ANTENNA LABORATORY

Technical Report No. 5

THE SERIES-FED, LOG-PERIODIC FOLDED DIPOLE ARRAY

by
K. G. BALMAIN and J. D. DYSON

Contract No. NEL 30508A

January 1964

Part 5 of Final Report
Covering the Period June 1, 1962-August 31, 1963

Sponsored by
U.S. NAVY ELECTRONICS LABORATORY
San Diego, California

DEPARTMENT OF ELECTRICAL ENGINEERING
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

Antenna Laboratory

Technical Report No. 5

THE SERIES-FED, LOG-PERIODIC FOLDED DIPOLE ARRAY

by

K. G. Balmain and J. D. Dyson

Contract No. NEL 30508A

January 1964

Part 5 of Final Report
Covering the Period June 1, 1962 - August 31, 1963

Sponsored by
U.S. NAVY ELECTRONICS LABORATORY
San Diego, California

Department of Electrical Engineering
Engineering Experiment Station
University of Illinois
Urbana, Illinois

ABSTRACT

The antenna ~~to be~~ described is a new type of unidirectional, plane-polarized, log-periodic antenna array in which the elements are folded dipoles connected in series with the wires of a feeder. In comparison with similar arrays of straight dipoles, the models tested exhibit smaller maximum width, higher directivity and higher impedance. However, construction of the folded dipole array is considerably more difficult due to the shape and required dimensions of the folded elements.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. INTRODUCTION

This report is concerned with the use of folded dipole elements in a log-periodic array. If the array is to operate over a wide range of frequencies it is clear that the elements cannot be connected in shunt across the feeder since the feeder would be effectively shorted out at low frequencies by the shortest elements. This objection to the use of folded dipole elements does not apply when the elements are connected in series with the feeder wires as shown in Figure 1.1. The series connection eliminates the "short circuit problem" but introduces an "open circuit problem" in the form of the quarter-wavelength antiresonance of a folded dipole; at the antiresonance the impedance is very high and the dipole is not an effective radiator when used singly. However it is conceivable that an array of antiresonant dipoles could make an effective radiator. These considerations suggest that the antiresonance effect could be utilized in log-periodic arrays and that such arrays might have smaller maximum widths than similar arrays of straight dipoles (which have been studied extensively by Carrel[1]). Several log-periodic folded dipole arrays have been constructed; measurements on them suggest that the folded dipole array is a useful antenna and show that some width reduction can be obtained. The work is discussed in detail in the following paragraphs (some of the following material has been presented in an earlier paper[2]).

2. PRINCIPLES OF OPERATION

To a first approximation, the elements in an array may be considered to possess the same properties (such as impedance) that they possess when used singly. Of special interest are the resonant lengths of a folded dipole since in a log-periodic array the elements contributing most strongly to the radiated field appear to be those of near-resonant length. In particular, a single folded dipole exhibits a first resonance (or antiresonance) which has been largely ignored in antenna design but which appears to be utilized in the arrays to be described. The first resonance occurs at dipole lengths between $.25\lambda$ and $.40\lambda$; the familiar half-wave resonance is in fact the second resonance of the folded dipole.

The input impedance of a folded dipole may be expressed as follows[3]:

