lowest operating frequency. It provides the described radiation pattern with a reasonably good bandwidth. Typically such an antenna with 13 elements will operate with a VSWR less than 2 over a range of 650 to 900 MHz. With proper scaling in size, the antenna would give corresponding bandwidth and VSWR at other parts of the VHF-UHF spectrum.

To show the physical arrangements a simple experimental model of a three-element interdigital array is shown in Fig. 1-1. The method of center feeding such an array to the one active element is clearly indicated. In the 13-element arrays considered in detail in this report there are six parasitic elements on each side of the active element. In progressing from one parasitic element to another, the end at which each element is bonded to the ground plane alternates. This is shown in Fig. 1-2. In this figure, for simplicity, we show an interdigital array of five elements only. Also shown are the various parameters used in the description of the array. In addition, a set of coordinate axes is shown which is useful in orienting the radiation patterns presented later.

Most of the experiments described here were based on the original 13-element wire antenna of the interdigital type. This was recessed and later provided with a dielectric cover. In addition, one entirely new interdigital antenna was fabricated by the etching process. The latter structure was etched on a copper-clad circuit board and an adjustable cavity was constructed to use with the antenna. The circuit board geometry is illustrated in Fig. 1-3. The shaded area in the drawing represents the copper foil. Unfortunately, this model proved to be very narrow banded. The necessary cavity dimensions to produce broadband VSWR characteristics could not be found. This design was not pursued further but the possibilities of etched construction have not been exhausted. Some further study would appear justifiable.

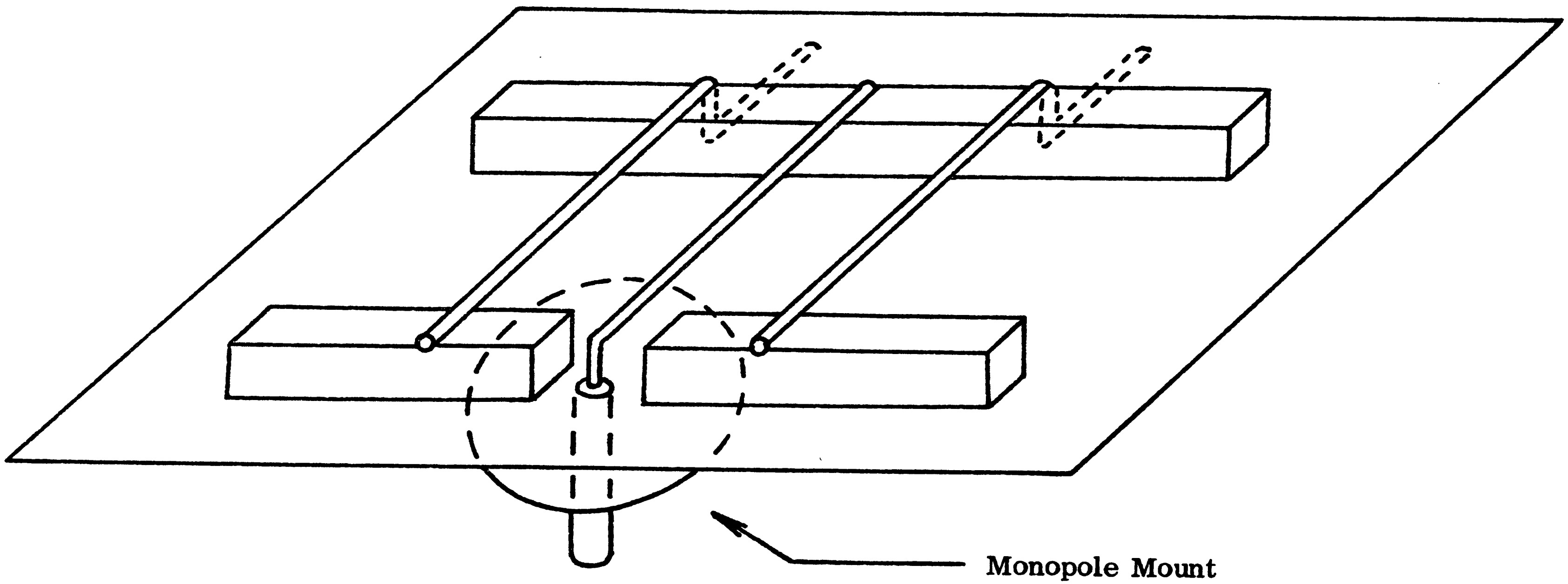


FIG. 1-1: EXPERIMENTAL MODEL OF A THREE-ELEMENT INTERDIGITAL ARRAY.

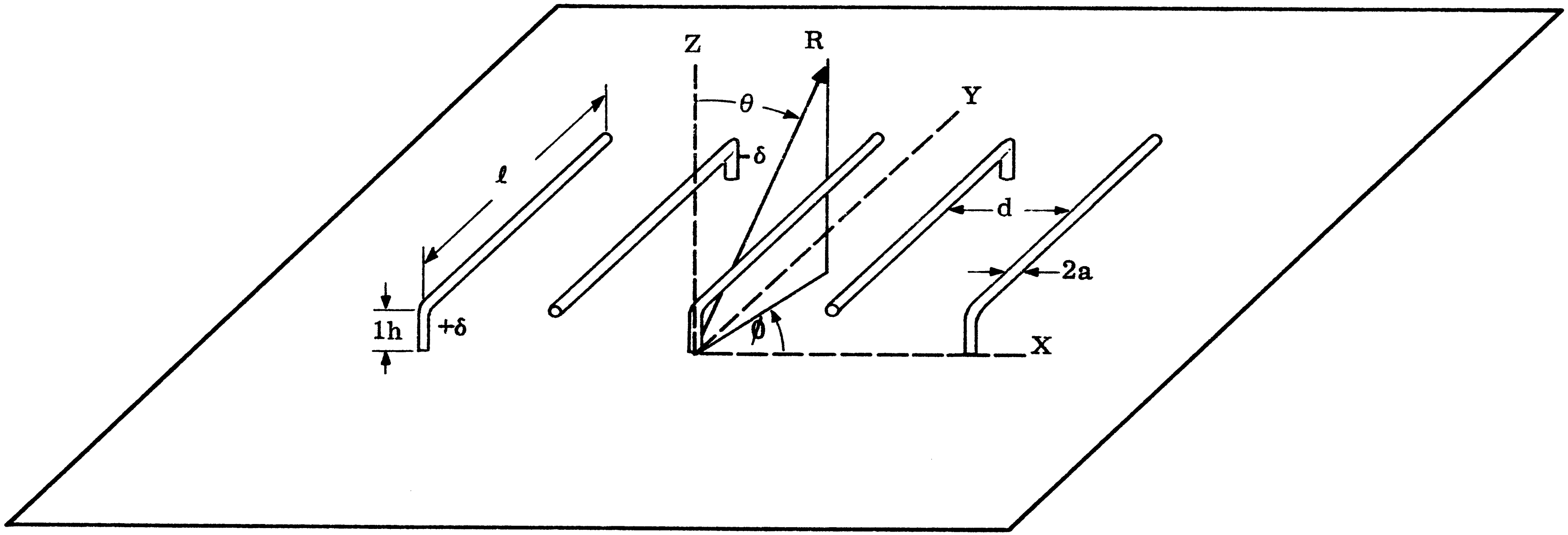


FIG. 1-2: FIVE-ELEMENT INTERDIGITAL ARRAY ANTENNA.

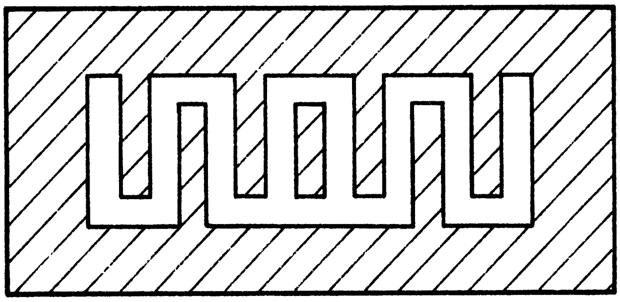


FIG. 1-3: ETCHED CONSTRUCTION OF INTERDIGITAL ANTENNA FROM COPPER CLAD CIRCUIT BOARD (Shaded area represents copper).

The patterns for the flush mounted model are somewhat less satisfactory than those obtained for the original mounting as reported in Report 1770-3-T. Relative gain measurements were made using the substitution method with an adjustable dipole used as the reference. The measurements made showed relative gains which varied from 6 to 16 dB below the dipole. As explained in Chapter III, some of these data were taken under non-optimum conditions and the low values may be considered suspect. Relative gain for cross polarized conditions are also given in Chapter III.

Actual construction of a 13-element interdigital array antenna is shown in the photograph of Fig. 1-4. Note the manner in which the antenna has been recessed into the metal plate. The bottom of the cavity is also metal. The surrounding metal plate has been provided with a shoulder to accommodate a fiber glass sheet as a cover plate. This antenna with and without a cover plate is the one used in all the experimental measurements performed in connection with this report.

Despite the imperfect patterns and the relatively low gain, it is believed that a small flush mounted antenna such as described herein will be useful for a number of practical applications.

