AD649838

EDL-M1016

AD

TECHNICAL REPORT ECOM-01829-M1016

LOG-PERIODIC ANTENNA TECHNIQUES

By

L. G. BULLOCK - C. T. ELFVING - S. K. MILLER

APRIL 1967

ECOM
UNITED STATES ARMY ELECTRONICS COMMAND FORT MONMOUTH, N.J.
CONTRACT DA 28-043 AMC-01829(E)
SYLVANIA
ELECTRONIC DEFENSE LABORATORIES
Mountain View, California

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

70

EDL-M1016

TECHNICAL REPORT ECOM-01829-M1016

APRIL 1967

LOG-PERIODIC ANTENNA TECHNIQUES

CONTRACT NO. DA 28-043 AMC-01829(E)

Prepared by
L.G. BULLOCK - C.T. ELFVING - S.K. MILLER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ELECTRONIC DEFENSE LABORATORIES
SYLVANIA ELECTRIC PRODUCTS INC.
Mountain View, California 94040

For

U.S. ARMY ELECTRONICS COMMAND, FORT MONMOUTH, NEW JERSEY 07703

CONTENTS

Section	Title	Page
1.	INDUCTIVELY LOADED FORESHORTENED LOG-PERIODIC ANTENNAS	1
1.1	Summary	1
1.2	Inductive Loading	1
1.3	Tilted Elements	21
1.4	Log-Periodic Antenna with Large α-Angle	26
2.	CAPACITIVELY LOADED FORESHORTENED LOG-PERIODIC DIPOLE ARRAYS	31
2.1	Summary	31
2.2	Types of Capacitive Loading Investigated	32
2.3	Measurements and Test Results	32
2.4	Future Plans	35
3.	SQUARE-BOOM LOG-PERIODIC ANTENNAS	36
3.1	Summary	36
3.2	Boom Construction and Impedance	36
3.3	Characteristic Impedance of Transmission Line	41
3.4	Antenna Performance	45
3.5	Conclusions	61

ILLUSTRATIONS

Figure	Title	Page
1	Design Ratio Versus Element Number	3
2	Element Foreshortening Versus Element Number	4
3	Foreshortening Versus Loading Coil Reactance	6
4	One Boom of a Loaded Log-Periodic Antenna with Varying Design Ratio and Constant Spacing-to-Length Ratio	7
5	Standard Log-Periodic Antenna	8
6	Absolute Gain of Standard Log-Periodic Antenna	10
7	Foreshortened Log-Periodic Antennas	11
8	Foreshortened Log-Periodic Antennas with Varying Design Ratios	12
9	Foreshortened Log-Periodic Antennas with Varying Design Ratios and Constant Spacing-to-Length Ratios	13
10	Standard Log-Periodic Antenna and Log-Periodic Antenna Foreshortened by 3:1	14
11	Patterns of Log-Periodic Antennas Foreshortened by 1.5:1	15
12	Gains of Log-Periodic Antennas Foreshortened by 1.5:1	16
13	Patterns of Log-Periodic Antennas Foreshortened by 2:1	17
14	Gains of Log-Periodic Antennas Foreshortened by 2:1	18
15	Patterns of Log-Periodic Antennas Foreshortened by 3:1	19
16	Gains of Log-Periodic Antennas Foreshortened by 3:1	20
17	Log-Periodic Antennas with Tilted Elements	22
18	Patterns of Conventional Log-Periodic Antennas with 23 Elements (Figure 17a)	23
19	Patterns of Conventional Log-Periodic Antennas with all 23 Elements Tilted 45-Degrees Forward (Figure 17b)	23
20	Patterns of Log-Periodic Antenna with all 15 Elements Tilted 45-Degrees Forward (Figure 17c)	24
21	Patterns of 23-Element Log-Periodic Antenna with Only the Longer Elements Tilted Forward (Figure 17d)	24
22	Patterns of 15-Element Log-Periodic Antenna with Only the Longer Elements Tilted Forward (Figure 17e)	25
23	Patterns of 15-Element Log-Periodic Antenna with the Longer Elements Bent Forward (Figure 17f)	25
24	Gain of 15-Element Log-Periodic Antenna with Longer Elements Bent Forward (Figure 17f)	27

ILLUSTRATIONS --Continued

Figure	Title	Page
25	Short-Boom Log-Periodic Antenna	28
26	Patterns of Short-Boom Log-Periodic Antenna (Figure 25a)	29
27	Patterns of Short-Boom Log-Periodic Antenna with 45 Degree Elements (Figure 25b)	29
28	Patterns of Short-Boom Log-Periodic Antenna with Bent Elements (Figure 25c)	30
29	Resistance Versus Antenna Length for Various Loadings	34
30	Array of Log-Periodic Dipole Antennas with Cylindrical Rod Beam	37
31	Array of Square-Boom Log-Periodic Dipole Antennas	38
32	Circularly Polarized Log-Periodic Dipole Antenna Employing Square-Boom Construction	39
33	Methods of Square-Boom Construction	40
34	Square-Boom Log-Periodic Dipole Antenna	42
35	Unloaded Transmission Line Impedance of Parallel-Plane Line (Square-Boom Configuration)	44
36	E-Plane Patterns for Antenna Model No. 1	47
37	H-Plane Patterns for Antenna Model No. 1	48
38	E-Plane Patterns for Antenna Model No. 2	49
39	H-Plane Patterns for Antenna Model No. 2	50
40	E-Plane Patterns for Antenna Model No. 3	51
41	H-Plane Patterns for Antenna Model No. 3	52
42	E-Plane Patterns for Antenna Model No. 4	53
43	Frequency Versus 3-db Beamwidth (Antenna Model No. 1)	55
44	Frequency Versus 3-db Beamwidth (Antenna Model No. 2)	56
45	Frequency Versus 3-db Beamwidth (Antenna Model No. 3)	57
46	Frequency Versus 3-db Beamwidth (Antenna Model No. 4)	57
47	VSWR Versus Frequency for Antenna Model No. 1	58
48	VSWR Versus Frequency for Antenna Model No. 2	59
49	VSWR Versus Frequency for Antenna Model No. 3	60

ABSTRACT

This report describes several investigations conducted during the past year in the area of log-periodic antennas. The work on inductively loaded, foreshortened log-periodic antennas included measurement of patterns and gains of antenna models which were foreshortened by various amounts. Capacitive top-loading of monopole antennas was also investigated to develop other techniques for log-periodic antenna foreshortening. Finally, a new, flat plate boom configuration for stronger and less expensive construction of log-periodic dipole array antennas is described.

BLANK PAGE

1. INDUCTIVELY LOADED FORESHORTENED LOG-PERIODIC ANTENNAS

1.1 Summary

The investigation of foreshortening log-periodic antennas by inductively loading the radiating elements was continued from last year's activities. This year's effort included a more careful look at how foreshortening affects the efficiency of the log-periodic antenna. Antenna models with maximum foreshortening of 1.5 to 1, 2 to 1, and 3 to 1 were constructed. Gains and patterns of these models were measured and compared with the gains and patterns of a conventional log-periodic antenna without any element foreshortening.

Another means of reducing the overall size of a log-periodic antenna was investigated this year. By folding the elements forward (from perpendicular to the transmission line-boom of the antenna) to an angle of 45 degrees, some size reduction can be realized. The effect of this folding on the performance of the antenna was measured on several antenna models, as described below.

Capacitive top-loading of the radiating elements is still another way of foreshortening a log-periodic antenna. The effects of several types of top-loading on the performance of a dipole is reported in Section 2. However, the results of measurements taken on a log-periodic antenna model using one form of capacitive top-loading of the elements are discussed briefly in the following paragraphs. These measurements also show the effect of a very large element-angle (α) on the performance of log-periodic antennas. An angle (α) of 126 degrees was used on this model to keep the boom length of the antenna below an allowable maximum for a specific application.

1.2 Inductive Loading

Before describing the measurements taken this year, the principles of inductively foreshortening log-periodic antennas will be briefly reviewed.

When designing a log-periodic antenna with foreshortened elements, it is not usually required to foreshorten all elements on the structure by the same amount. On the contrary, it is desirable to keep the foreshortening to a minimum to retain the highest possible element efficiency. This suggests a constant-width antenna,

1.2 (Continued)

with the largest foreshortening applied to the longest, low-frequency elements and with less foreshortening for the elements of higher frequencies, up to the point on the structure where no foreshortening would be required. At this point a regular unloaded log-periodic antenna would continue to the highest frequency of interest.

To maintain the same frequency-independent performance through the loaded portion of the antenna as through the unloaded portion, the current distribution in the elements around a resonant element must be the same for the two regions. As the inductive loading of the elements in the foreshortened region of the antenna is increased, the Q of the element increases. Because the foreshortened or loaded elements are more frequency-sensitive than the unloaded elements, the resonant frequencies of the loaded elements must be closer together to allow the same current flow in the elements around a resonant element for all frequencies of antenna operation. This means that the electrical lengths of the loaded elements must be more nearly alike; in other words, the design ratio (τ) must become larger as the inductive loading is increased.

The required rate of change of the design ratio (τ) is shown in Figure 1 for four common values of τ_o, the design ratio of the unloaded section of the antenna. The element numbers (n) of Figure 1 are for the loaded elements of the structure, starting with the element with the least amount of loading.

With the design ratios known, the electrical lengths and thus the required element foreshortenings can be obtained for all elements in the loaded region of the antenna, using the following relationships:

$$\tau_n^{1/2} = \frac{\ell_{n-1}}{\ell_n} \; ; \quad \text{Foreshortening} = \text{F.S.} = \frac{\ell_n}{\ell_o} \; ,$$

where ℓ_o is the length of the longest unloaded element.
The amount of foreshortening required for each element is shown in Figure 2.

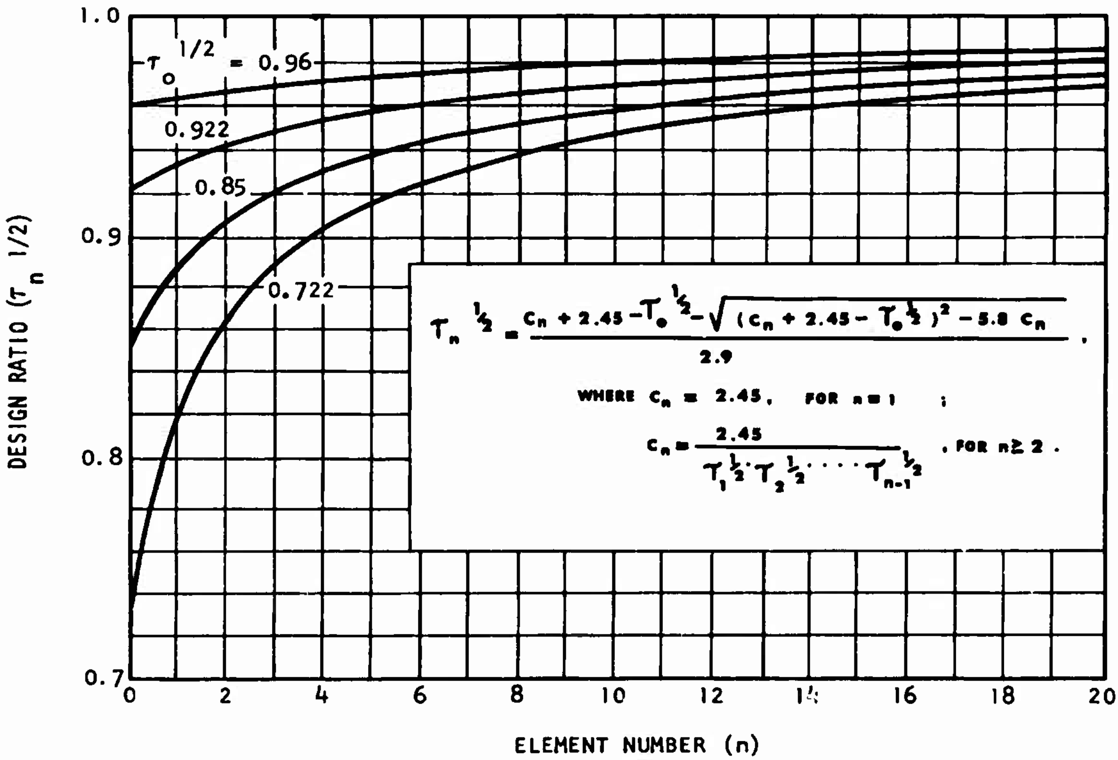


Figure 1. Design Ratio Versus Element Number.