$$Z_{in} = \frac{4Z_d Z_t}{2Z_d + Z_t} \qquad (1)$$

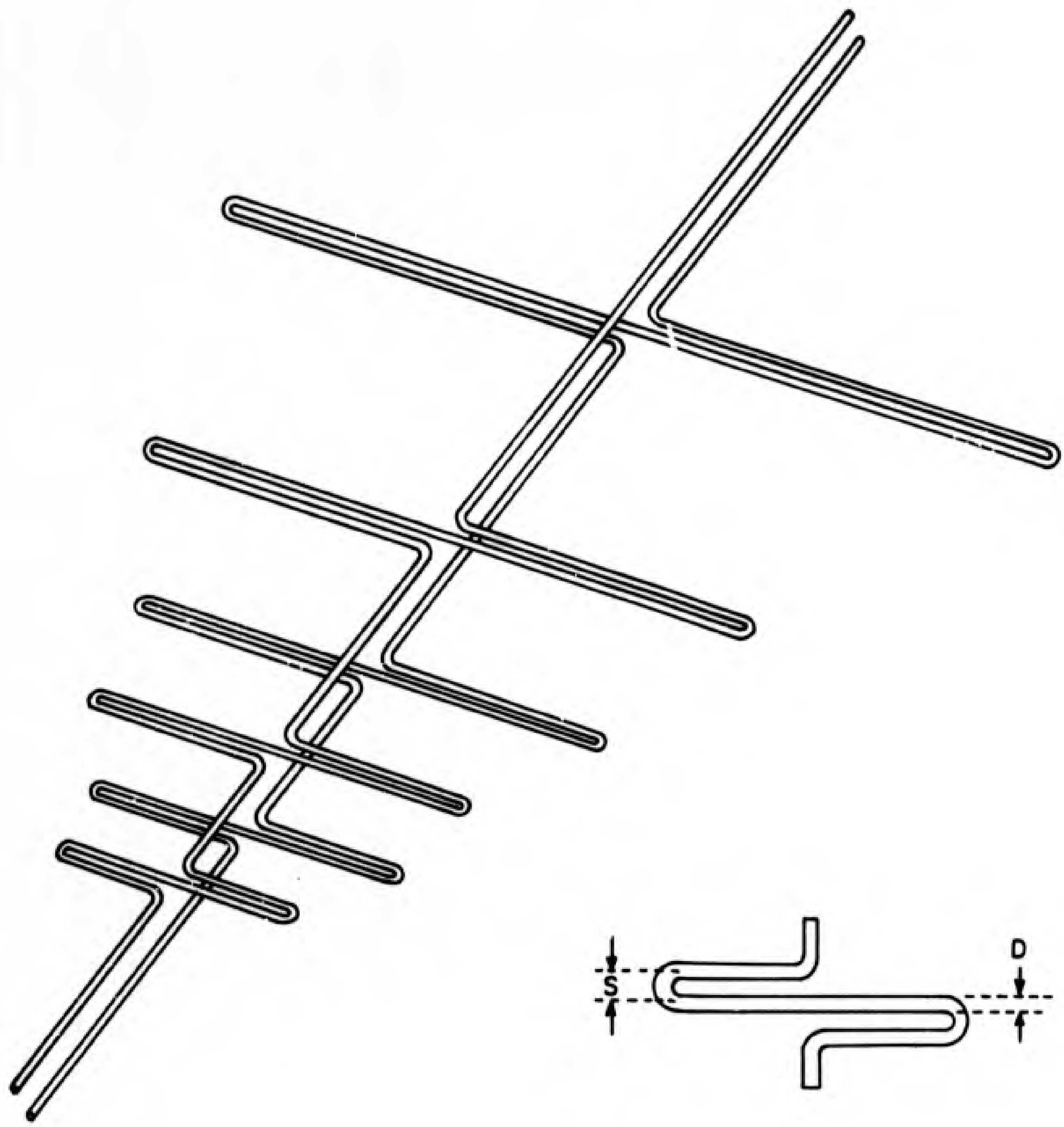


Figure 1.1. The Series-Fed, Log-Periodic Folded Dipole Array.

In the above formula, Z_t is the input impedance of the shorted transmission line making up half the folded dipole and Z_d is the input impedance of a straight dipole made up of the two folded dipole conductors connected together. Z_t is given by

$$Z_t = j\, Z_c \tan \beta \frac{\ell}{2} \qquad (2)$$

where Z_o is the characteristic impedance of the shorted transmission line, $\beta = \frac{\omega}{c}$, and ℓ is the dipole length. The equivalent diameter D_e necessary to obtain Z_d is given by

$$D_e = D\sqrt{2\,\gamma} \qquad (3)$$

where $\gamma = \frac{S}{D}$ (see Figure 1.1).

Equation (1) shows that $2Z_d$ and Z_t are in parallel; thus if X_d and X_t are the reactive parts of Z_d and Z_t, resonance occurs when $2X_d \approx - X_t$. The behavior of $2X_d$ and $-X_t$ is sketched as a function of dipole length in Figure 2.1 from which it is evident that the resonant length can be increased either by decreasing the conductor spacing S or by decreasing the conductor diameter D. The resonant length is quite sensitive to changes in folded dipole dimensions, a factor which complicates array design considerably.

The above paragraphs have developed the viewpoint that the log-periodic antenna is an array of resonant elements. The phasing of these elements can be displayed on the Brillouin (or k-β) diagram of the array. It has been demonstrated[4] that the Brillouin diagram suggests the division of periodic antennas into two classes, those that exhibit resonance characteristics (monopole and dipole arrays) and those that do not (helix and zig-zag arrays). Measured Brillouin diagrams suggest that the folded dipole array belongs to the non-resonant class. Evidently the words "resonant" and "non-resonant" both can be applied to the antenna depending on whether the element impedance or the cell-to-cell phasing is being discussed.

3. EXPERIMENTAL RESULTS

If only the first resonance region in a log-periodic folded dipole array were excited, the array could be truncated where the element length is sub-