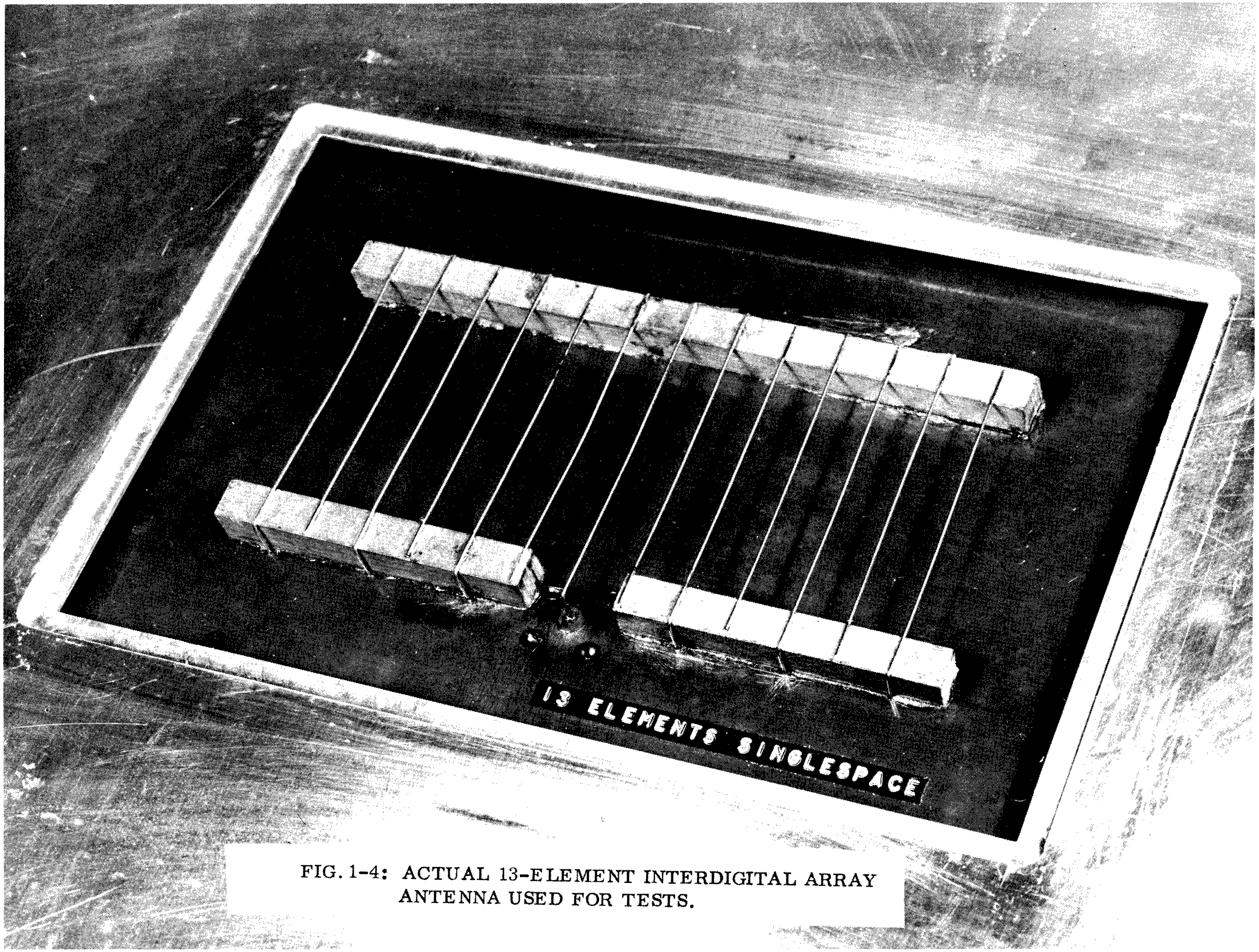


FIG. 1-4: ACTUAL 13-ELEMENT INTERDIGITAL ARRAY ANTENNA USED FOR TESTS.

II

VSWR AND PATTERN STUDIES

2.1 Physical Arrangements

One of the earlier 13-element wire interdigital antennas similar in construction to that shown in Fig. 1-1 was recessed and provided with a dielectric cover. This antenna was tested for VSWR, radiation patterns and gain relative to a half wavelength dipole. Figure 2-1 shows a sketch giving the general features of the arrangement except that the actual number of elements is not displayed; the antenna tested is shown in Fig. 1-4.

All the experimental models studied in this report used a 10" x 15" sheet of copper for a ground plane. The necessary opening in this sheet was made to accommodate the recessed structure. The thickness of the copper was 0.02". The antenna elements were constructed from a wire with a diameter of 0.08 cm. The 13-element antenna tested had the following physical parameters: ℓ = 8,0 cm, h = 1.0 cm, a = 0.04 cm and α = 1.2 cm (see Fig. 1-2).

2.2 Impedance Data

The VSWR was obtained using a swept frequency measuring technique. For reference an oscilloscope trace was displayed using a 100 ohm load resistance which represents a VSWR of 2.0 with respect to the 50 ohm cable. Then an oscilloscope trace was obtained for the flush mounted 13-element interdigital array using a dielectric cover. Both the reference trace for VSWR of 2.0 and the observed trace for the 13-element array have been drawn without modification in Fig. 2-2. It can be observed that the VSWR of this array is less than 2.0 for the frequency range of 650 to 900 MHz. This is a bandwidth of 250 MHz. Although specific data were not included in this report, the effects from the dielectric cover were observed. Without the cover the general VSWR trace is much the same as shown in this figure except for minor variations at the low frequency end.

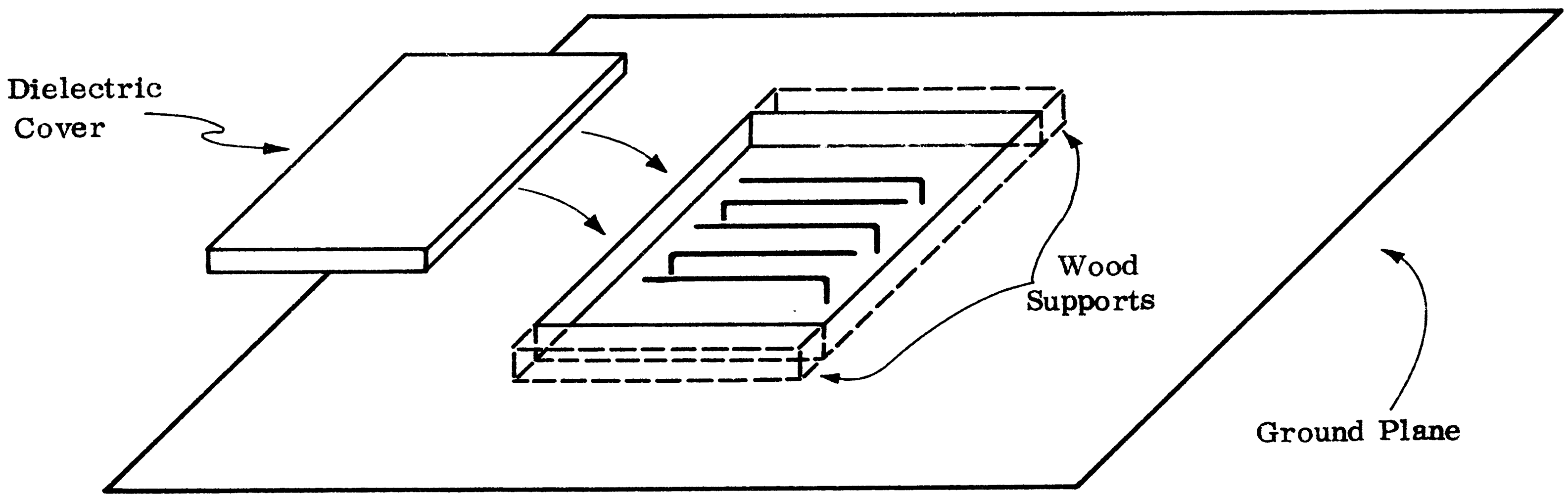
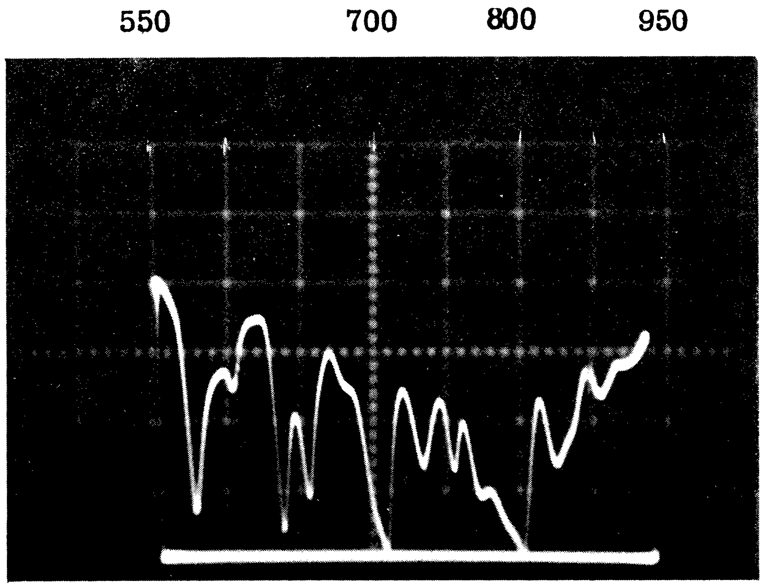
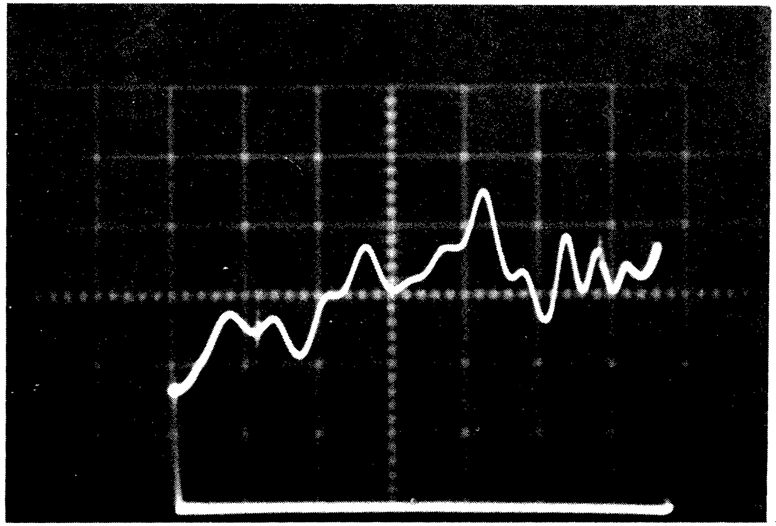


FIG. 2-1: RECESSED INTERDIGITAL ANTENNA WITH DIELECTRIC COVER PLATE.