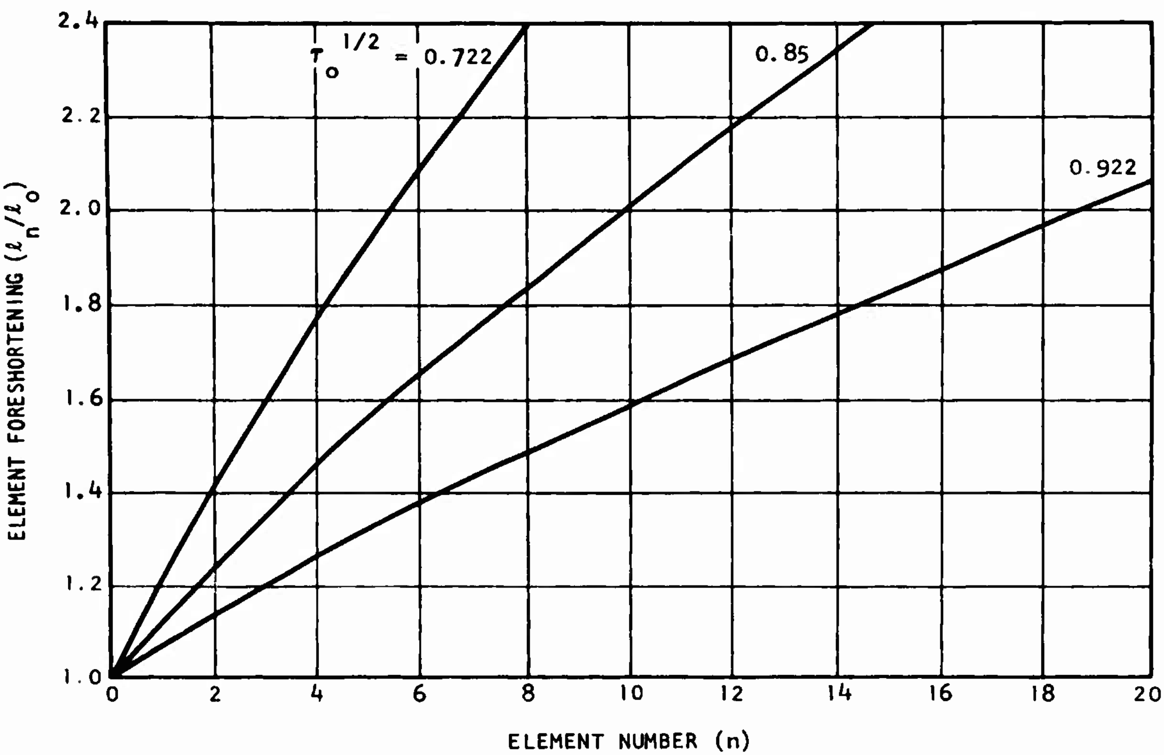


Figure 2. Element Foreshortening Versus Element Number.

1.2 (Continued)

The amount of loading coil reactance required to obtain a given amount of foreshortening is dependent on the diameter and length of the elements and the position of the coil on the element. Figure 3 shows inductive reactance versus foreshortening which was experimentally determined for base-loaded, very thin wire elements.

By increasing the design ratio, τ, as the amount of inductive loading is increased, the current distribution in the elements about the resonant element is kept the same throughout the entire frequency range of the structure. The "active region", or the radiating portion of the antenna, thus contains the same number of elements at any operating frequency throughout the band. To ensure a pseudo-frequency independent type of operation over the whole frequency band, the size of the active region must be kept constant in terms of wavelengths, throughout the band. This is done by keeping the element-spacing-to-electrical-length ratio constant.

The spacing-to-electrical-length ratio is

$$\frac{S}{\ell} = \frac{1 - \tau}{\tan \frac{\alpha}{2}}$$

If τ increases, α has to decrease to keep this ratio constant.

Because the required number of elements is greater (as discussed earlier), a constant spacing-to-length ratio throughout the structure results in a longer structure than that of a regular log-periodic dipole array.

Figure 4 shows an antenna configuration with an increasing design ratio, τ, and a constant spacing-to-electrical-length ratio, designed for frequency-independent operation.

Experimental Models. To verify the design principles described above and to determine the efficiency loss with increasing element foreshortening, several antenna models were built and tested this year.

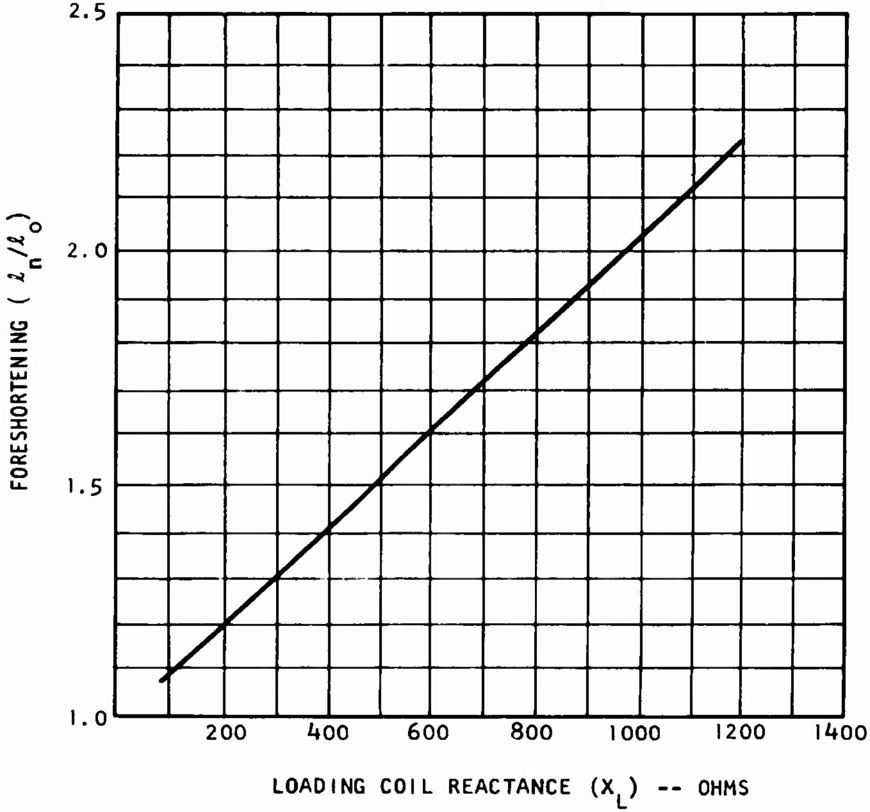


Figure 3. Foreshortening Versus Loading Coil Reactance.

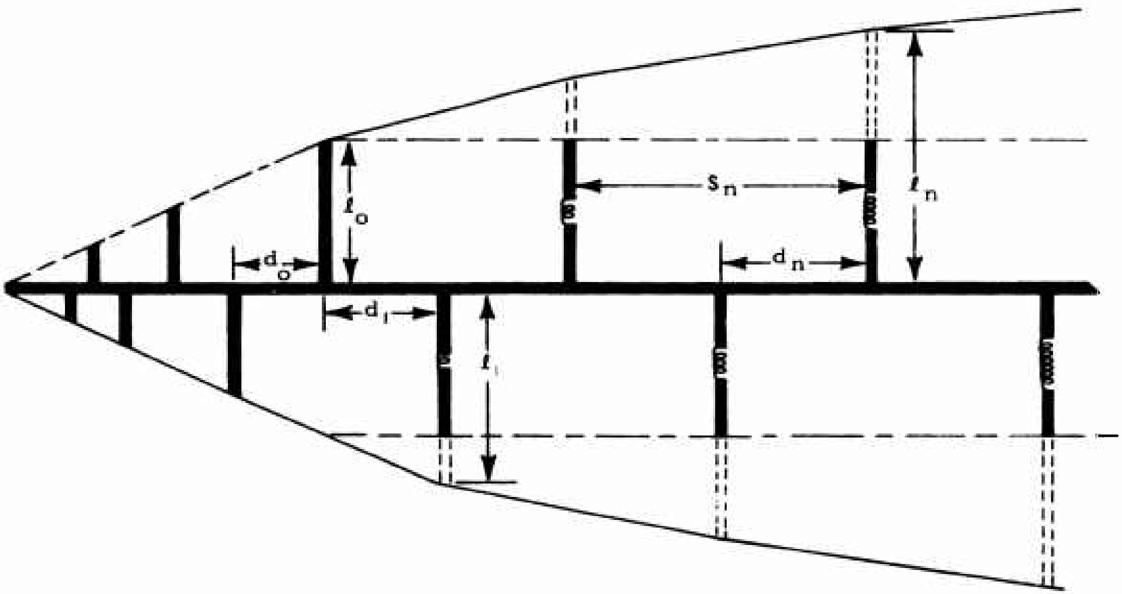


Figure 4. One Boom of a Loaded Log-Periodic Antenna with Varying Design Ratio and Constant Spacing-to-Length Ratio

1.2 (Continued)

Figure 5 is a photograph of a regular log-periodic antenna without any inductive loading applied to the elements. This antenna was used as a standard, to which all subsequent foreshortened log-periodic antennas were compared. The specific design parameters of this antenna were:

a. $\tau_o^{1/2} = 0.85$

b. $\alpha/2 = 22.5°$

c. ℓ_n = 12 inches (longest element)

d. Frequency range = 250 to 800 Mc.

Figure 5. Standard Log-Periodic Antenna

1.2 (Continued)

The absolute gain, with respect to isotropic, of the unloaded log-periodic antenna is shown in Figure 6. This antenna and the loaded antennas were all constructed in a similar manner, with a 50-ohm coaxial cable feeding the antenna through one of the antenna booms in a conventional way. No attempts were made to match the nominal impedance of the antenna (approximately 125-ohms for the unloaded antenna) to the 50-ohm impedance of the feed line.

Figures 7, 8, 9, and 10 show photographs of the various foreshortened antennas that were built and tested. The antennas of Figure 7 have been foreshortened to various degrees by inductively loading the elements, but the increasing Q of the elements has not been compensated for by increasing the design ratio, τ. The antennas of Figure 8 are foreshortened by the same amounts, but the design ratio increases as the loading increases to give the antenna the proper number of radiating elements at any frequency. The spacing between elements has not been adjusted to keep the spacing-to-length ratio constant throughout the structure for a frequency independent type of operation. The axial lengths of these antennas are the same as those of Figure 7. Figures 9 and 10 show the models built with compensating design ratios, τ, and with constant spacing-to-length ratios. In Figure 10 the unloaded antenna, with which the performance of the other antennas are compared, is shown with the 3:1 foreshortened antenna.

The effect of increasing the design ratio, τ, and keeping the spacing-to-length ratio constant can be seen on the E-plane patterns and relative gains of Figures 11 through 16. The dotted straight line on the gain curves of Figures 12, 14, and 16 is the 6-db per octave decrease in efficiency that can be expected of a single dipole, even when an effective impedance matching technique is used. The matching technique involves tuning out the antenna reactance and then using reactive matching or an impedance matching transformer to match the resistance level of the antenna circuit to the load. If no matching is attempted, but the dipole is connected directly to the transmission line, the efficiency will decrease at a rate of 12-db per octave as the frequency is reduced below resonance.