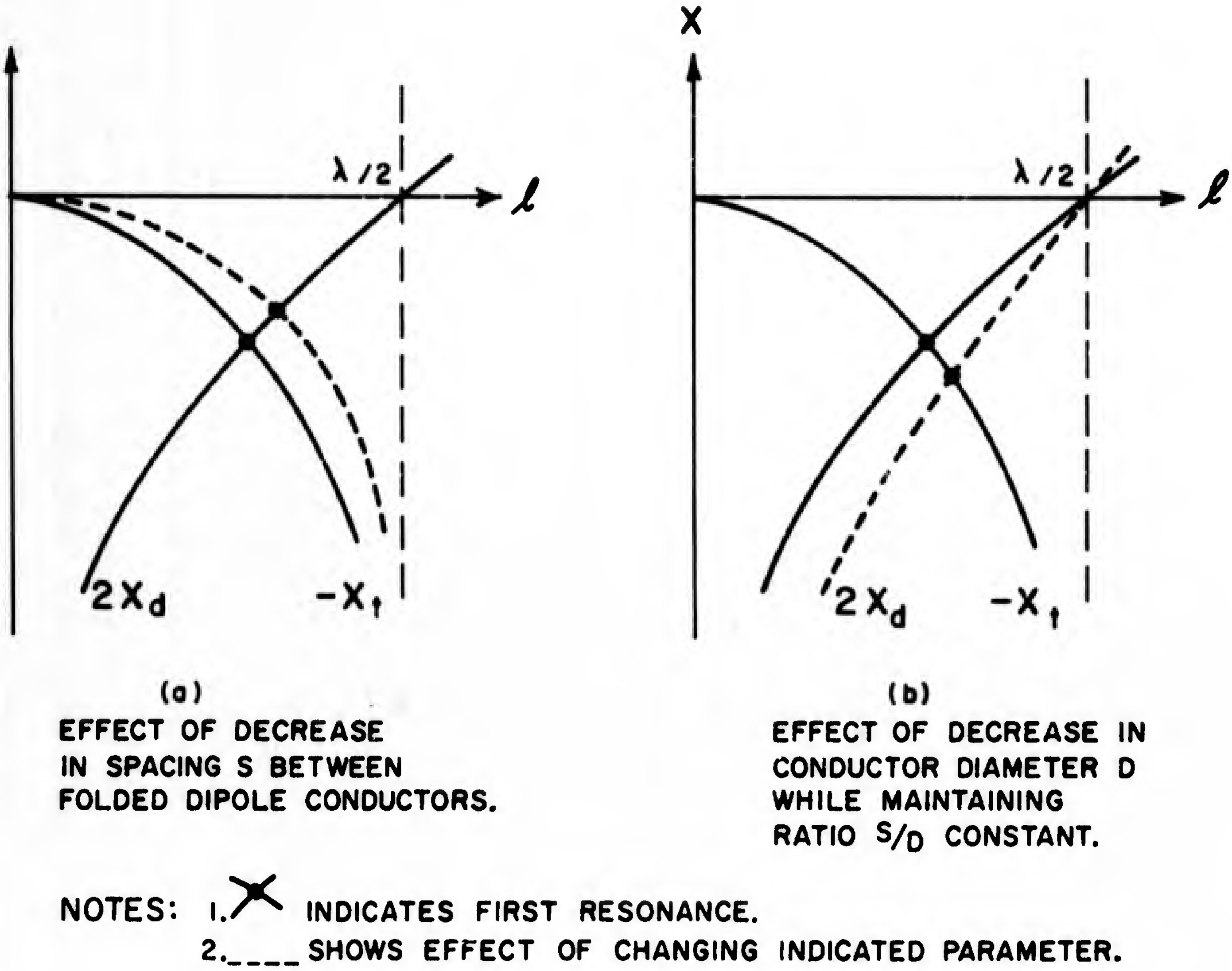


Figure 2.1. Graphs of Reactance vs. Element Length Showing the First Resonance of a Folded Dipole Element.

stantially less than a half-wavelength. A width reduction of this type amounting to 22% (a saving of four elements) has been obtained with one antenna model, the criterion for low frequency cutoff being a 12 db front-to-back ratio. The width reduction was obtained at the cost of a 0.4 db loss in directivity at the lowest operating frequency. The array width and directivity (see Kraus[5] for definition) are compared with those of the corresponding straight dipole array computations given by Carrel[1]. The experimental model had the parameter values $\tau = .94$, $\sigma = .10$ where τ is the length ratio between adjacent elements and σ is the distance in wavelengths between a half-wavelength element and its next-smaller neighbor.

Most of the log-periodic folded dipole arrays constructed so far exhibit a midband directivity which is equal to or greater than the theoretical directivity of similar arrays of straight dipoles. One array with $\tau = .90$, $\sigma = .10$ had a midband directivity of 10.8 db, 2.0 db higher than the corresponding array of straight dipoles. However, this array exhibited no width reduction. A typical midband voltage radiation pattern is shown in Figure 3.1.

It should be noted that the choice of parameters in the aforementioned arrays was found to be fairly critical. The characteristic impedance Z_o of the folded elements was about 120 ohms; higher values tended to result in objectionable sidelobes and back lobes in the radiation patterns. In addition, values of ℓ/D_e much smaller than about 30 resulted in beam splitting and sidelobes. The feeder impedance used was 160 ohms; values up to 250 ohms were tried but in general, feeder impedances between 150 and 200 ohms gave the best results.

A few antennas have been constructed using printed circuit techniques; a photograph of one is shown in Figure 3.2. The folded elements are shorted back from the end to compensate for the change in phase velocity along the dipole due to the dielectric sheet. For this array $\tau = .90$, $\sigma = .10$ and $z_o \approx 120$ ohms. The feeder impedance is approximately 200 ohms. The longest element is a half-wavelength at 750 Mc and the structure bandwidth ratio is 4.3:1.

A set of radiation patterns for the printed circuit antenna is shown in Figure 3.3. The average directivity is about 8.6 db, identical to the theoretical value for straight dipoles and .5 to 1.0 db over the experimental values for straight dipoles. The width reduction is approximately 10% and the frequency bandwidth ratio is 3.5:1. The Smith chart of Figure 3.4 displays a set of impedance measurements referred to 300 ohms and covering the same frequency range as used in the radiation pattern measurement. The VSWR of all but two of the points is