13-element Flush Mounted Interdigital Array
650 - 900 Bandwidth (250 MHz)



100 Ohm Load (Resistive) VSWR = 2.0

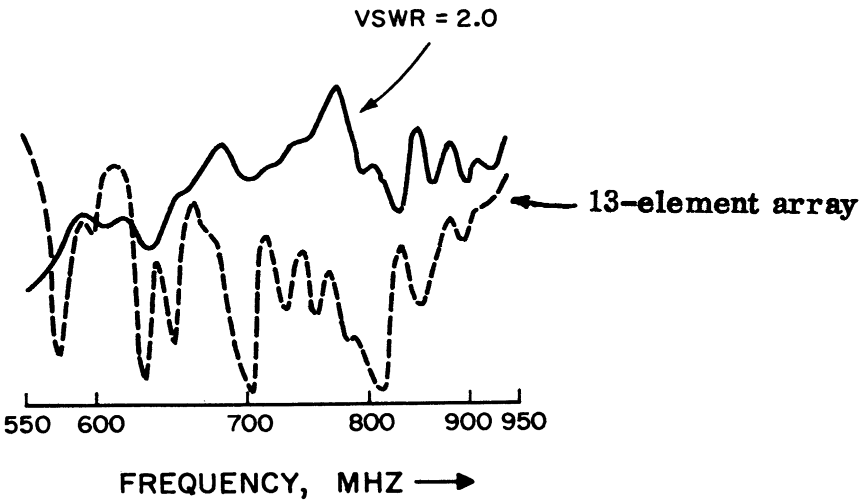


FIG. 2-2: VSWR CURVE FOR 13-ELEMENT INTERDIGITAL ANTENNA (FLUSH MOUNTED) WITH REFERENCE CURVE (VSWR = 2.0).

2.3 Radiation Patterns

All of the pattern and gain measurements were made on the 50-foot antenna range on the roof of the George Granger Brown Laboratory Building. The transmitting antenna was of the linearly polarized log-tooth type. It was adjusted to transmit vertical polarization for H plane patterns and changed to horizontal polarization for E plane patterns. For all patterns the test antenna which served as the receiving antenna was rotated about a vertical axis.

All patterns are polar in form and linear in power. It should be noted that the indicated signal level is not necessarily proportional to relative gain since the receiver gain was ordinarily adjusted to produce patterns appropriately sized with respect to the recorder paper. When gain measurements were being made, proper account was taken of the receiver gain settings.

Three types of patterns were taken; two of which were co-polarized and the third was for the cross polarized condition. As is implied, co-polarized means that the transmitting and receiving antennas are aligned so as to cause the dominating polarizations to be parallel.

For the patterns designated E_ϕ (x, z) the array was mounted as in Fig. 2-3(a) with the elements vertical and spread out in the horizontal direction. The array was rotated about the vertical Y axis thus producing an X-Z cut and a co-polarized pattern since vertical polariation is transmitted. This would be an H plane pattern.

For the patterns designated E_θ(y, z) the 13-element array is arranged with the elements in the horizontal direction and spread out in the vertical direction as shown in Fig. 2-3(b). The antenna is rotated about the vertical axis producing a cut in the Y-Z plane. Since the transmitting antenna is polarized in the horizontal direction, an E plane co-polarized pattern is obtained.

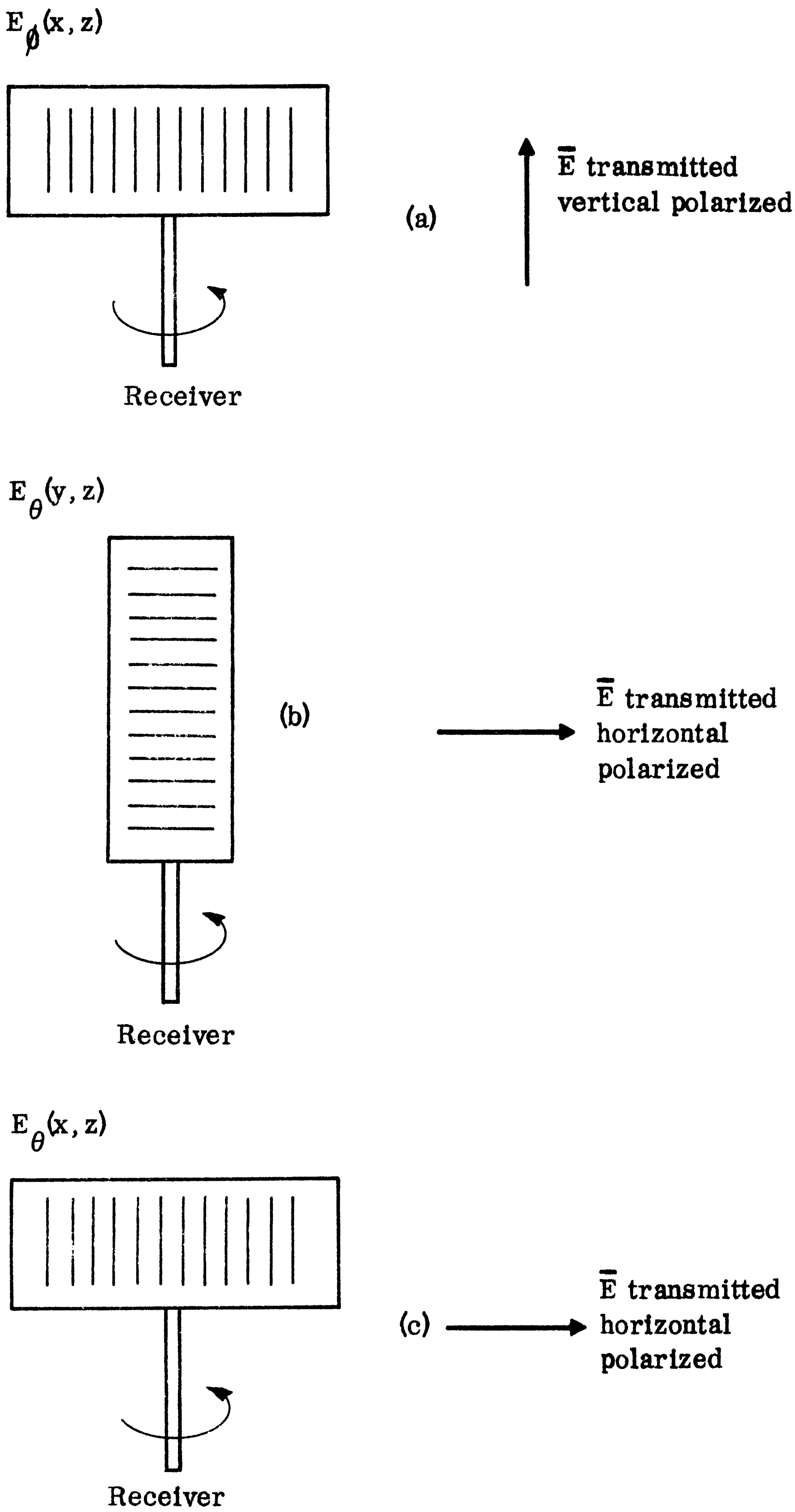


FIG. 2-3: EXPERIMENTAL SETUPS FOR VARIOUS CUTS

Since the interdigital array is known to have a strong cross polarized component (Report 1770-3-T), a series of cross polarized patterns were taken. These were designated as $E_\theta(x, z)$. For these patterns the array was set up as in Fig. 2-3(c), with the elements vertically oriented and it was rotated about the vertical axis. The cross polarized pattern results from the fact that the transmitted polarization is horizontal causing the subscript to be θ instead of ϕ as in the first set of patterns.

Figures 2-4 through 2-6 show the patterns for the $E_\phi(x, z)$ or H plane case. The frequency range from 400 to 900 MHz is covered. In general, broadside beams are shown with reasonably good directivity. Three of the patterns (2-5b, 2-6c and 2-6d) show a tendency towards endfire behavior. It is noted that these patterns are in the upper part of the frequency band.

The $E_\theta(y, z)$ or E plane patterns are shown in Figs. 2-7 and 2-8. The frequency range covered extends from 400 to 900 MHz, although fewer patterns are included in this series. Since this orientation provides a pattern cut parallel to the array elements, one would expect results similar to an E plane pattern of a single monopole close to and parallel to a ground plane. The pattern is complicated due to the contribution of the short part of the radiator perpendicular to the ground plane and also due to the effect of the dielectric cover plate. It is to be observed that from 400 to 550 MHz, the broadside pattern is very similar to that obtained for the previous series. It is seen that from the consideration of these two orthogonal cuts, the antenna provides plum shaped broadside patterns with very low backlobe. Altogether these two series of patterns show that the 13-element interdigital array antenna has a desirable forward broadside characteristic. In Fig. 2-7(d) the pattern is split. As the frequency is increased above 600 MHz, the split pattern behavior involving some endfire action is continued. Thus it is to be seen from these two series of radiation patterns that the best performance as a broadside radiator is 400 to 600 MHz.