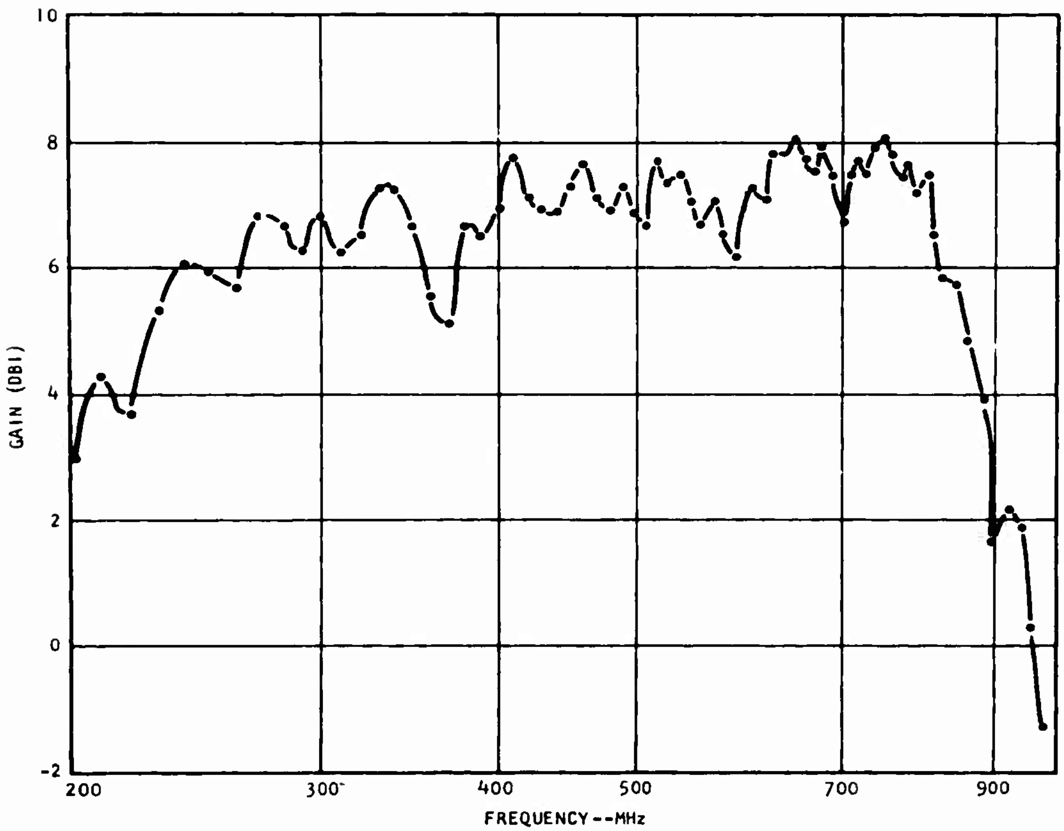
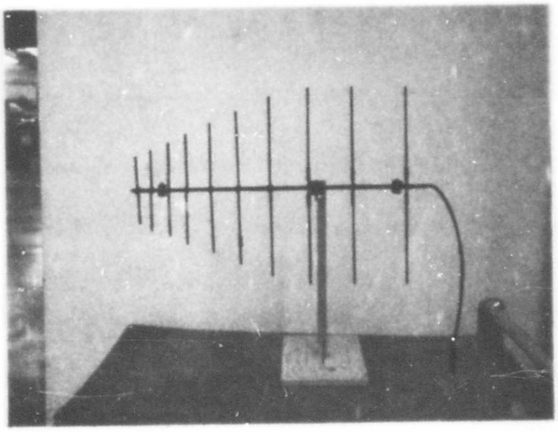
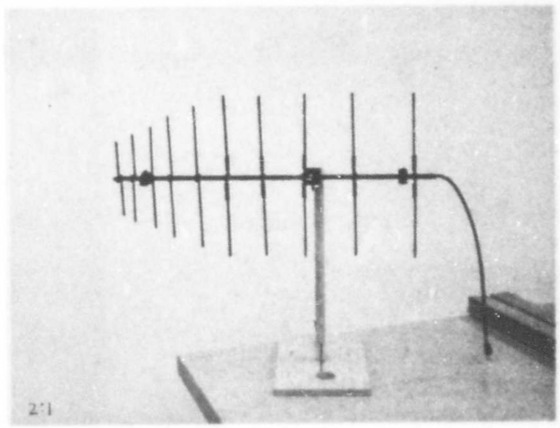


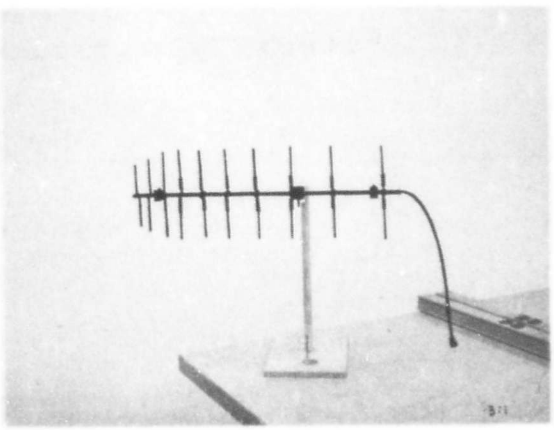
Figure 6. Absolute Gain of Standard Log-Periodic Antenna



1.5:1 Foreshortening
at 250 MHz

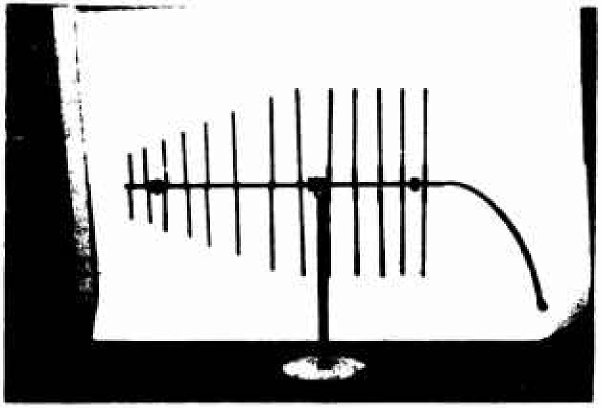
2:1 Foreshortening
at 250 MHz



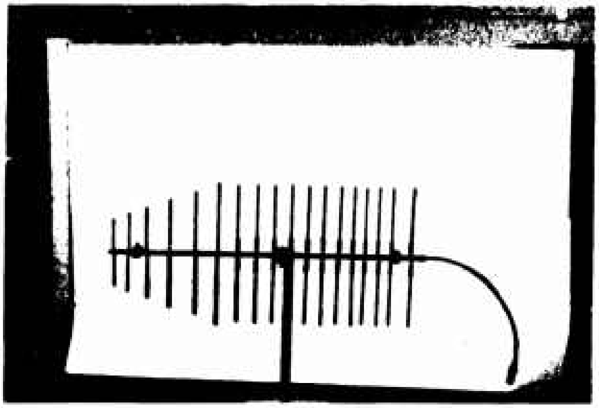


3:1 Foreshortening
at 250 MHz

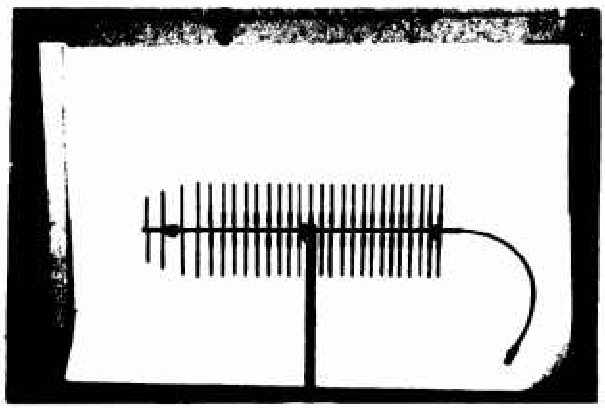
Figure 7. Foreshortened Log-Periodic Antennas



1.5:1 Foreshortening at 250 MHz with changing τ

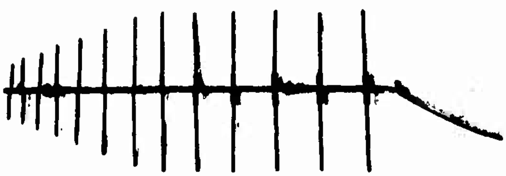


2:1 Foreshortening at 250 MHz with changing τ

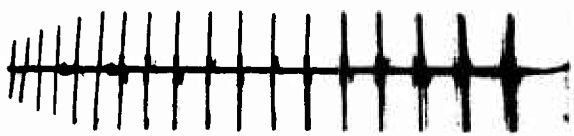


3:1 Foreshortening at 250 MHz with changing τ

Figure 8. Foreshortened Log-Periodic Antennas with Varying Design Ratios



1.5:1 Foreshortening at 250 MHz with changing τ and constant S/ℓ



2:1 Forshortening at 250 MHz with changing τ and constant S/ℓ

Figure 9. Foreshortened Log-Periodic Antennas with Varying Design Ratios and Constant Spacing-to-Length Ratios

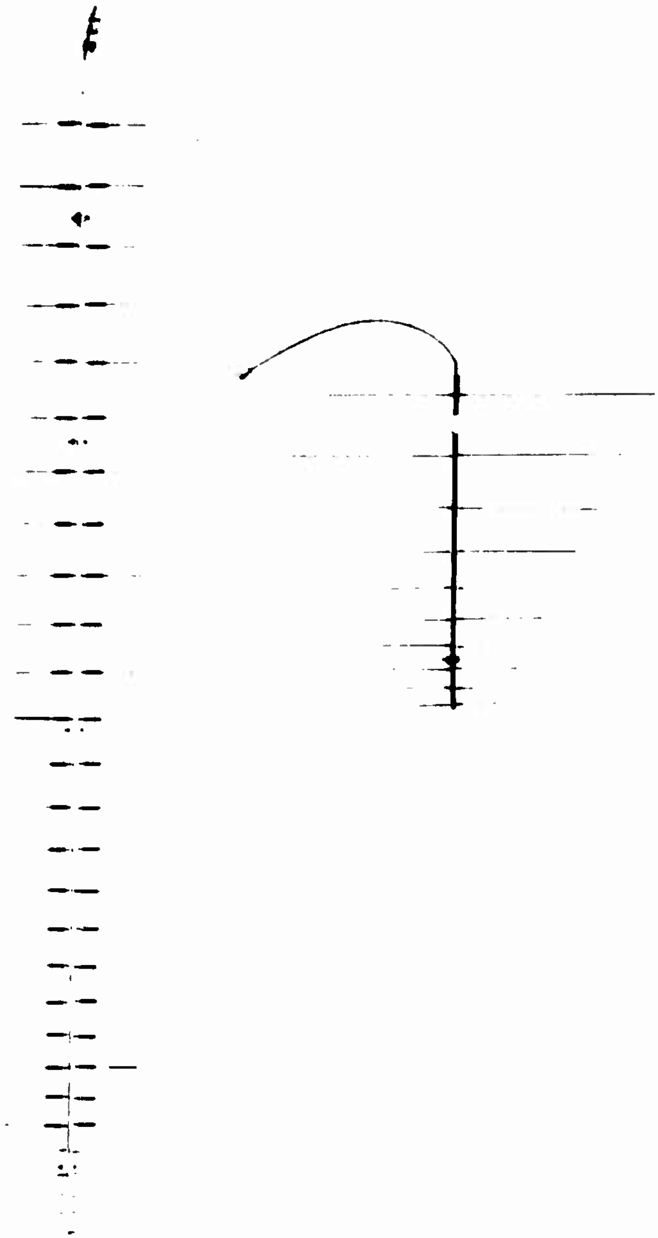


Figure 10. Standard Log-Periodic Antenna and Log-Periodic Antenna Foreshortened by 3:1