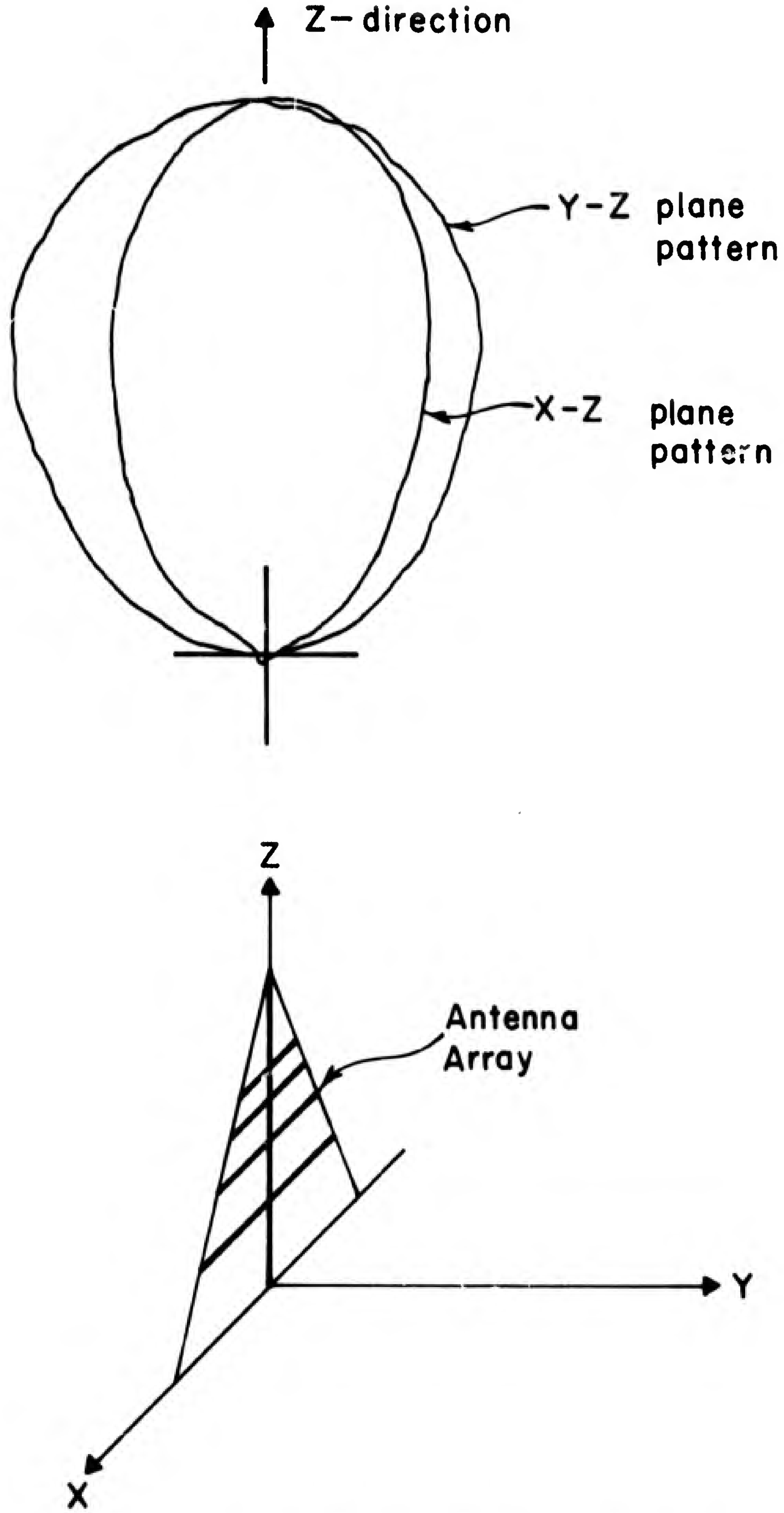
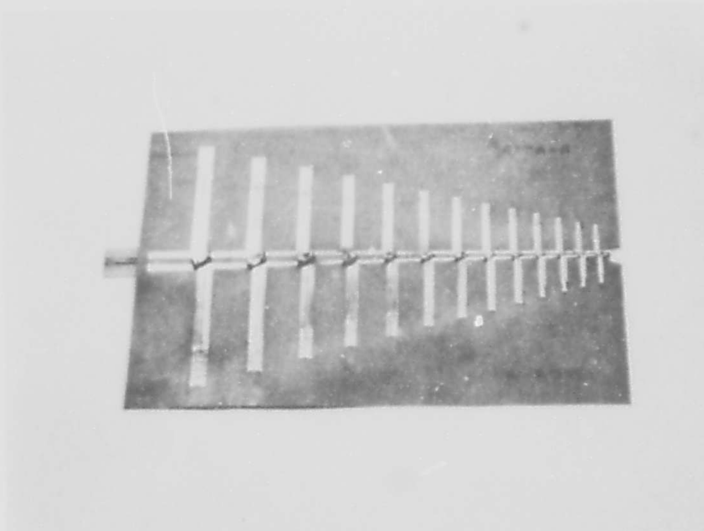
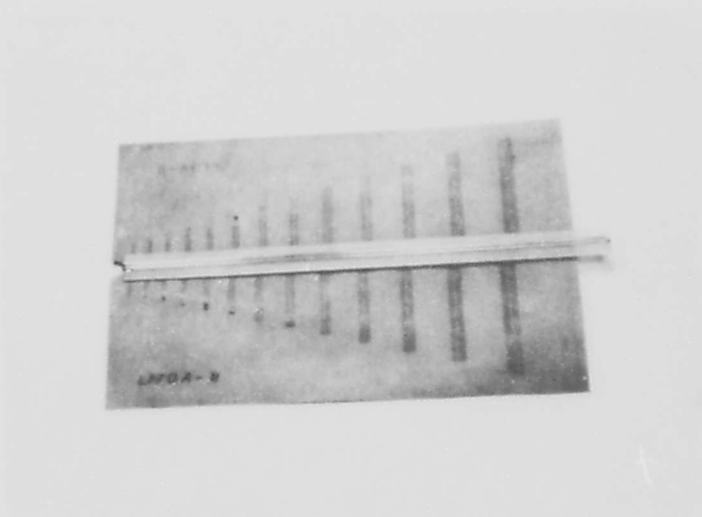


Figure 3.1. Typical Midband Radiation Patterns.



FRONT VIEW



BACK VIEW

Figure 3.2. A Printed Circuit Folded Dipole Array.
(Front and back views).