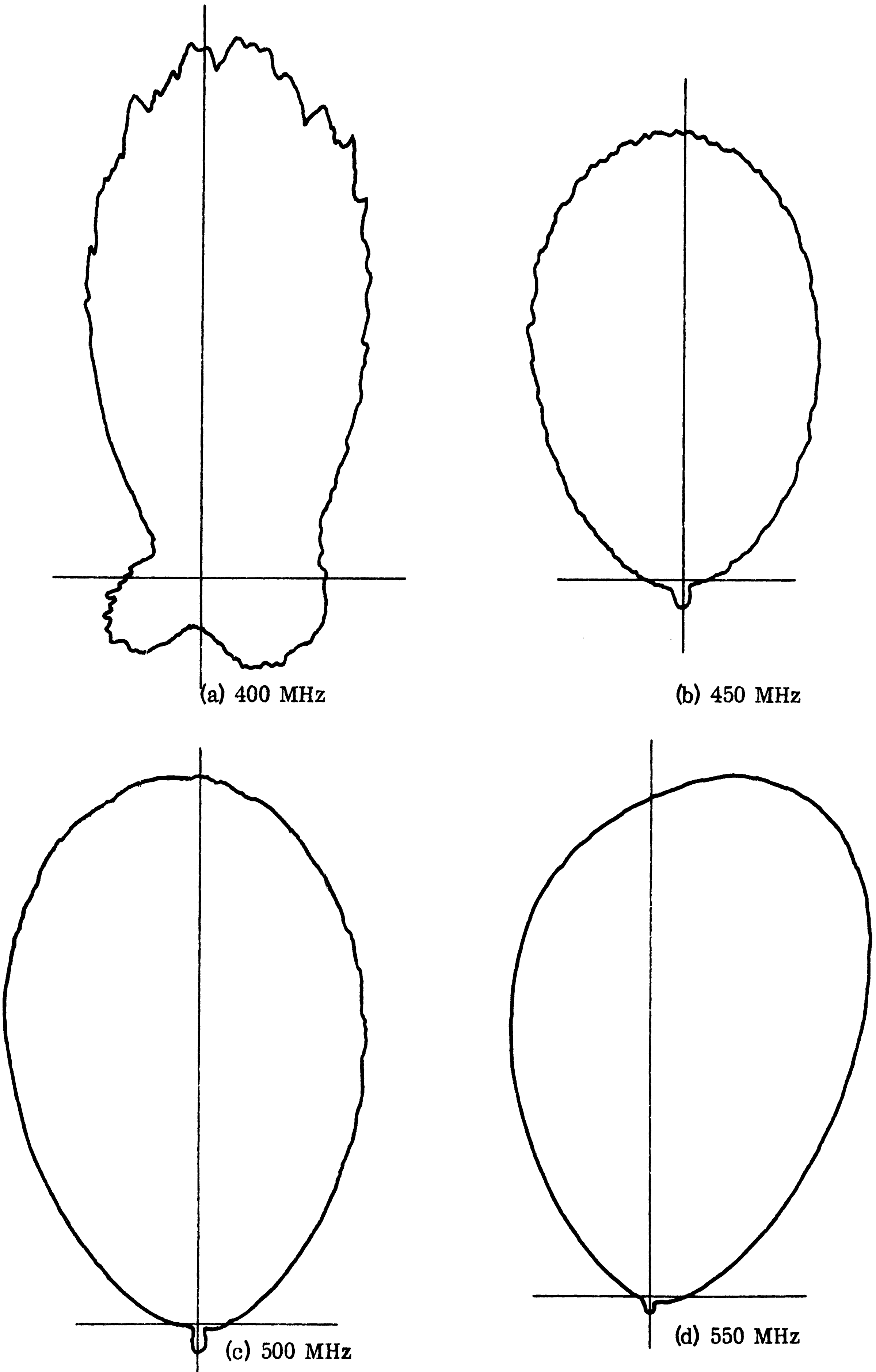


FIG. 2-4: $E_\phi(x,z)$ PATTERNS; 13-ELEMENT INTERDIGITAL ARRAY FLUSH MOUNTED WITH COVER

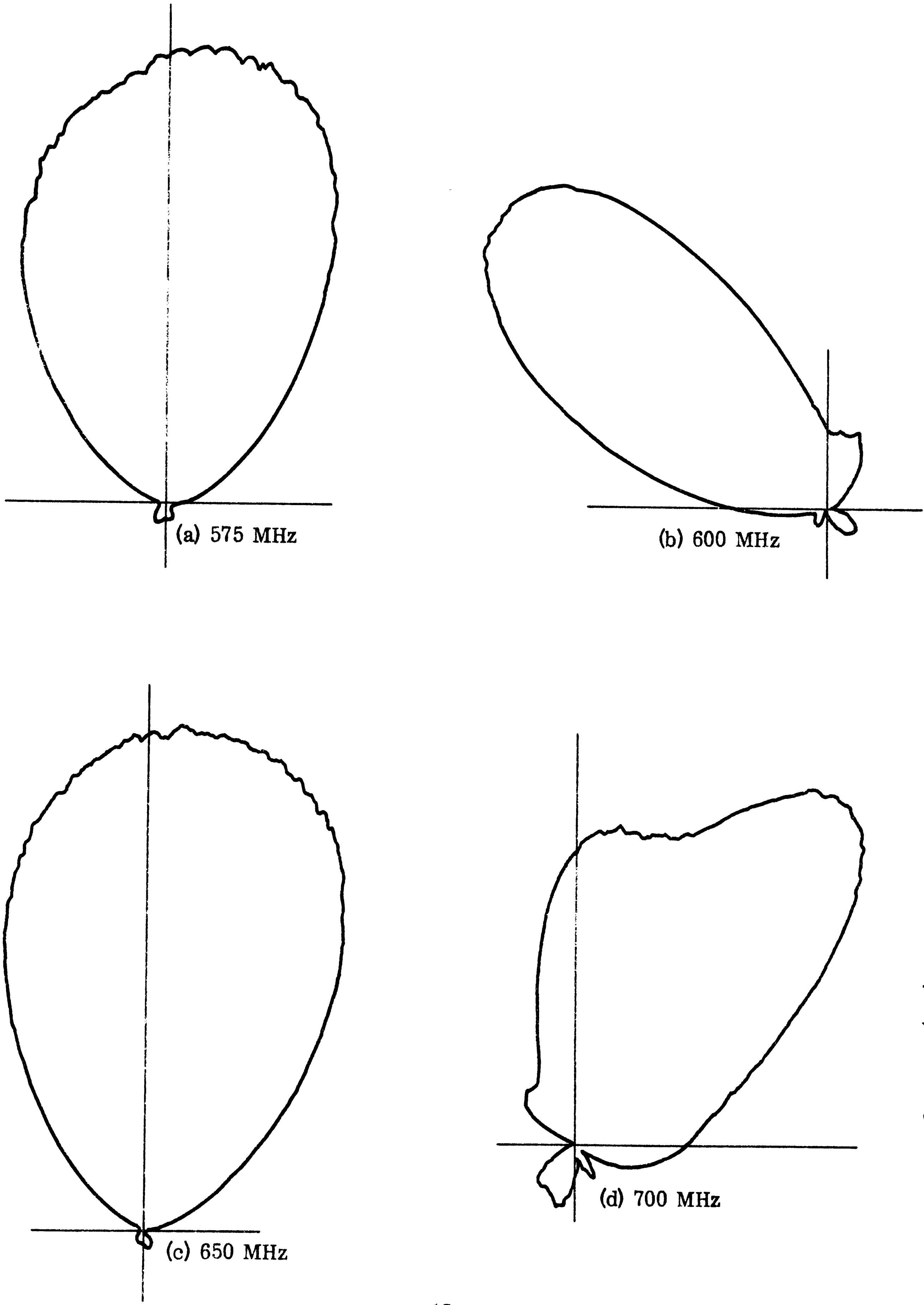


FIG. 2-5: $E_\phi(x,z)$ PATTERNS; 13-ELEMENT INTERDIGITAL ARRAY FLUSH MOUNTED WITH COVER.