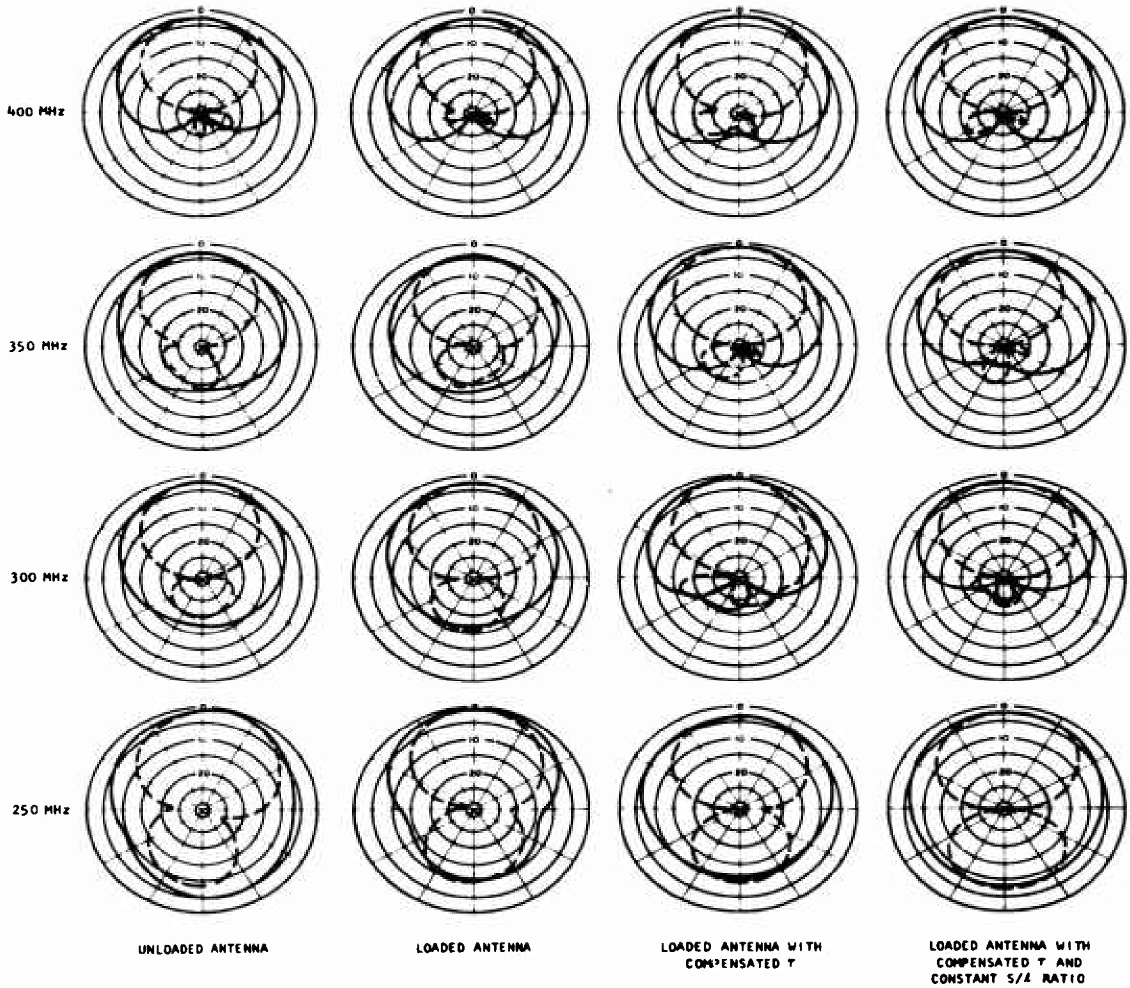


Figure 11. Patterns of Log-Periodic Antennas Foreshortened by 1.5:1.

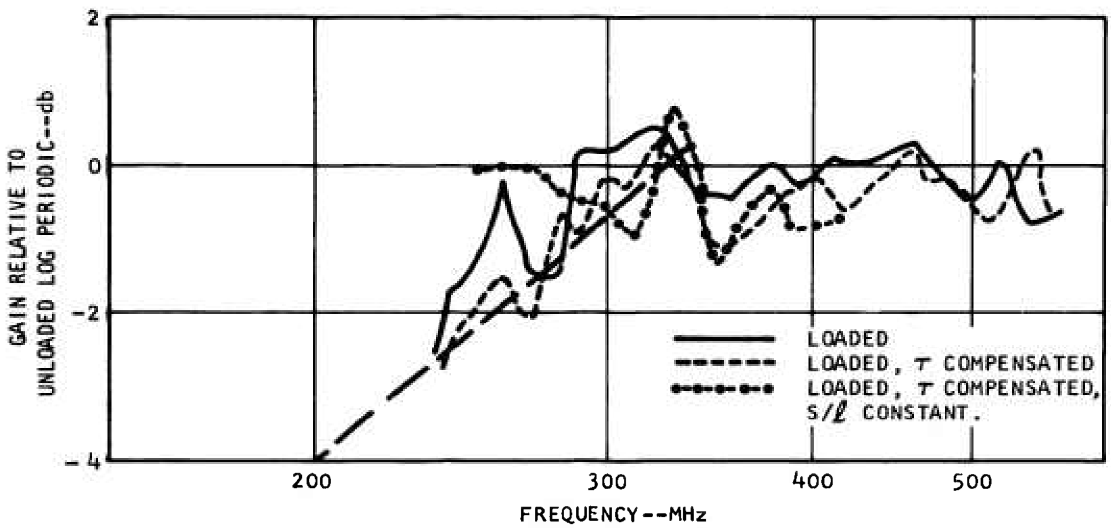


Figure 12. Gains of Log-Periodic Antennas Foreshortened by 1.5:1.

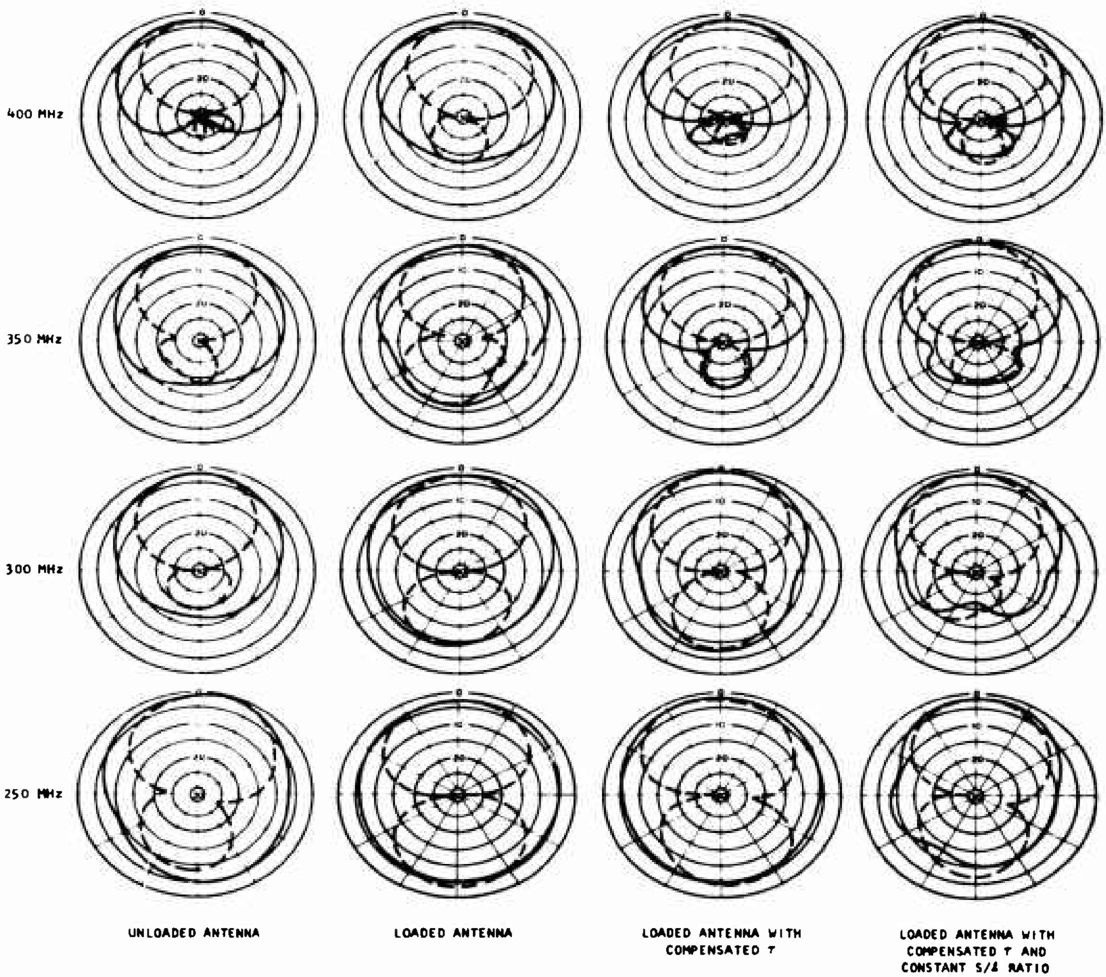


Figure 13. Patterns of Log-Periodic Antennas Foreshortened by 2:1.

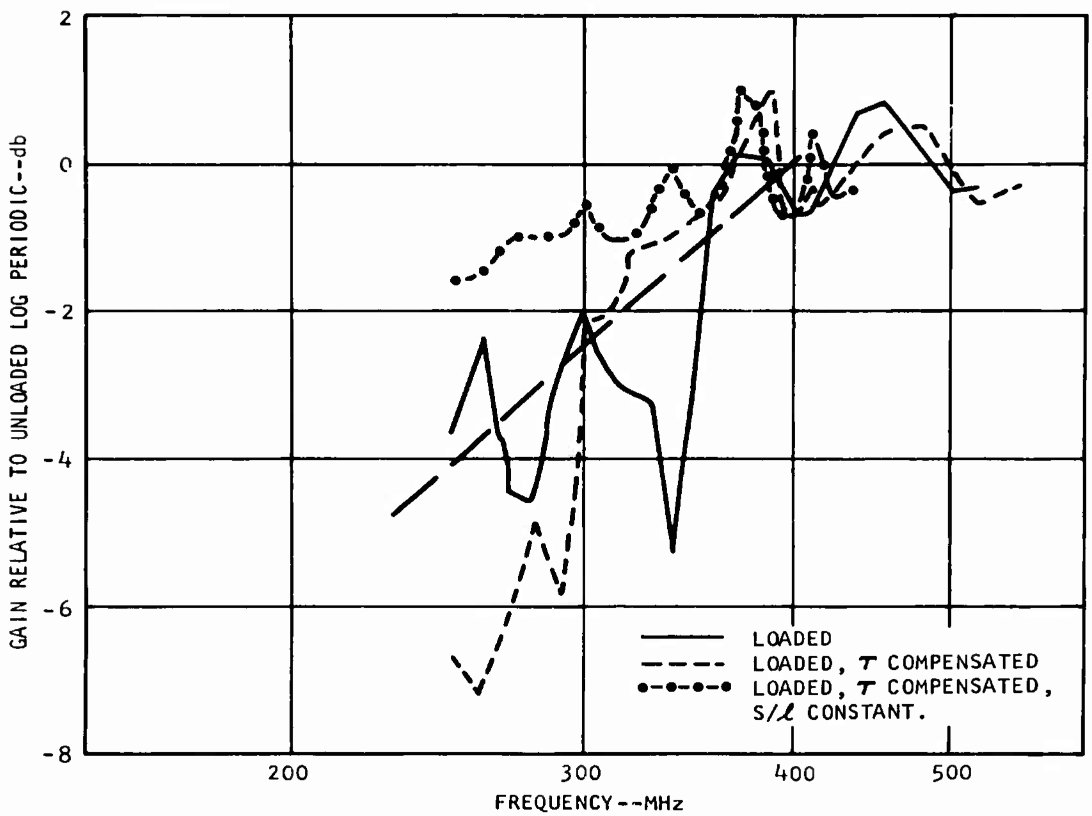


Figure 14. Gains of Log-Periodic Antennas Foreshortened by 2:1.