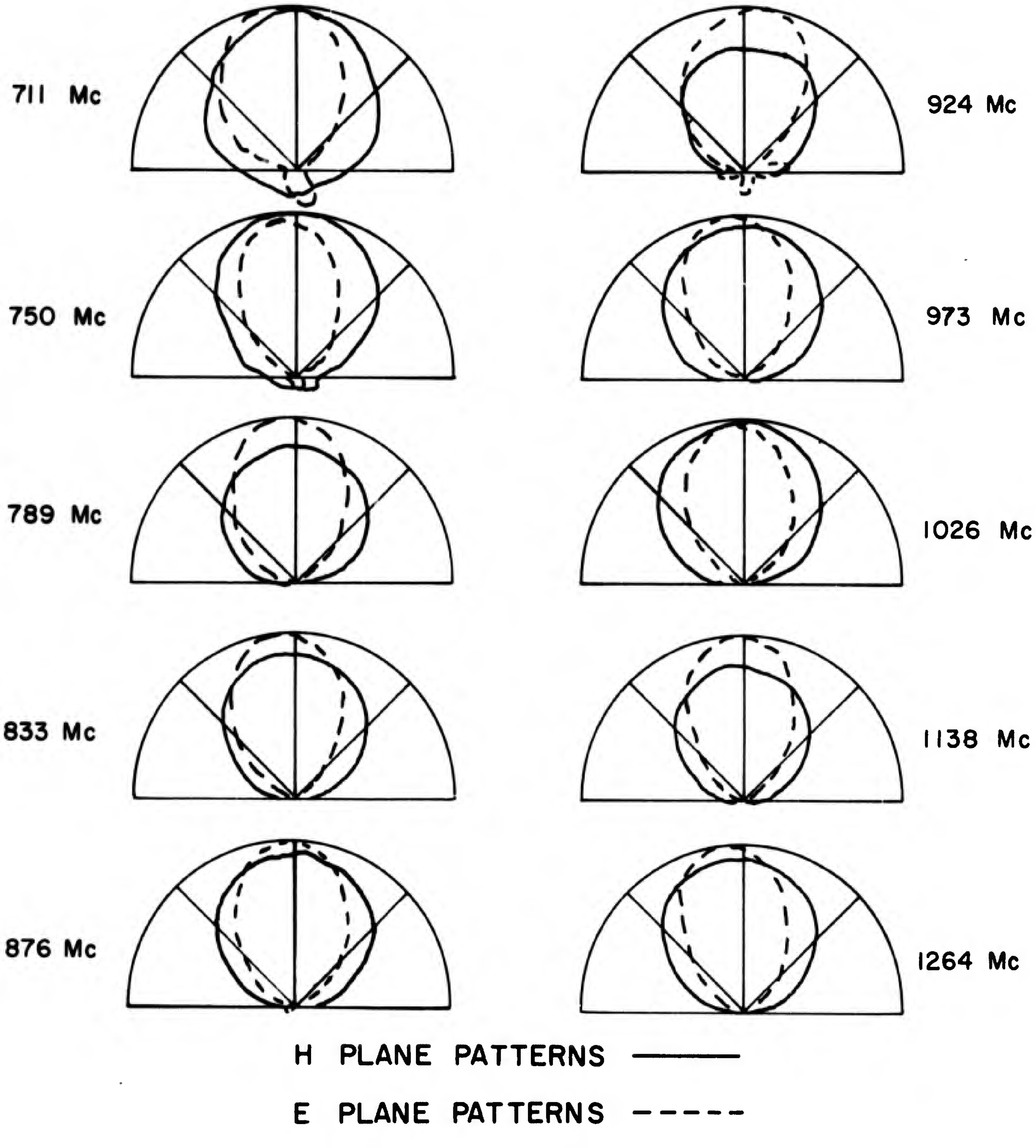


Figure 3.3a. Radiation Patterns of the Printed Circuit Array of Figure 3.2.