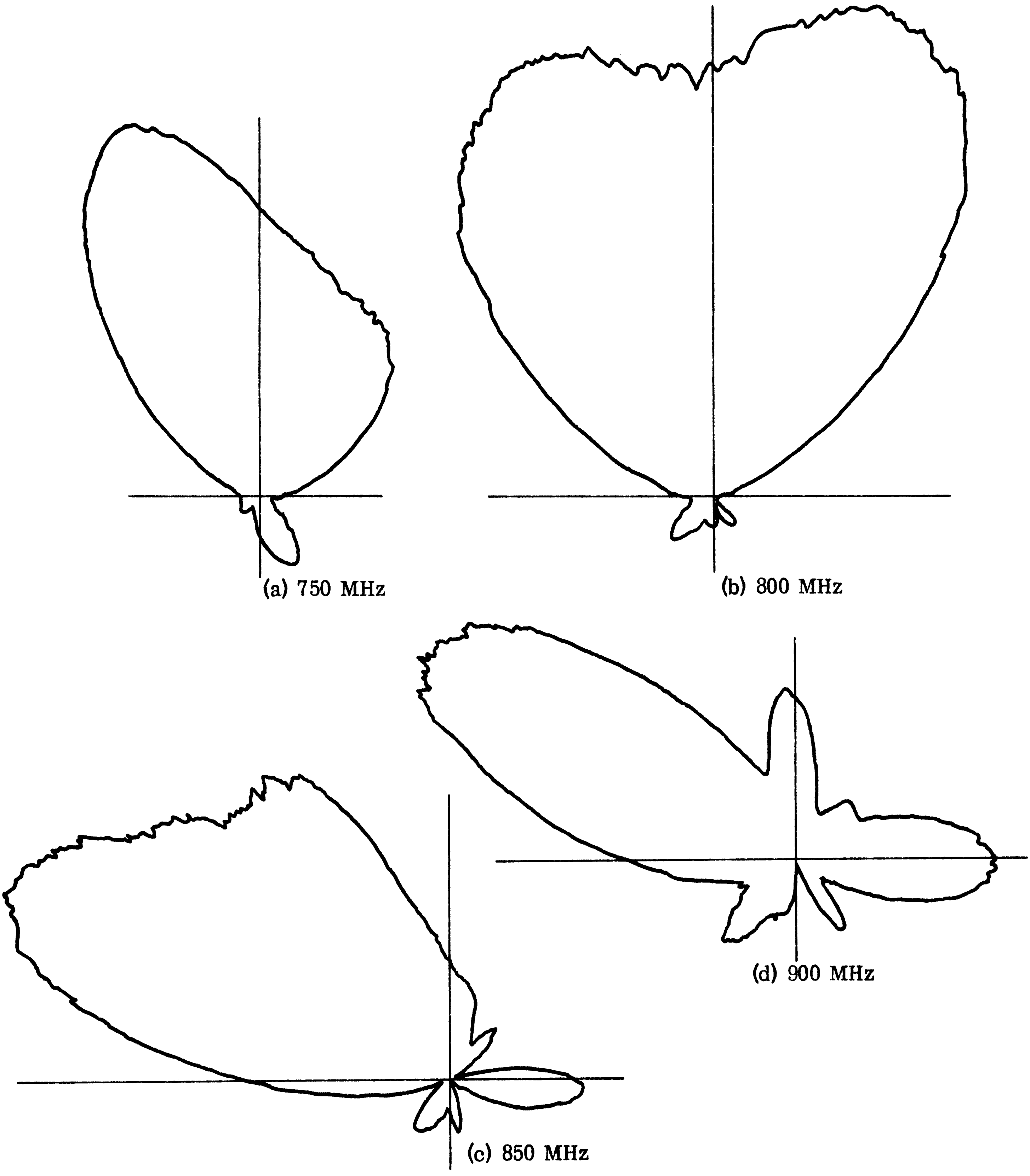


FIG. 2-6: $E_\phi(x,z)$ PATTERNS; 13-ELEMENT INTERDIGITAL ARRAY FLUSH MOUNTED WITH COVER

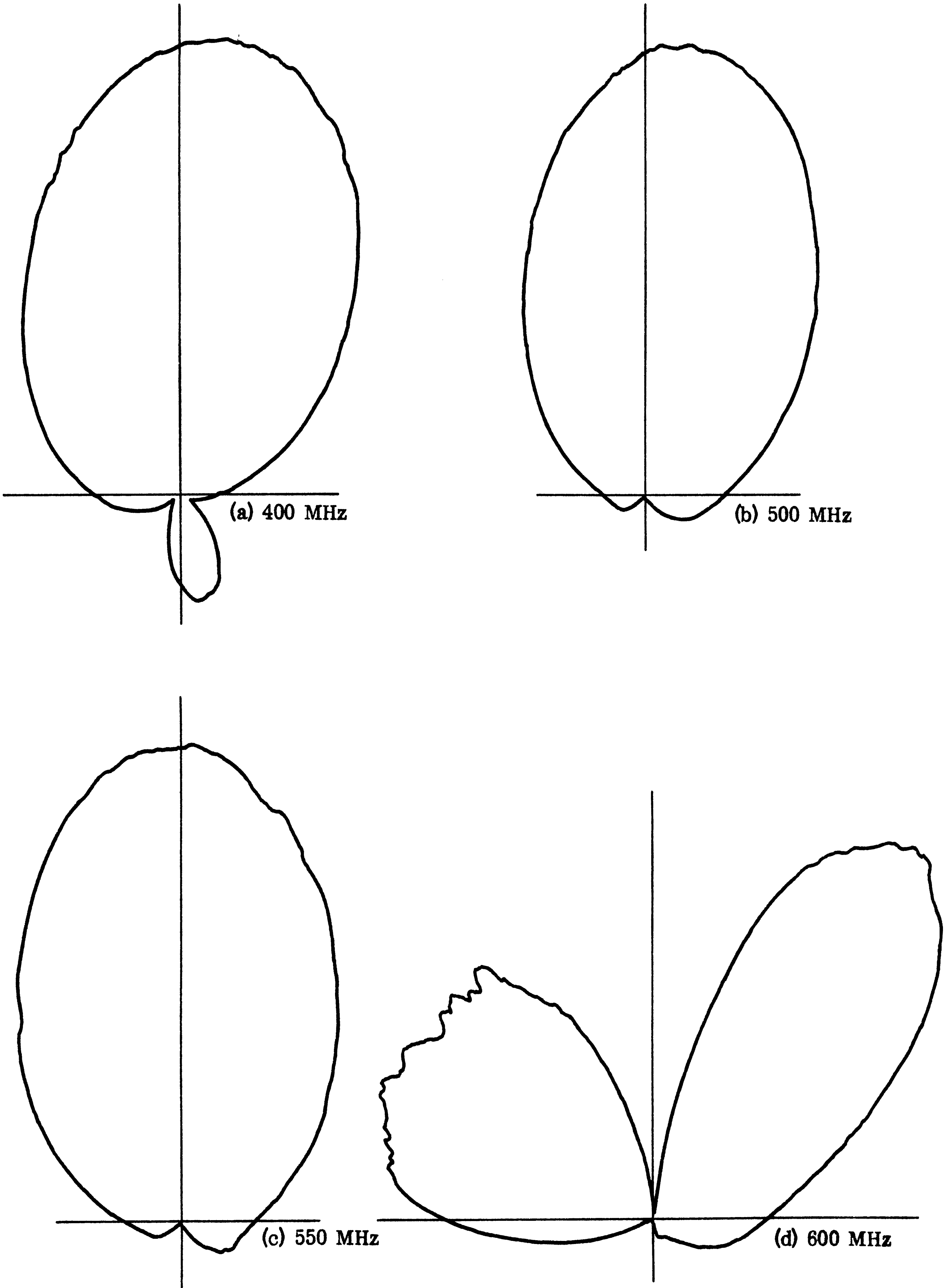
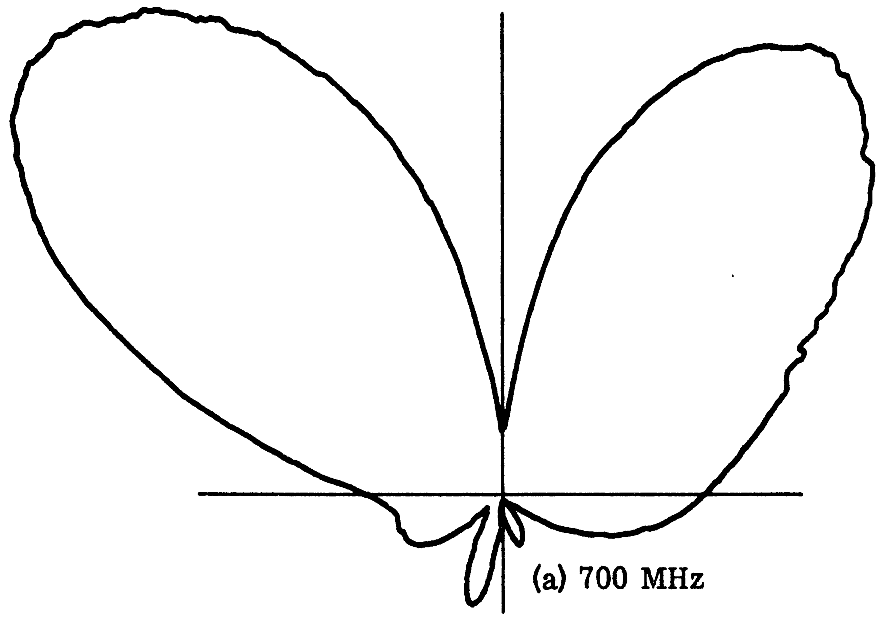
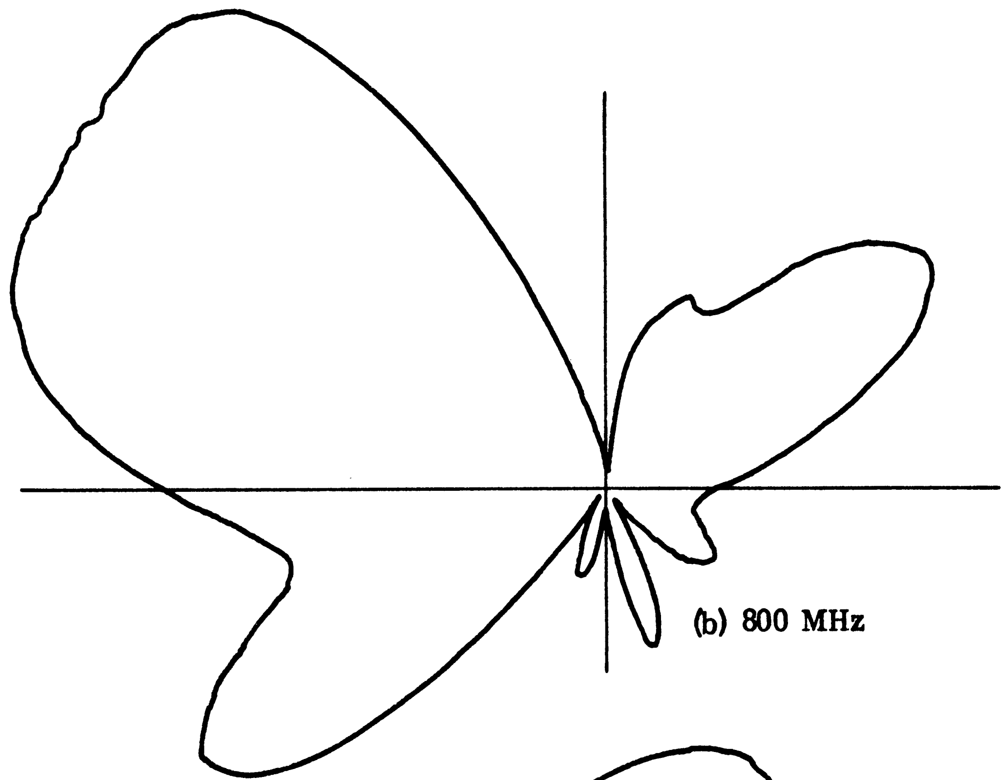


FIG. 2-7: $E_\theta(y,z)$ PATTERNS ; 13-ELEMENT INTERDIGITAL ARRAY FLUSH MOUNTED WITH COVER.