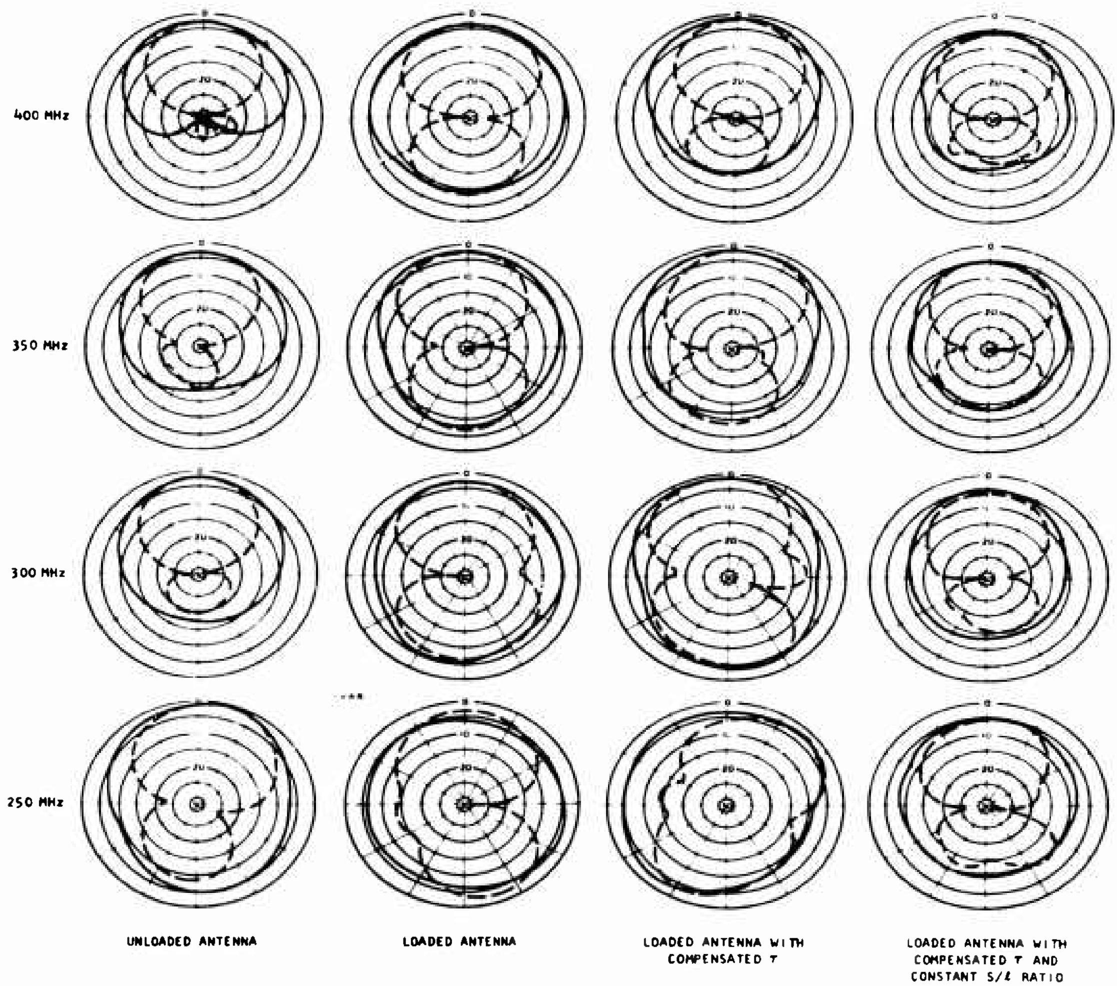


Figure 15. Patterns of Log-Periodic Antennas Foreshortened by 3:1.

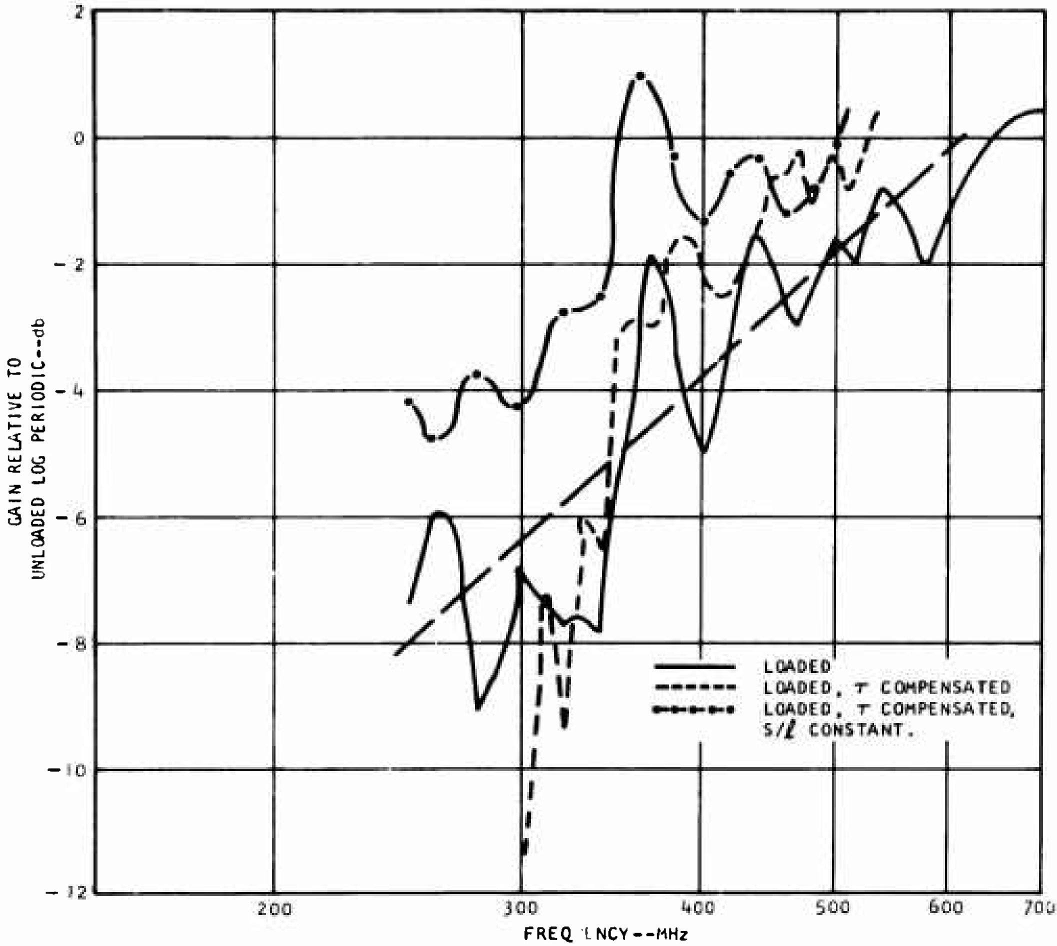


Figure 16. Gains of Log-Periodic Antennas Foreshortened by 3:1.

1.2 (Continued)

As can be seen from both the patterns and the gain curves, little improvement is obtained by increasing the number of elements through the loaded portion of the antenna unless the spacing between elements is adjusted to maintain a constant spacing-to-electrical-length ratio. However, making this adjustment, a log-periodic antenna can be reliably operated even though it has been foreshortened in width by as much as a factor of three. This will result in a loss in absolute gain of only approximately 4-db (still approximately 2-db above isotropic) and with a directivity approximately equal to that of the unloaded antenna. Less than 2-db is lost in the case of a 2:1 foreshortening (Figure 14).

1.3 Tilted Elements

A small amount of foreshortening can be obtained without inductive loading by simply tilting the radiating elements of a log-periodic antenna forward. With an angle of 45 degrees between the elements and the boom, instead of the conventional 90 degrees, a foreshortening of 1.41:1 is obtained. The effect of tilting the elements is illustrated by the measurements discussed in the following paragraphs.

Figure 17 is a sketch of six different log-periodic antennas constructed and tested during this investigation. In all six antennas the longest element is 10 inches and the shortest element is one inch. E-plane patterns, as shown in Figure 18 through 23, were measured from 300 MHz to 1500 MHz. The antenna of Figure 17(a) has the following design parameters:

a. $\tau^{1/2} = 0.90$

b. $\alpha/2 = 35.5$ degrees

c. Number of elements: 23

d. Boom length: 12.5 inches

The patterns of this conventional log-periodic antenna are shown in Figure 18. Figure 19 shows the patterns of the same antenna with all elements tilted forward by 45 degrees Figure 17(b). A large degradation in the performance of the antenna is readily seen in the broader beamwidth patterns with a lower front-to-back ratio.

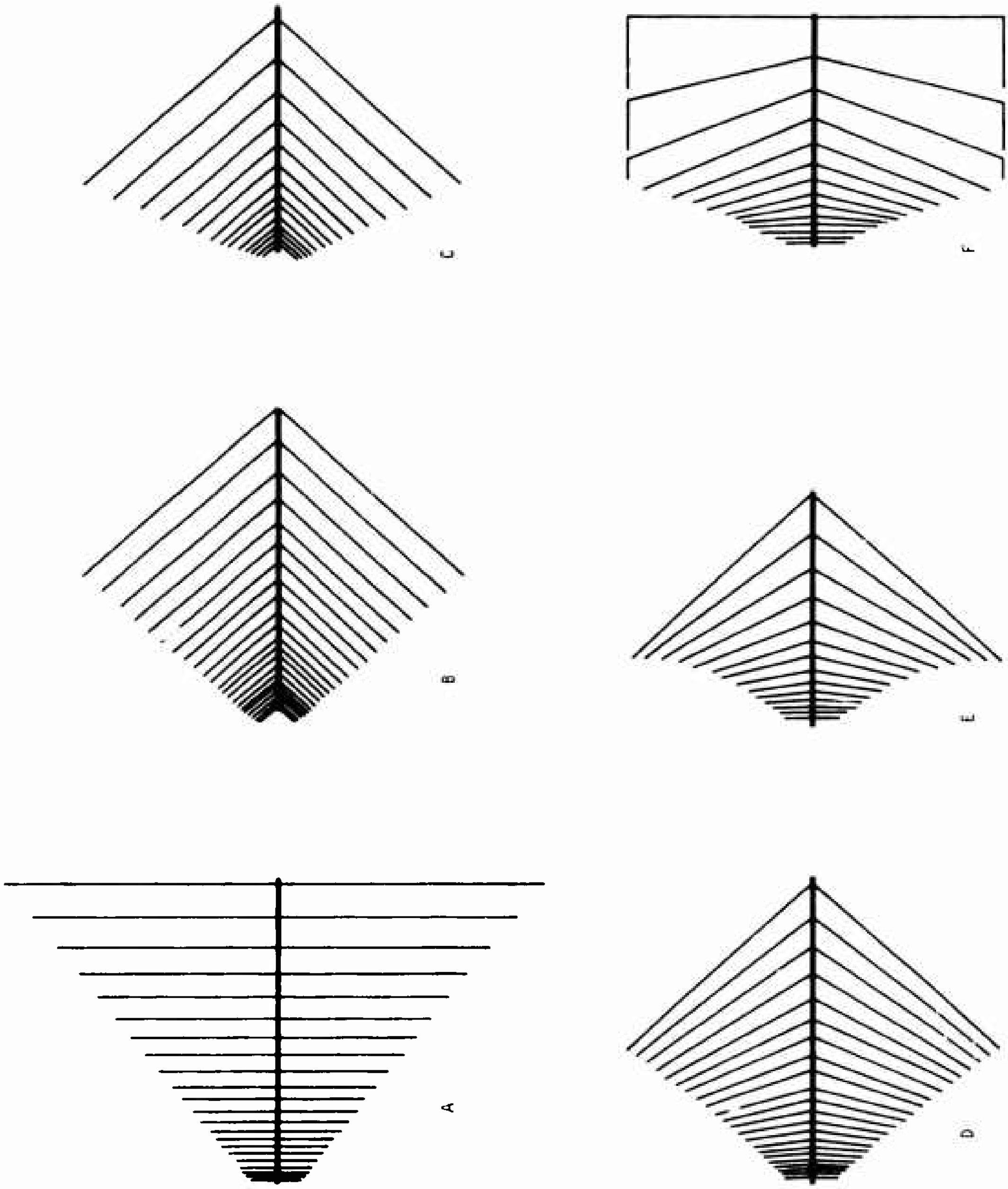


Figure 17. Log-Periodic Antennas with Tilted Elements.