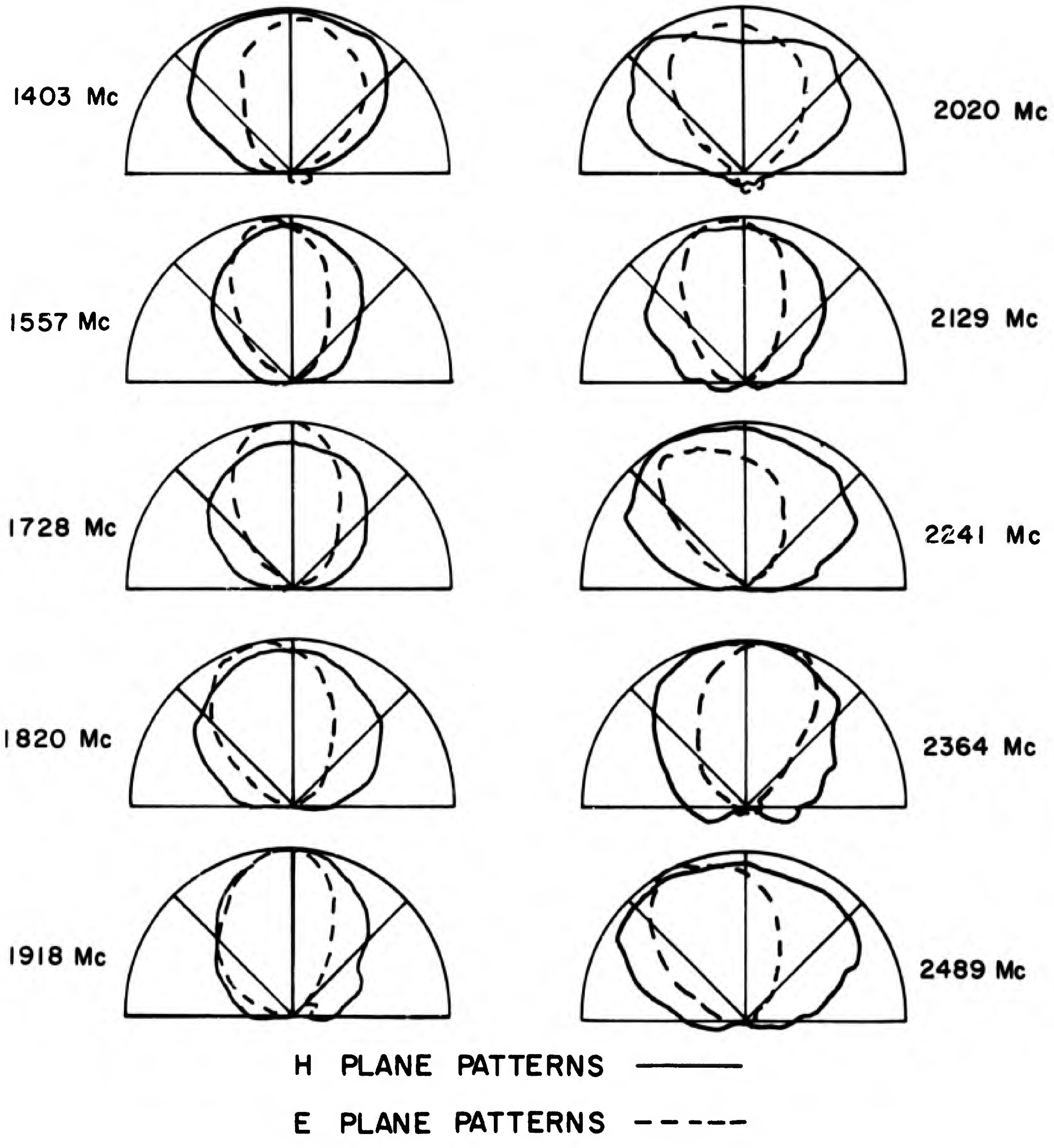


Figure 3.3b. Radiation Patterns of the Printed Circuit Array of Figure 3 2.

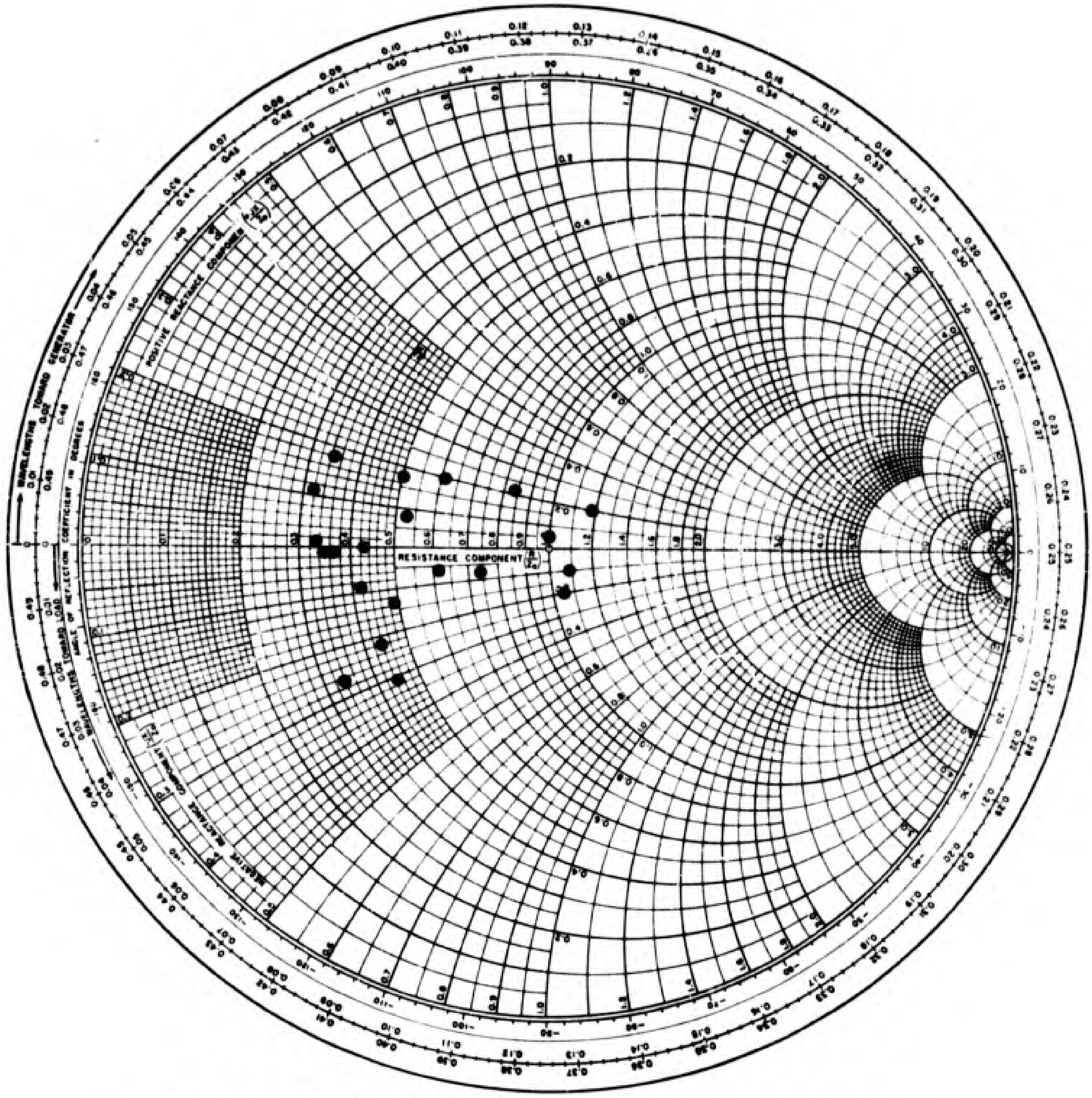


Figure 3.4. Impedance of the Printed Circuit Array.

less than two, referred to 190 ohms. The measured input impedances on this antenna (and on others) are very close to the characteristic impedance of the feeder.