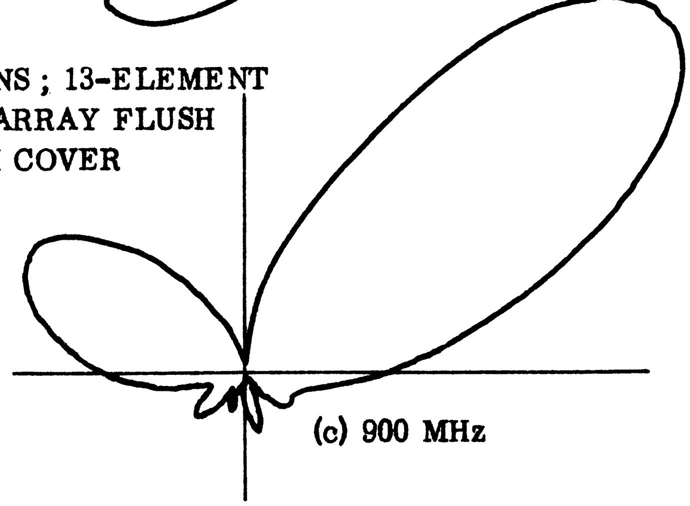


FIG. 2-8: $E_\theta(y,z)$ PATTERNS ; 13-ELEMENT INTERDIGITAL ARRAY FLUSH MOUNTED WITH COVER

A limited number of $E_\theta(y, z)$ patterns were taken with the cover removed from the array. These are shown in Fig. 2-9 for frequencies from 500 to 900 MHz. Unfortunately some of the plots are rather small but even so the major pattern characteristics can be seen. These patterns show that the dielectric cover has a significant effect at some frequencies. It is apparently responsible for the split pattern at 600, 700 and 800 MHz seen in Figs. 2-7(d), 2-8(a) and 2-8(b). At 900 MHz, the split pattern occurs both with and without the dielectric cover plate. It is possible that the cover plate helps to introduce a surface wave; this might or might not help to produce a split pattern depending on the phase of the two components.

The cover plate design was determined only on the basis of VSWR performance. It is seen now that its effect on pattern behavior must also be considered. The dielectric cover used was 1/32" thick fiber glass, 9" long and 6" wide.

Another series of patterns for the 13-element interdigital array antenna were taken for cross polarization response. Figures 2-10 and 2-11 show these patterns. These plots have been made sufficiently large so that the detailed characteristics can be easily observed, hence, it must be mentioned that the gain of the receivers used in the taking of the patterns has been increased so that the pattern scale is not an indication of the amount of cross polarization present. Actually, it was found that the cross polarization was very low for this type of antenna. In this series of patterns, designated $E_\theta(x, z)$, tests were made ranging from 500 to 900 MHz. In general, multi-lobe patterns were obtained as are typical in the cross polarization response. It is to be observed that at 600 and 680 MHz the pattern indicates some sensitivity in the backward half space. Although this has been exaggerated by using a high receiver gain and although the response is considerable, compared to the front lobe, nevertheless, it represents a low sensitivity and directivity compared to the forward broadside lobe obtained in the co-polarized patterns.

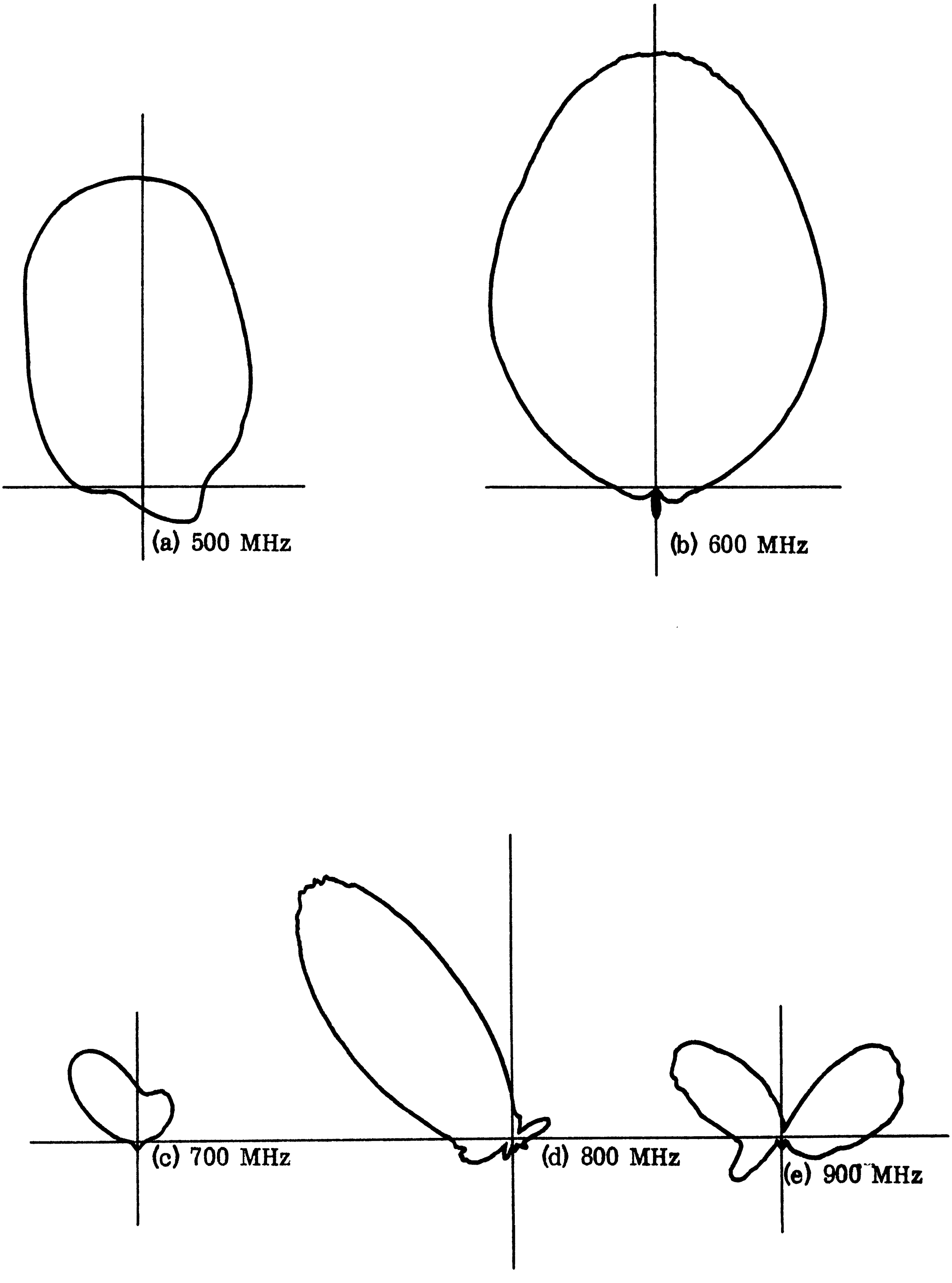


FIG. 2-9: $E_{\theta}(y,z)$ PATTERNS ; 13-ELEMENT INTERDIGITAL ARRAY FLUSH MOUNTED WITH COVER OFF.