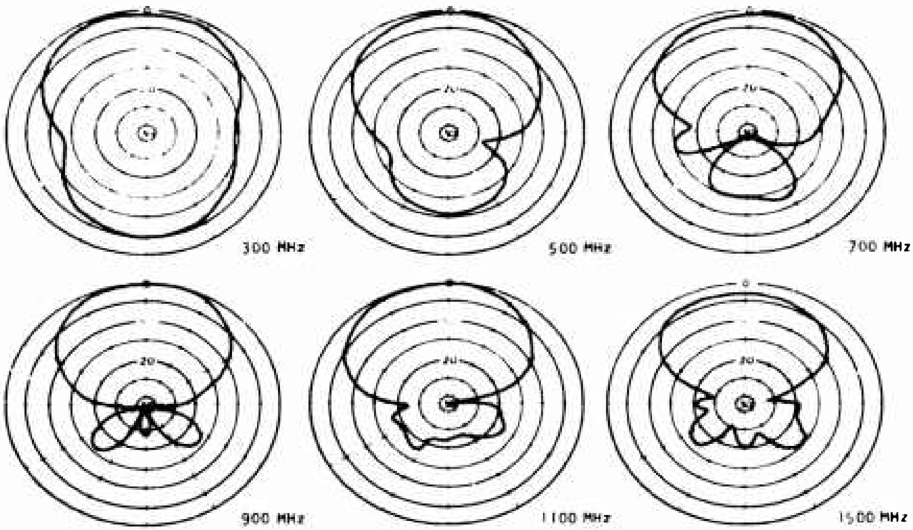


Figure 18. Patterns of Conventional Log-Periodic Antennas with 23 Elements (Figure 17a)

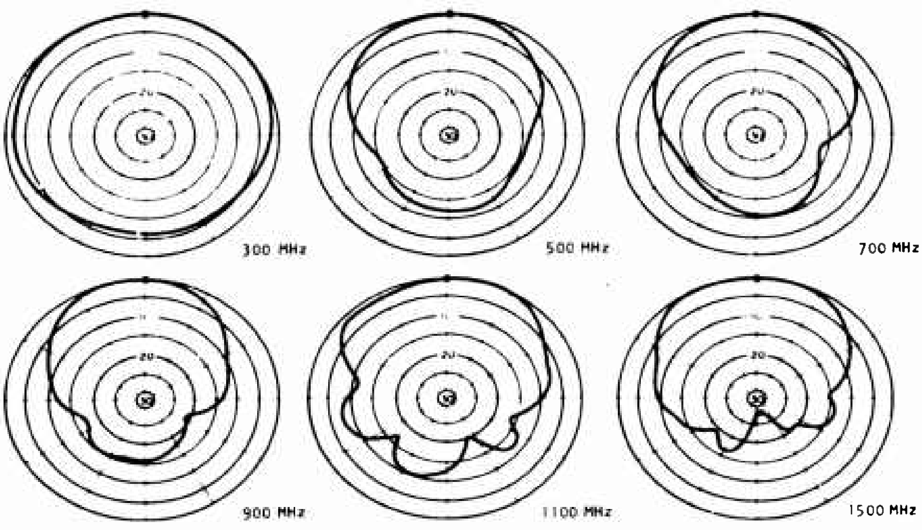


Figure 19. Patterns of Conventional Log-Periodic Antennas with all 23 Elements Tilted 45-Degrees Forward (Figure 17b)

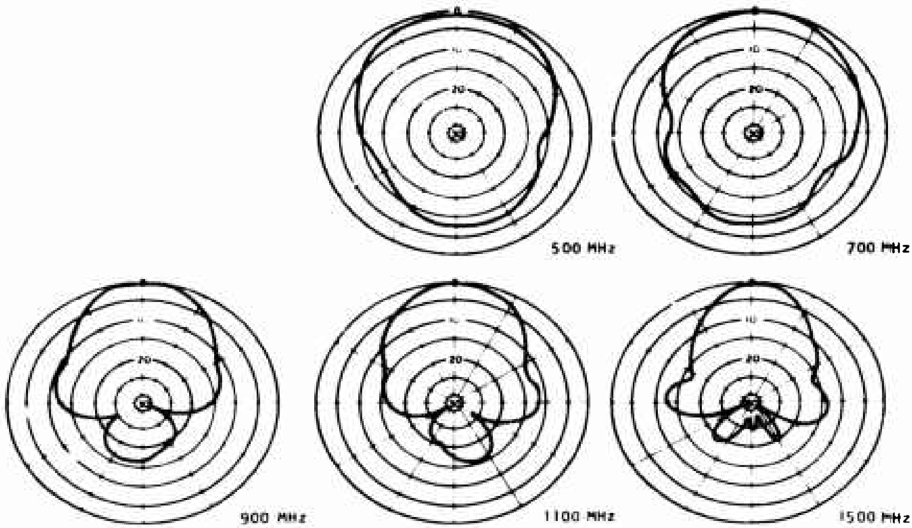


Figure 20. Patterns of Log-Periodic Antenna with all 15 Elements Tilted 45-Degrees Forward (Figure 17c)

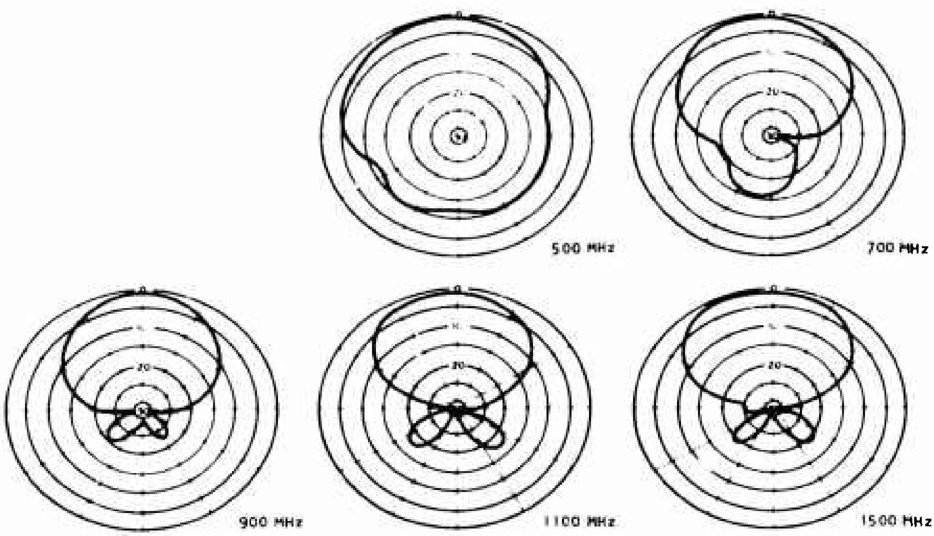


Figure 21. Patterns of 23-Element Log-Periodic Antenna with Only the Longer Elements Tilted Forward (Figure 17d)

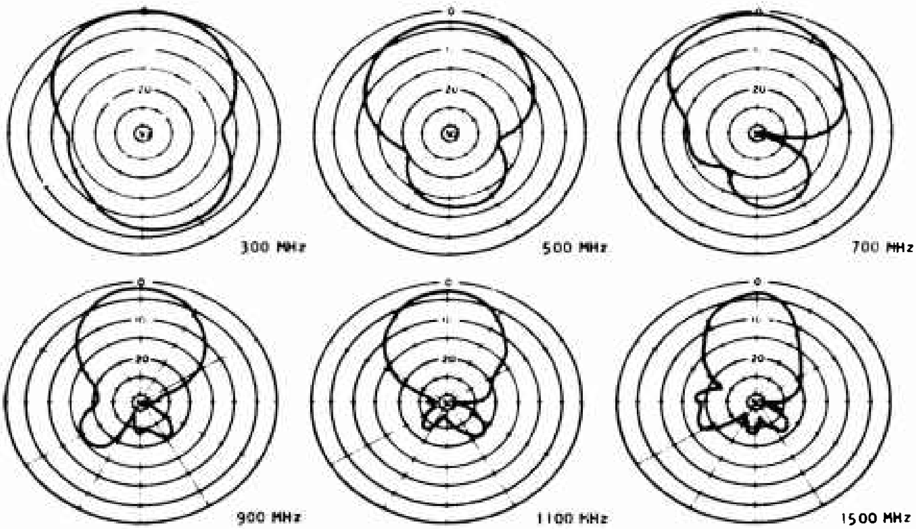


Figure 22. Patterns of 15-Element Log-Periodic Antenna with Only the Longer Elements Tilted Forward (Figure 17e).

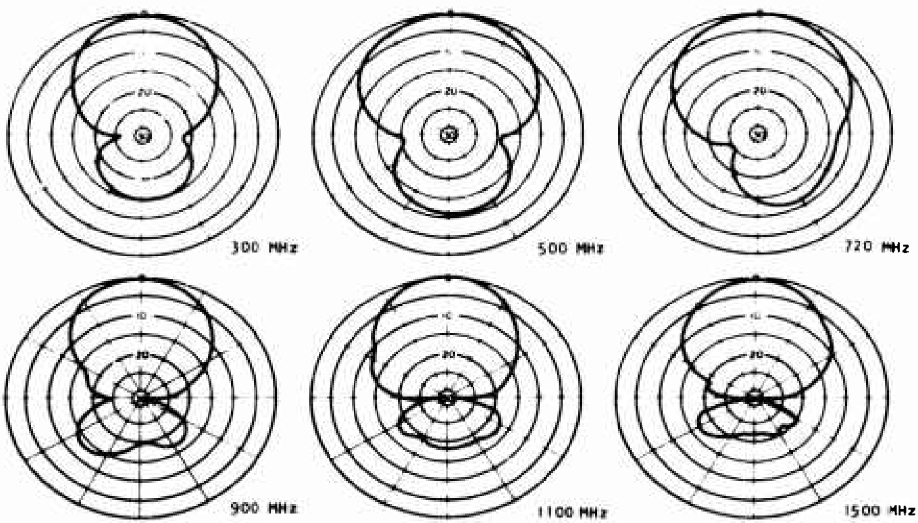


Figure 23. Patterns of 15-Element Log-Periodic Antenna with the Longer Elements Bent Forward (Figure 17f)

1.3 (Continued)

A decided improvement in the patterns was noticed at least at the higher end of the band (Figure 20) when the design parameters of the structure were changed to (Figure 17c):

a. $\tau^{1/2} = 0.838$

b. $\alpha/2 = 45$ degrees

c. Number of elements: 15

d. Boom length = 11.5 inches

Since no foreshortening of the total antenna structure is accomplished by tilting the shorter elements of the structure, the antennas of Figures 17(b) and 17(c) were rebuilt as shown in 17(d) and 17(e), respectively. The angle between the elements and the boom of these structures varies gradually from 45 degrees at the longest element to 90 degrees at the smallest. The patterns of Figures 21 and 22 reflect this change in the structures. They show improved patterns with narrower beams and higher front-to-back ratios for the higher frequencies, where the elements are tilted less than 45 degrees. The performance at 300 M'Iz, however, could not be improved until the configuration shown in Figure 17(f) was constructed. Here also the longest elements were straightened out to make an angle of 90 degrees with the boom, and the foreshortening was obtained by putting a 90-degree bend in these longest elements. The patterns of this antenna are shown in Figure 23 and the gain in Figure 24.

1.4 Log Periodic Antenna with Large α-Angle

Another short investigation undertaken this year concerned foreshortening the boom of a log-periodic antenna. The particular application of the antenna restricted its boom length to approximately one-eighth of a wavelength at the low frequency of operation. To operate over an octave band, from 500 to 1000 MHz, a log-periodic antenna with an α-angle of 126 degrees, from tip to tip of the radiating elements, was required. A sketch of this antenna is shown in Figure 25(a). As expected, the E- and H-plane patterns of this antenna (Figure 26) were similar to those of a dipole which is the limiting case of a log periodic antenna with an α-angle of 180 degrees. Only a small front-to-back ratio distinguishes these patterns from dipole patterns.