The excitation of the elements in the printed circuit antenna has been estimated from near field amplitude measurements along the array. These measurements were made with a small, shielded loop located in the (y,z) plane (see Figure 3.1) one centimeter from the array and with the loop axis parallel to the z axis. Figure 3.5 is a typical near field amplitude graph and shows clearly the excitation of two regions, one near the first resonance ($\ell \approx 1/3\lambda$) and one near the second resonance ($\ell \approx 1/2\lambda$). The increased gain of this type of antenna is believed to result from the extended active region. However, size reduction clearly depends on the antenna's ability to radiate most of its energy in the region of the first resonance.

The phase characteristics of the printed circuit array were measured with the same experimental set-up as used for the near field amplitude measurements; a typical Brillouin diagram is shown in Figure 3.6. This diagram does not exhibit the resonant characteristics of diagrams for monopole and dipole arrays. Instead it has an appearance similar to that obtained for the zig-zag and concial log-spiral antennas[6]. The asymptotic line in the Brillouin diagram was determined from the ratio of cell width "a" to the total conductor length per cell. The excellent agreement between this line and the experimental points suggests a wave velocity equal to the velocity of light along the conductor.

4. CONCLUSIONS

It has been demonstrated that the series-fed, log-periodic folded dipole array is a useful antenna, especially in the printed circuit form. In comparison with arrays of straight dipoles, higher gain, higher impedance and width reduction as high as 23% have been obtained. However, it is clear that more study is necessary in order to determine the optimum dimensions of the array and to realize the maximum width reduction which may be on the order of 30%.

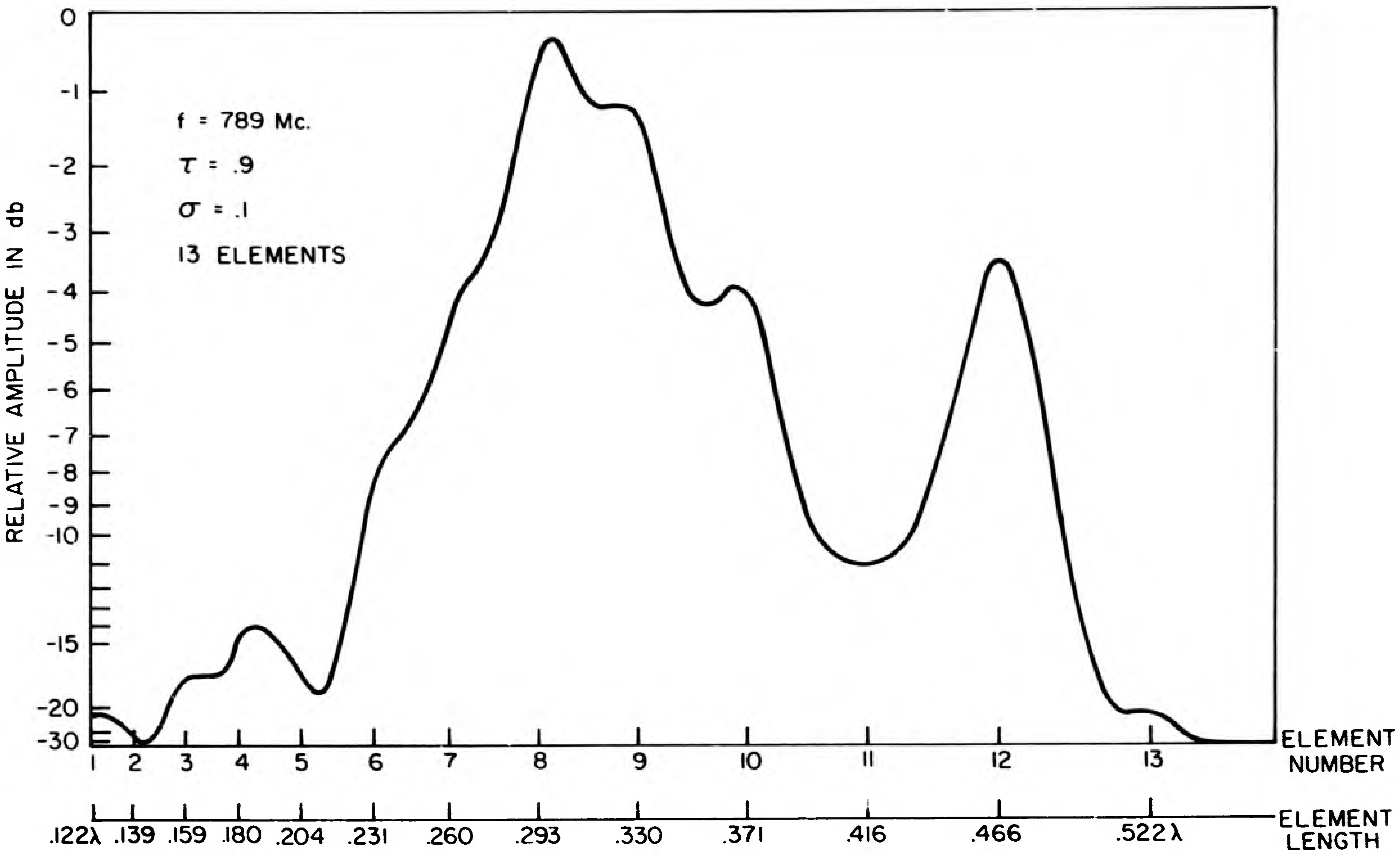


Figure 3.5. Near Field Amplitude of the Printed Circuit Array.