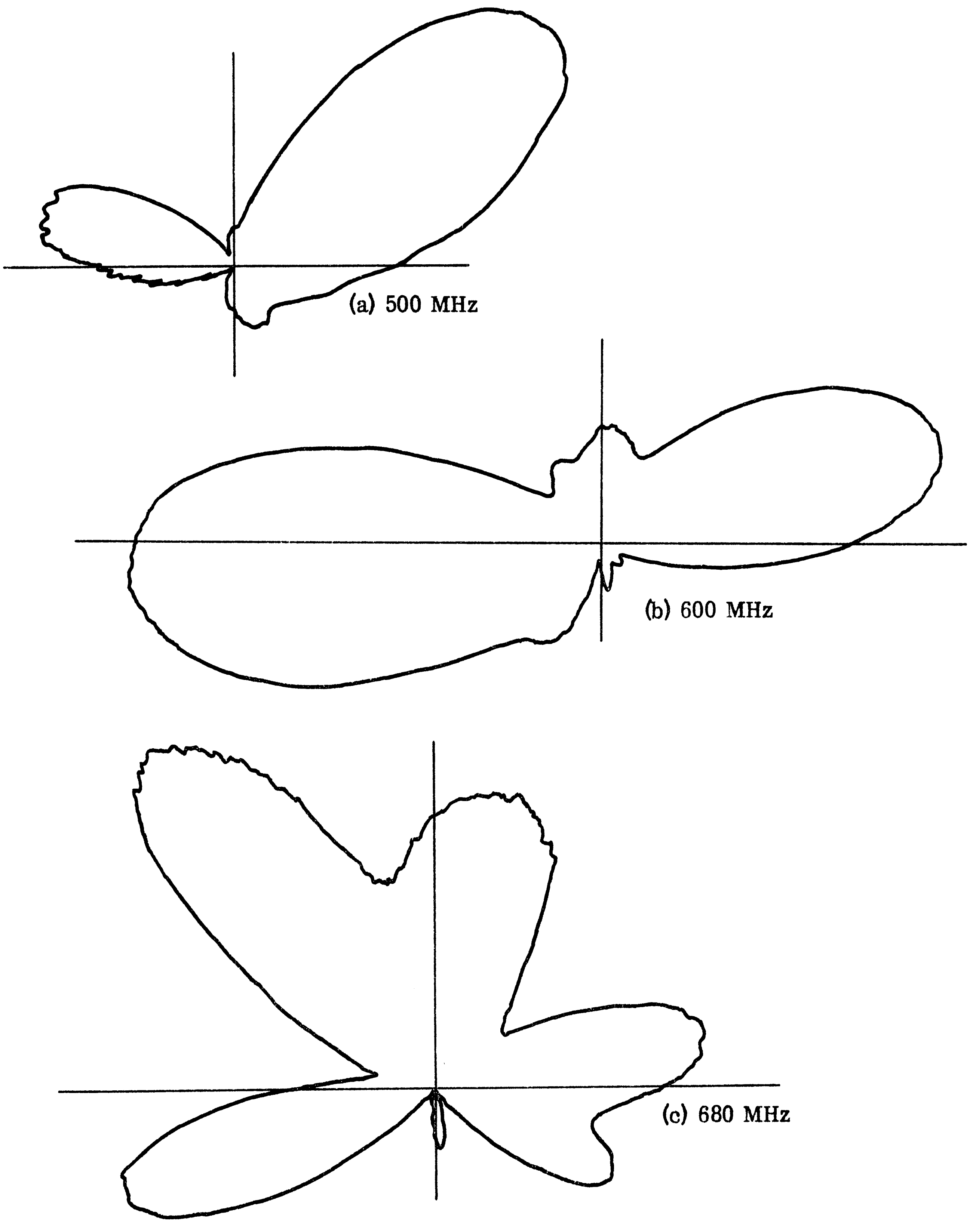


FIG. 2-10: $E_\theta(x,z)$ CROSS POLARIZED PATTERNS ; 13-ELEMENT INTERDIGITAL ARRAY FLUSH MOUNTED WITH COVER.

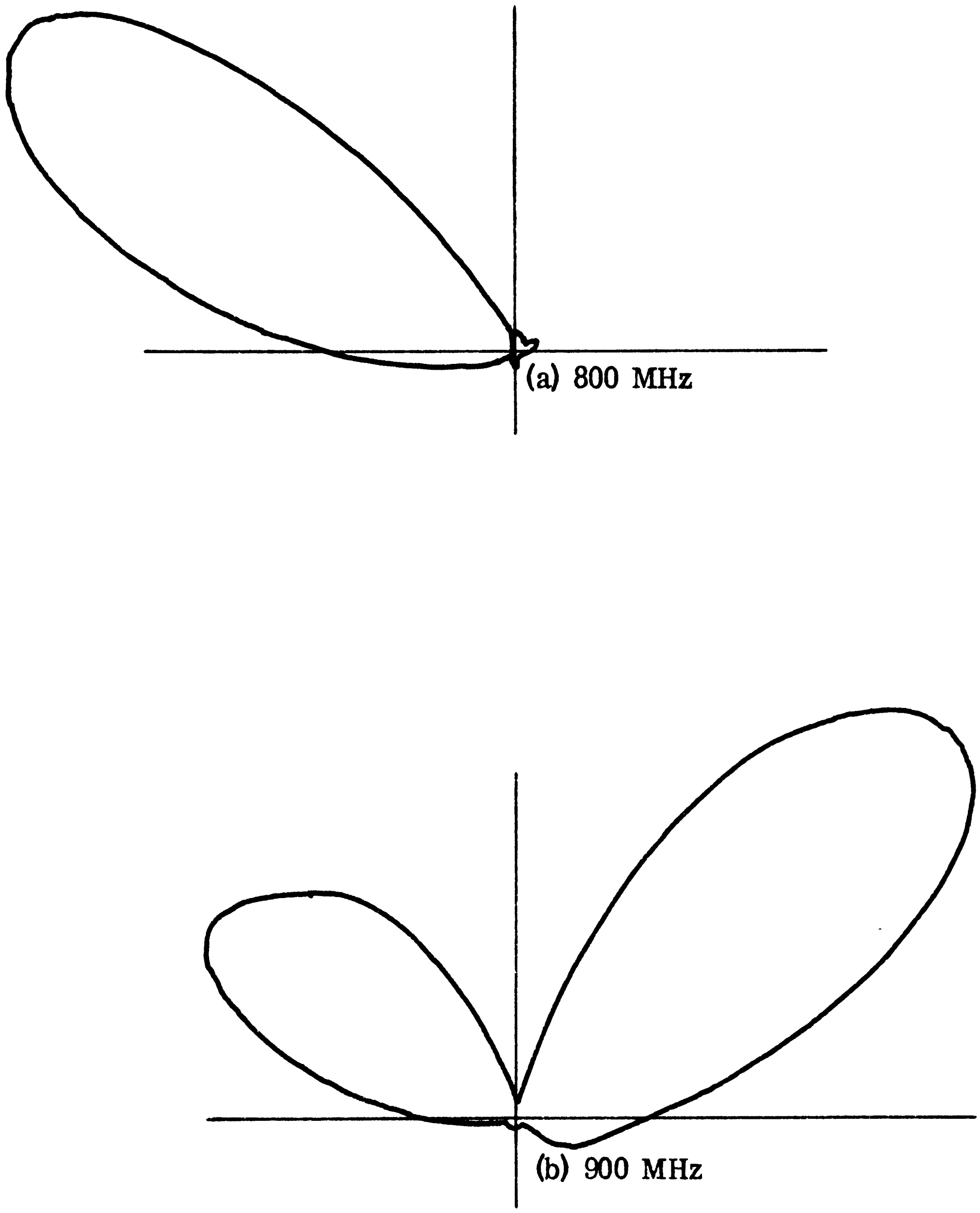


FIG. 2-11: $E_\theta(x,z)$ CROSS POLARIZED PATTERNS ; 13-ELEMENT INTERDIGITAL ARRAY FLUSH MOUNTED WITH COVER.

III
RELATIVE GAIN MEASUREMENTS

3.1 Arrangement of Equipment

These measurements were performed on the same test set-up as was used in Chapter II. The received power of the 13-element flush mounted interdigital array was compared with the received power of a half wave dipole. The linearly polarized log-tooth antenna was used as a transmitting antenna oriented for horizontal polarization. The dipole and the interdigital array antenna were used interchangeably as the receiving antenna. Data were obtained with and without a dielectric cover plate over the interdigital array.

The relative gain was determined by recording the receiver gain setting and noting the difference in peak level of the patterns being compared. Some error in the readings due to receiver drift was possible, however, the time between readings while the two antennas were interchanged was kept to a minimum. The electric dipole antenna which was fed from a broadband hybrid was adjustable and set to a length of $0.46\ \lambda$ at each frequency used.

3.2 Scope of Data

The array patterns are not repeated here since they were shown in Chapter II. Patterns of the dipole are shown, however, for frequencies from 500 through 900 MHz. Figures 3-1 and 3-2 are typical dipole patterns and they help to show that the dipoles were properly adjusted and the antenna range was in order.

The relative gain was determined for five frequencies for both properly polarized and for the cross polarized condition. The results are given in Tables III-1 and III-2. In each case, the relative gain is given for two conditions — first with the dielectric cover on, and then with the cover off the interdigital array.