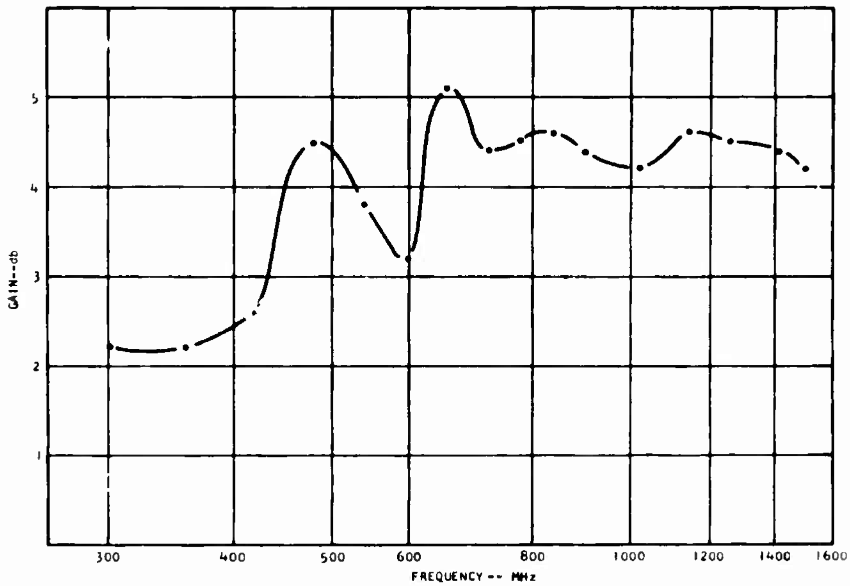


Figure 24. Gain of 15-Element Log-Periodic Antenna with Longer Elements Bent Forward (Figure 17f)

1.4 (Continued)

A small foreshortening of the width of the antenna by tilting or bending the elements, as shown in Figures 25(b) and 25(c), again demonstrated that the best results are obtained by keeping the elements perpendicular to the boom and bending the tips of the longest elements 90 degrees forward. The E- and H-plane patterns of these two antennas are shown in Figures 27 and 28. It is interesting to note that even the performance at the high end of the band is better with the antenna of Figure 25(c). With the other two antennas the patterns break up at 1000 MHz, even though the size of the smallest element is the same for all three antennas.

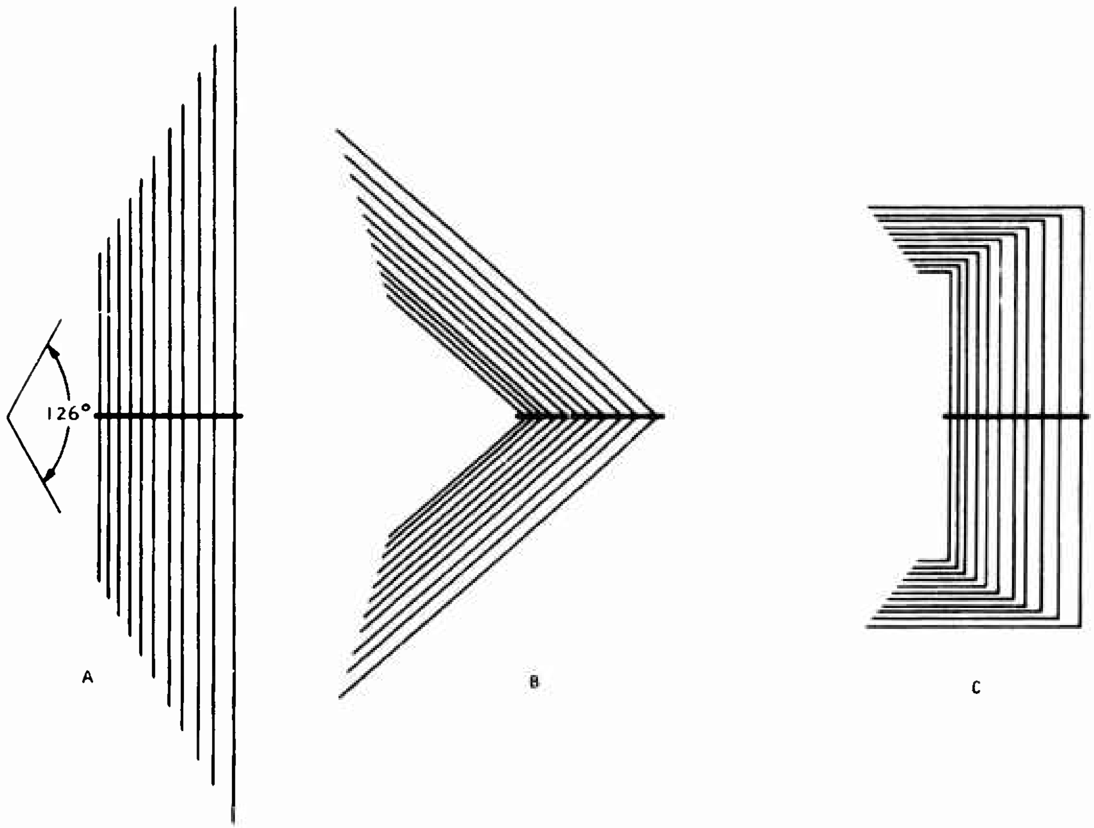


Figure 25. Short-Boom Log-Periodic Antenna

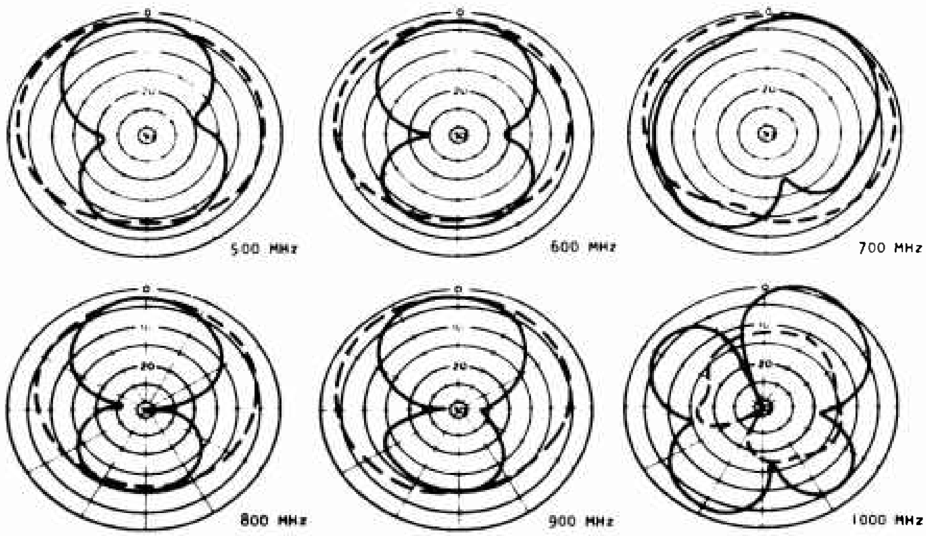


Figure 26. Patterns of Short-Boom Log-Periodic Antenna (Figure 25a)

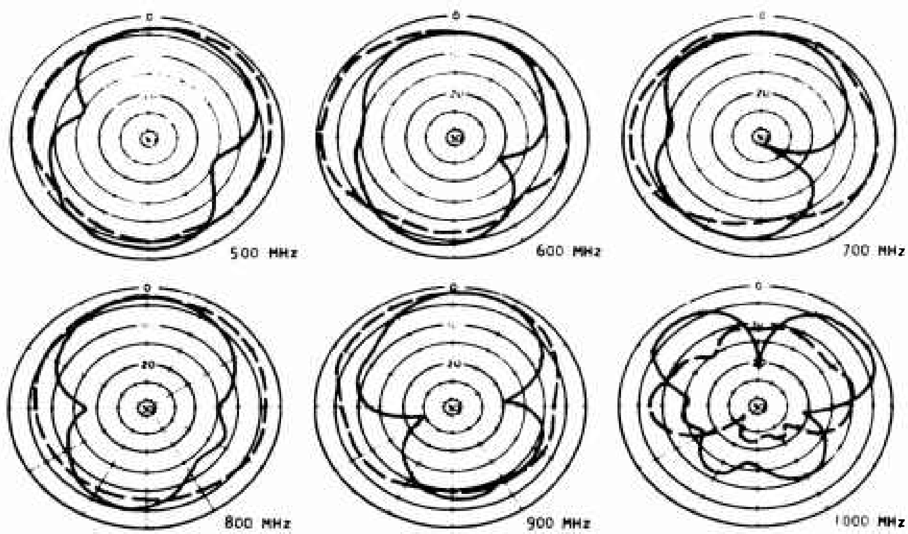


Figure 27. Patterns of Short-Boom Log-Periodic Antenna with 45 Degree Elements (Figure 25b)

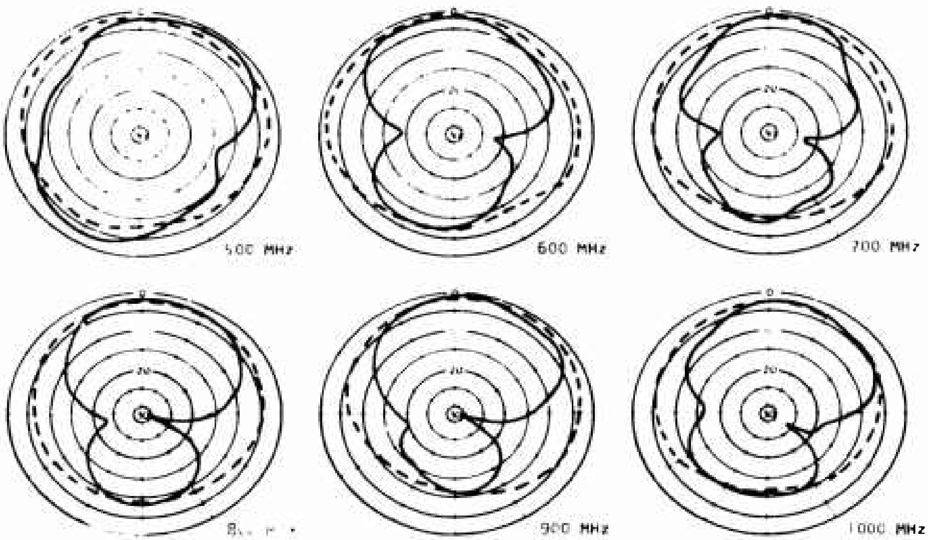


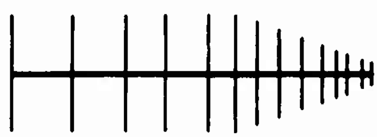
Figure 28. Patterns of Short-Boom Log-Periodic Antenna with Bent Elements (Figure 25c)

2. CAPACITIVELY LOADED FORESHORTENED LOG-PERIODIC DIPOLE ARRAYS

2.1 Summary

This research program was initiated to investigate the effects of capacitive loading on the efficiency of foreshortened log-periodic dipole arrays. The results of this program were then to be compared with the results of previous investigations on inductively loaded log-periodics to determine if one method of foreshortening has any electrical advantage over the other regardless of the mechanical advantages or disadvantages. However, the program was not completed during this R&D year and the results presented here involve only a part of the initial phase, that of investigating two methods of capacitive loading a monopole over a ground plane.

It has been well established that for many applications the broadband log-periodic antenna is very useful; however, because of its physical size which is a half-wavelength in width at the lowest frequency, its application in some areas is often limited. Because of this, methods of reducing the size of the log-periodic have been studied by various researchers. These methods generally involve either inductive or capacitive loading of the elements so as to reduce their size. The loading is generally applied most heavily to the low frequency or longest elements and is progressively reduced for the shorter elements. As shown below, the result is a structure that is of constant width up to the point that no foreshortening or loading is required. Beyond this point, the structure tapers to the feed point in the conventional manner.