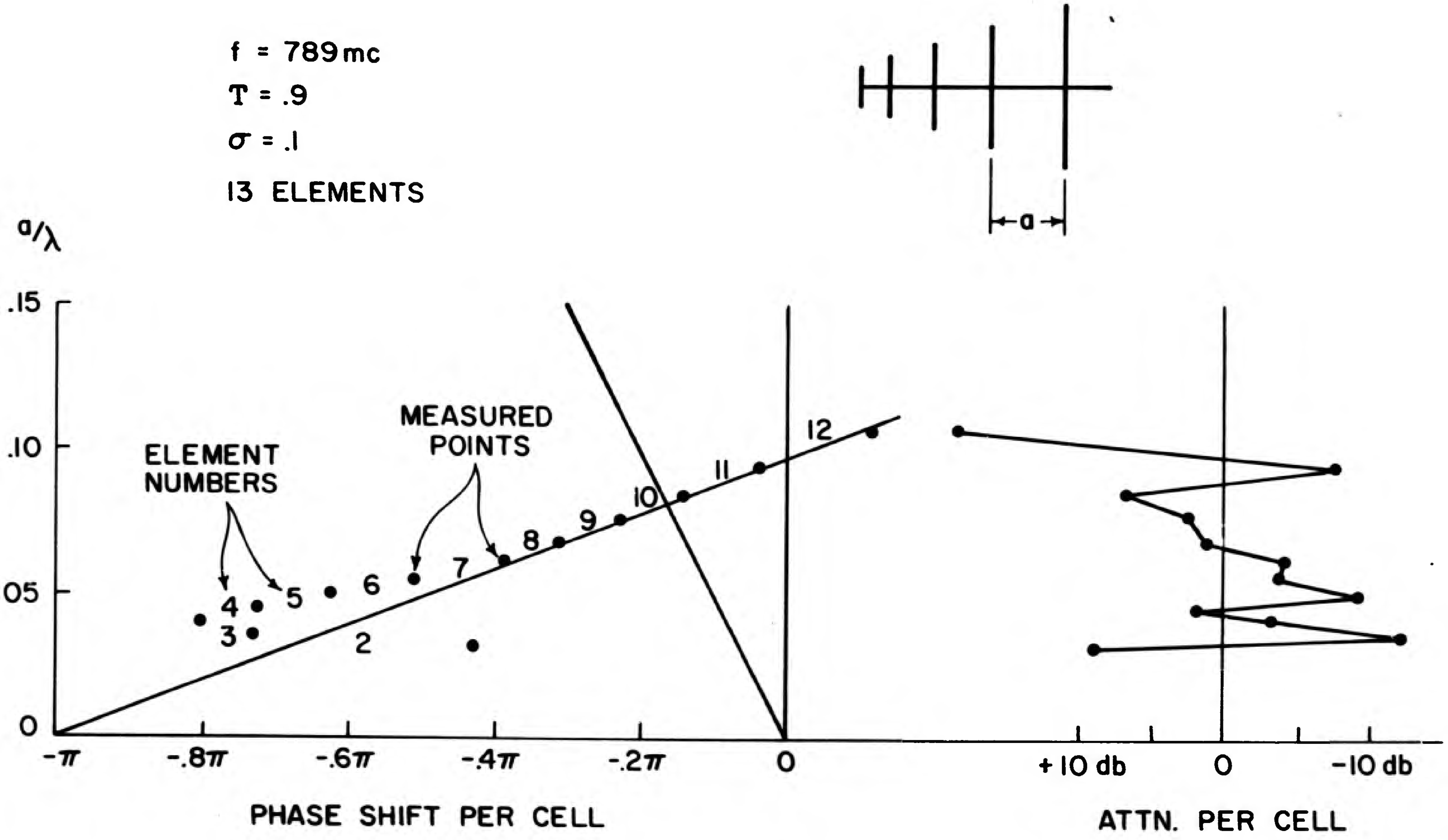


Figure 3.6. Brillouin Diagram Obtained from Near Field Measurements. The Cells are Numbered 1 to 13, Beginning with the Smallest; the Longest Element is 20 cm. long.

REFERENCES

1. Carrel, R.L., "Analysis and Design of the Log-Periodic Dipole Antenna", Antenna Laboratory Technical Report No. 52, Electrical Engineering Research Laboratory, University of Illinois.

2. Balmain, K.G. and Dyson, J.D., "The Series-Fed, Log-Periodic Folded Dipole Array", Presented at the 1963 PTGAP International Symposium, Boulder, Colorado, July, 1963.

3. Antenna Engineering Handbook (H. Jasik, Editor), Chapter 3, McGraw-Hill, 1961.

4. Mayes, P.E., Deschamps, G.A., Patton, W.T., "Backward-Wave Radiation from Periodic Structures and Applications to the Design of Frequency-Independent Antennas", Proc. IRE, Vol. 49, No. 5, pp. 962-963, May 1961. (Treated in greater detail in Technical Report No. 60, Antenna Laboratory, University of Illinois, Contract AF33(657)10474, December 1962.)

5. Kraus, J.D., Antennas, Page 27, McGraw-Hill, 1950.

6. Dyson, J.D., "Near Field Measurements on the Conical Logarithmic Spiral Antenna" Presented at the 1963 PTGAP International Symposium, Boulder, Colorado, July 1963.