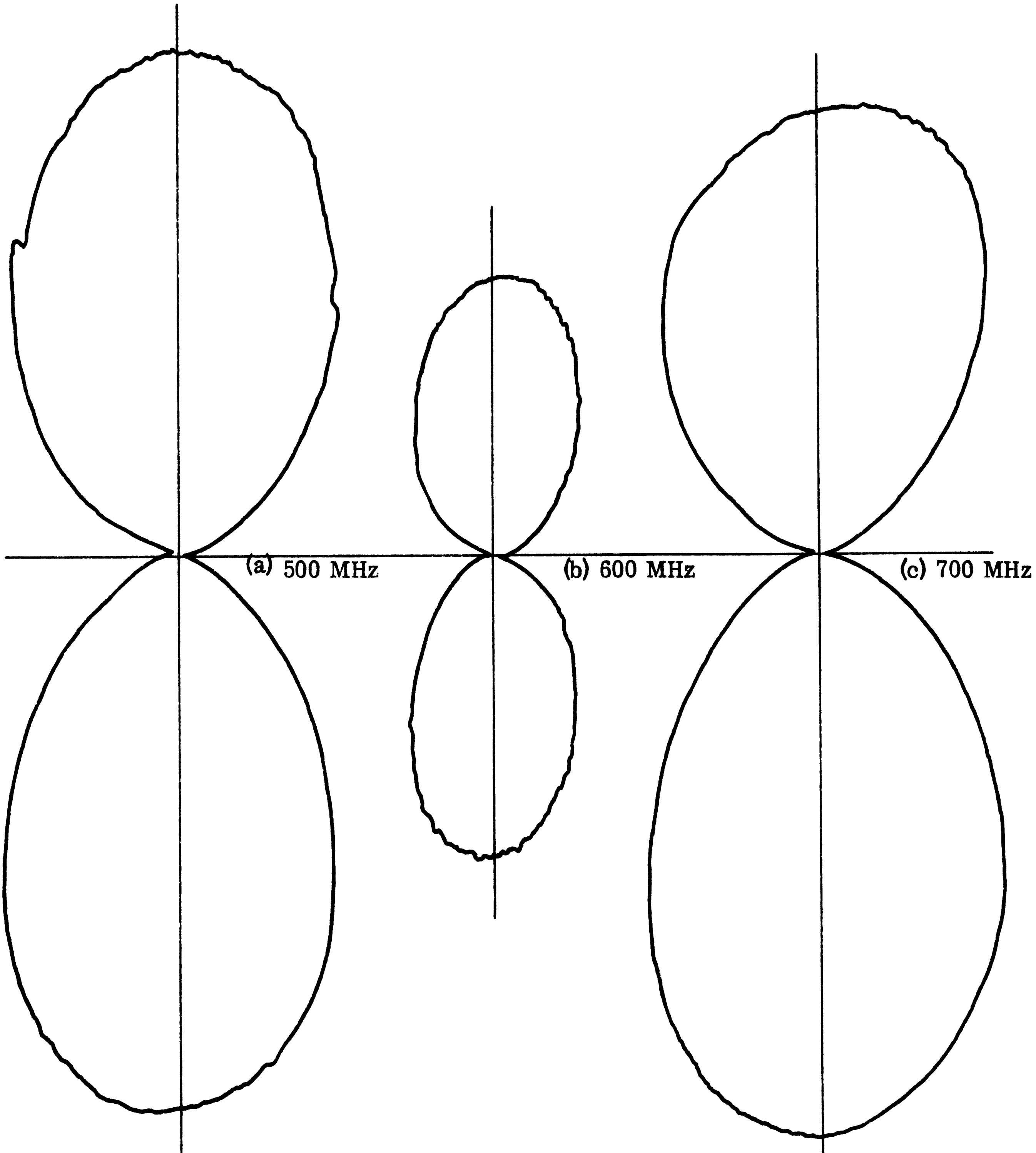


FIG. 3-1: E-PLANE PATTERN OF A DIPOLE ADJUSTED FOR A LENGTH OF 0.46 λ .

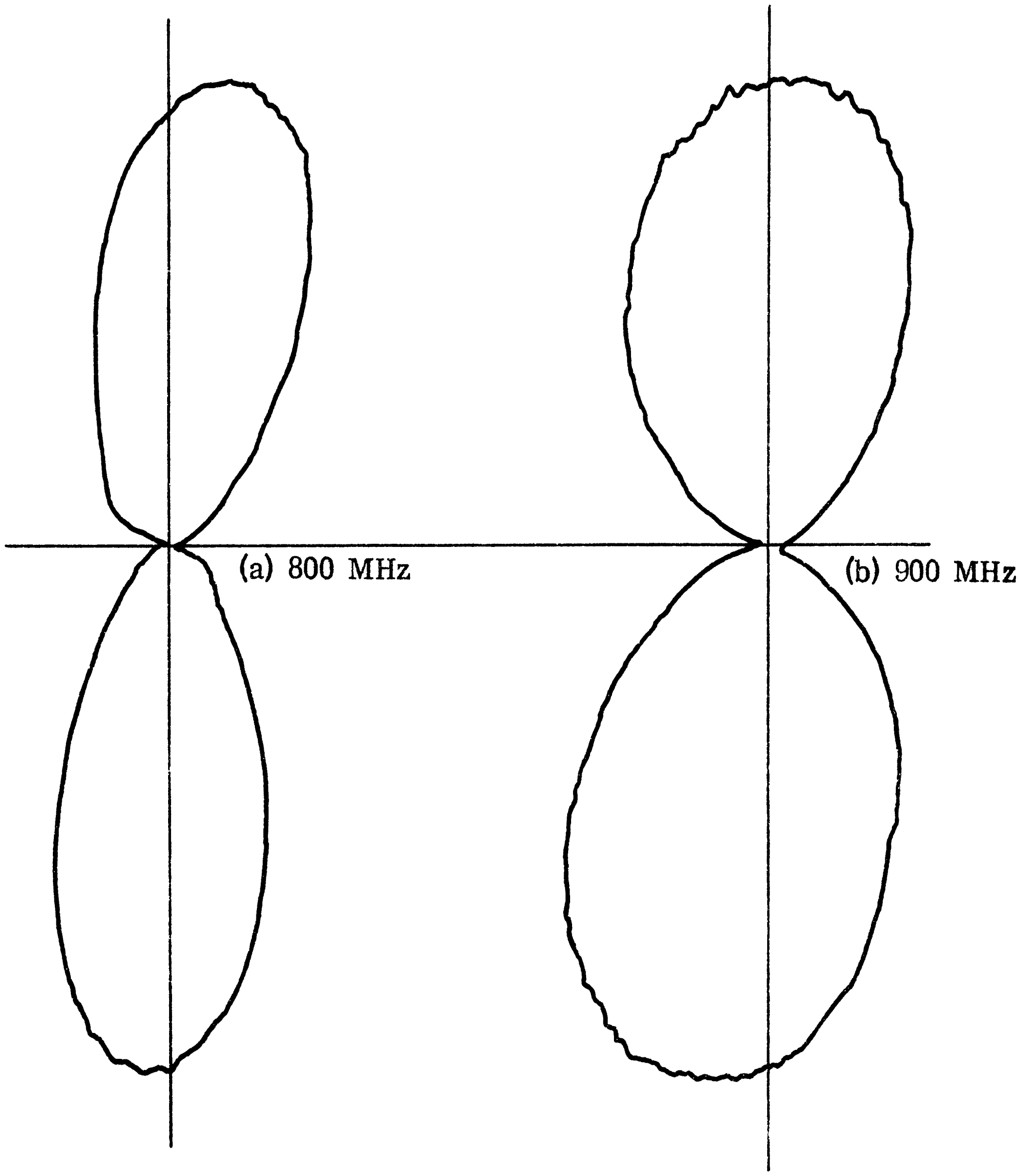


FIG. 3-2: E-PLANE PATTERN OF A DIPOLE ADJUSTED FOR A LENGTH OF 0.46 λ .

TABLE III-1: RELATIVE GAIN FOR 13-ELEMENT INTERDIGITAL ARRAY

Frequency MHz	dB Below a Dipole Cover On	dB Below a Dipole Cover Off
500	12.5	21.5
600	16	6.5
700	15.5	14
800	13	11
900	6	9

TABLE III-2: RELATIVE GAIN FOR CROSS POLARIZATION CONDITIONS FOR THE 13-ELEMENT INTERDIGITAL ARRAY

Frequency MHz	dB Below a Dipole Cover On	dB Below a Dipole Cover Off
500	35	34
600	19	17
700	11	14
800	12	10
900	8	7.5

Some caution is necessary in interpreting the data. The results in the first table were obtained using the highest peak in the $E_\theta(y,z)$ patterns and comparing this with the highest of the two dipole lobes for corresponding frequencies. The ratio of these two signals was converted into dB and then adjusted to account for any difference in the receiver gain setting when the two patterns were recorded. It should be noted that this does not necessarily represent the highest gain of the interdigital array. The $E_\theta(y,z)$ cuts are in the Y-Z plane but in several cases the peak of the array pattern is to the right or the left of the Y-Z plane. This can be seen from the $E_\phi(x,z)$ patterns (e.g. Figs. 2-5b, 2-6c and 2-6d). Furthermore, even if there is a broadside beam in the E_ϕ (x, z) patterns, a split beam or an "endfire" beam in the E_θ(y, z) patterns would result in an indicated low gain. To determine the maximum gain, it would have been necessary to rotate the array on the pedestal in both azimuth and elevation for maximum signal since the peak beam frequently occurs in one of the four quadrants rather than at broadside. It is believed that the substantial differences in relative gain due to the cover shown in Table III-1 for 500 and 600 MHz is due to this effect. We have evidence that the cover causes changes in the beam direction or shape. This was shown in the last part of Chapter II.

Based on the above, it is concluded that the recorded relative gain may be too low. There is no reason to believe that it is too high. The low gain performance is not entirely unanticipated; an antenna operating in close proximity to a ground plane is in part shorted out by the presence of the conducting plane. Such a plane imposes a restrictive boundary condition for the existing field conditions.

The relative gain for the cross polarized case was obtained by making use of dipole patterns similar to those shown in Figs. 3-1 and 3-2 and the E_θ(x, z) patterns. The remarks made in reference to peak gain data apply equally well to the cross polarized data. The results obtained are given in Table III-2. Since this table indicates the level of the cross polarized signal, it should be as low as possible since it represents wasted energy in most normal operations. It is seen that the level is quite low for 500 MHz. It increases to a level which may be unacceptable for some uses at 900 MHz.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) The University of Michigan Radiation Laboratory 2455 Hayward Street Ann Arbor, Michigan 48105	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP NA

3. REPORT TITLE

Experimental Studies on a 13-Element Interdigital Array Antenna

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical, Scientific

5. AUTHOR(S) (First name, middle initial, last name)

John A. M. Lyon and William W. Parker

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1971	28	1

8a. CONTRACT OR GRANT NO. F33615-68-C-1381	9a. ORIGINATOR'S REPORT NUMBER(S) 1770-7-T
b. PROJECT NO. 6278, Task 627801	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	AFAL-TR-71-185

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT

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At the lower range of frequencies the antenna provides a broadside plum-shaped pattern. At higher frequencies there is some end-fire radiation and a split-beam pattern is ultimately observed. Numerous radiation patterns and data on the relative gain are presented. The range of gain is 6 to 16 dB below a half wave resonant dipole. Arguments are presented which indicate that the reported gain is very conservative because of a number of factors; it is expected that the actual gain is higher than recorded. The VSWR is less than 2 over a frequency range from 400 to 650 MHz, the recommended range for broadside operation. The radiation patterns also show a very low side lobe and back lobe level for the frequency range.

DD FORM 1 NOV 65 1473

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Interdigital Array						
Finger-like Array						
Physically Small Antennas						
Parasitic Monopole Array						
Interdigital Antenna Elements						