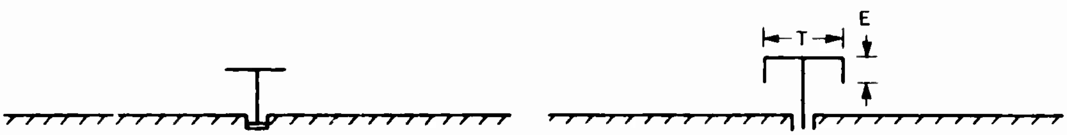
Constant Width Form of Foreshortened Log-Periodic Dipole Array

2.1 (Continued)

Investigations of the efficiency of inductively loaded log-periodic have indicated that as the amount of inductive loading is increased, the efficiency of the antenna is reduced. It follows then that the constant width log-periodic dipole array becomes less and less efficient as the radiation or active region* progresses into the more heavily loaded region. Measurements described in paragraph 1.2 indicate that for a foreshortening of 3:1, the gain is reduced to approximately 40 percent of an unloaded structure.

2.2 Types of Capacitive Loading Investigated

Simple "T"-loading and "E"-loading were the two types of capacitive loading investigated.



(a) T-loading (b) E-loading

The amount of T-loading (length of the tophat section) was increased until the monopole had been foreshortened by approximately 61 percent. The E-loading, which consisted of the tophat with the ends bent down, was increased until the foreshortening was approximately 63 percent.

The results of these measurements are discussed in paragraph 2.3.

2.3 Measurements and Test Results

In order to apply capacitive loading to a log-periodic dipole array, it is necessary to first study the effects of the capacitive loading on the dipole element itself. To do this a test program was set up to determine the effects of capacitive

*The active region is the area from which the radiation takes place. It consists of one or more elements.

2.3 (Continued)

loading on the length and impedance of a monopole over a ground plane. A five-foot square ground plane was used over a frequency range of approximately 320 to 1000 MHz. The effects of the ground plane on the impedance of the monopole were neglected because the mutual impedance effects on the elements within the log-periodic dipole array would probably be considerably greater than the inaccuracies due to the smallness of the ground plane.

The test series consisted of measuring the resistance and reactance of the monopole over approximately ± 10 percent of the resonant frequency for each loading configuration. The T-loading was varied between 8 and 200 percent of the monopole length. For the E-loading, the T-length was varied between 8 and 100 percent of the monopole length, while the E-length varied between 0 and 83 percent. The results of these measurements are plotted in Figure 29.

The uppermost line in Figure 29 marked "T-loading only", shows the resonant resistance and the amount of loading for various antenna lengths where T-loading only is employed. For example, if it is necessary to "T"-load a monopole so that its length is 53 degrees, it may be seen from Figure 29 that the T-length is 0.83 times the monopole length and the resistance at resonance is 28 ohms.

The amount of E-loading necessary to obtain a given monopole length depends upon the T-length employed. There are many combinations of T- and E-lengths which will provide the required monopole length. For example, using the 53 degree-long monopole discussed above, the E-length is 0 for a T-length of 0.83 times the monopole length, 0.08 for a T-length of 0.67, 0.5 for a T-length of 0.25, 0.67 for a T-length of 0.17 and so on. Notice, however, that as the amount of E-loading increases, the radiation resistance decreases; for example, when the E-loading was 0 for the 53-degree monopole, the resistance was 28-ohms, while with a 0.67 E-loading, the resistance is 19.4-ohms. Thus, if E-loading is necessary, it should be used as little as possible in order to keep the radiation resistance as high as possible.

Examination of the reactance variation at resonance indicates that for both T- and E-loading, the change in reactance is approximately constant for a

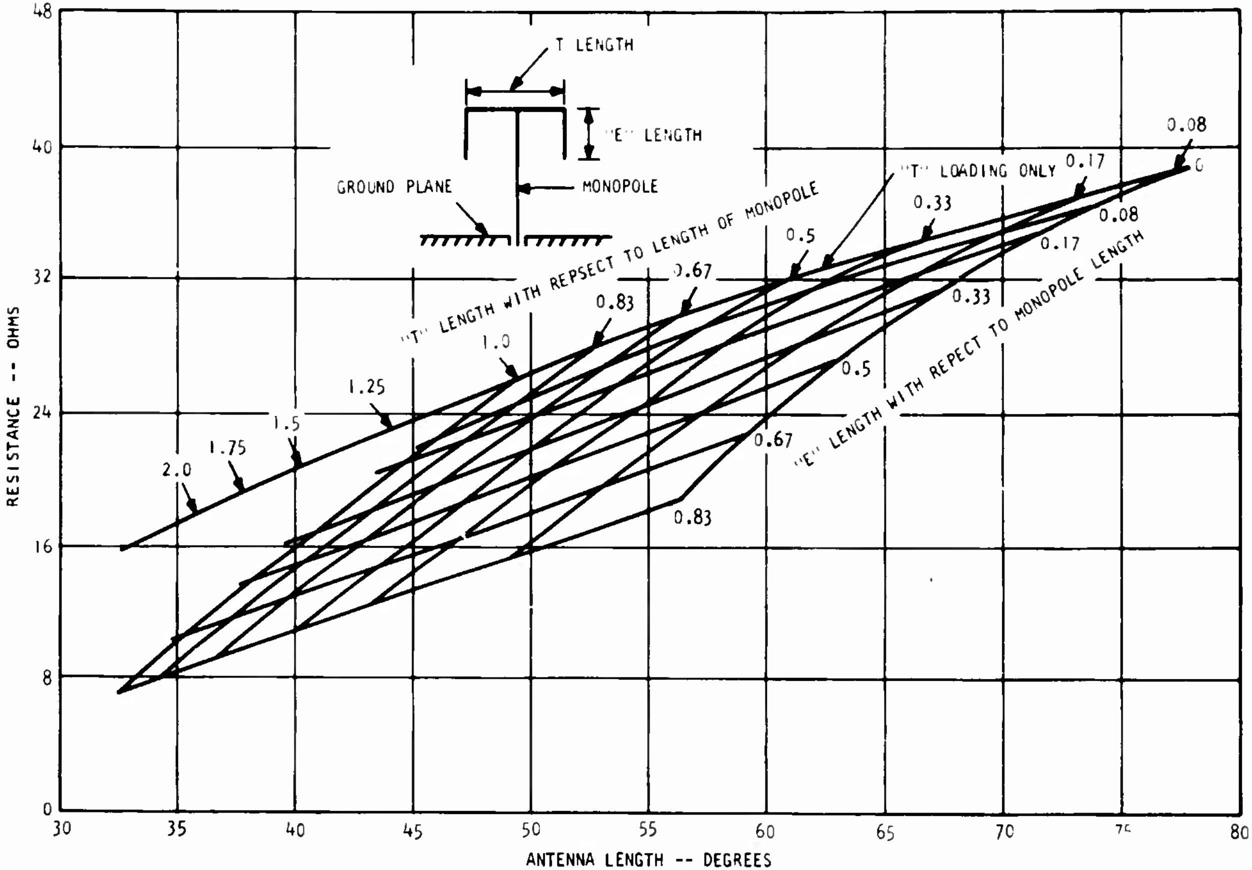


Figure 29. Resistance Versus Antenna Length for Various Loadings

2.3 (Continued)

given percentage change in frequency around the resonant frequency. For example, at 80 degrees electrical length, a ± 10-percent change (8 degrees) in electrical length produces a reactance change of + 38 to - 38 ohms; at 40 degrees, a ± 10-percent change (4 degrees) also gives a change of + 38 to - 38 ohms.

From these measurements it appears that the greatest problem in applying the capacitively loaded monopole to the log-periodic dipole array is that of matching the low element radiation resistance to the boom transmission line.

2.4 Future Plans

It is expected that the capacitively loaded log-periodic dipole array program will be continued during the next R&D year. The program will consider other forms of capacitively loading the elements, construction of several capacitively loaded log-periodic dipole arrays and extensive measurements on them to determine their efficiency and other parameters.

3. SQUARE-BOOM LOG-PERIODIC ANTENNAS

3.1 Summary

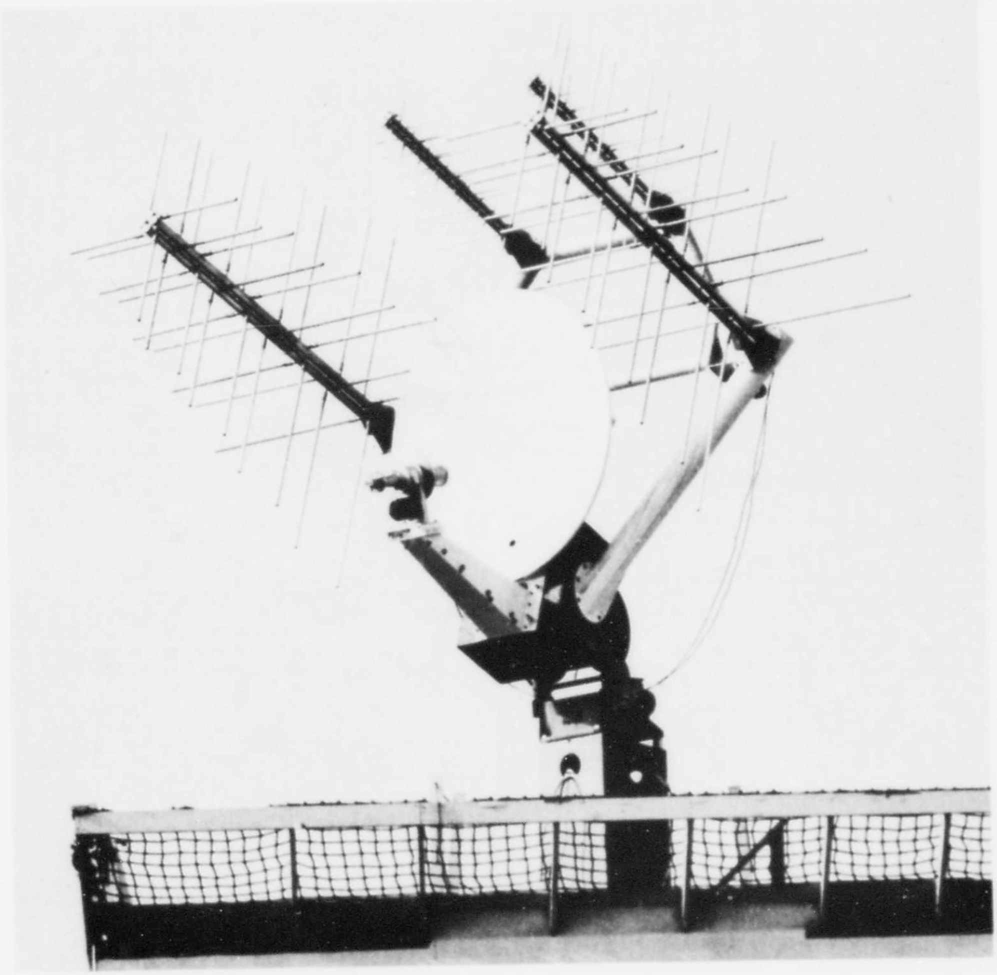
Conventional tubing has several shortcomings when it is used for booms on crossed-dipole log-periodic antennas. The primary objections are the high cost of construction and lack of mechanical strength. The high cost results from mechanical difficulties encountered in attaching the dipole elements to the cylindrical rods and in tapering the diameter of the rod for use over a large band of frequencies. The following paragraphs discuss a design developed by Sylvania in which the rods are replaced by a square boom. The "square-boom" design greatly reduces the antenna construction difficulties and increases the mechanical strength of the boom. When the square-boom design is employed with the proper design parameters, the electrical performance of the log-periodic dipole antenna is not degraded in any manner.

The log-periodic dipole antenna employing conventional cylindrical rods or tubes as booms is shown in Figure 30. This antenna is normally fed by a coaxial line inserted through the back of one of the hollow cylindrical booms; the shield is connected to its half of the feeder line at the front of the boom and the center conductor is connected to the other half of the boom.

Figures 31 and 32 show the boom technique developed by Sylvania and Figure 33 shows details of the boom construction. The boom structure (Figure 33a) is constructed of two right-angle metal sheets which replace the cylindrical rods of the linearly polarized log-periodic dipole antenna. Figures 33b and 33c show two types of booms that can be used for either the linear or circularly polarized log-periodic dipole antenna. The feed mechanism is essentially identical to the antenna of Figure 30. The coaxial line is inserted through the back of the boom and the outer shield is electrically bonded to one side of the boom. The inner conductor feeds the opposite side of the boom at the apex.

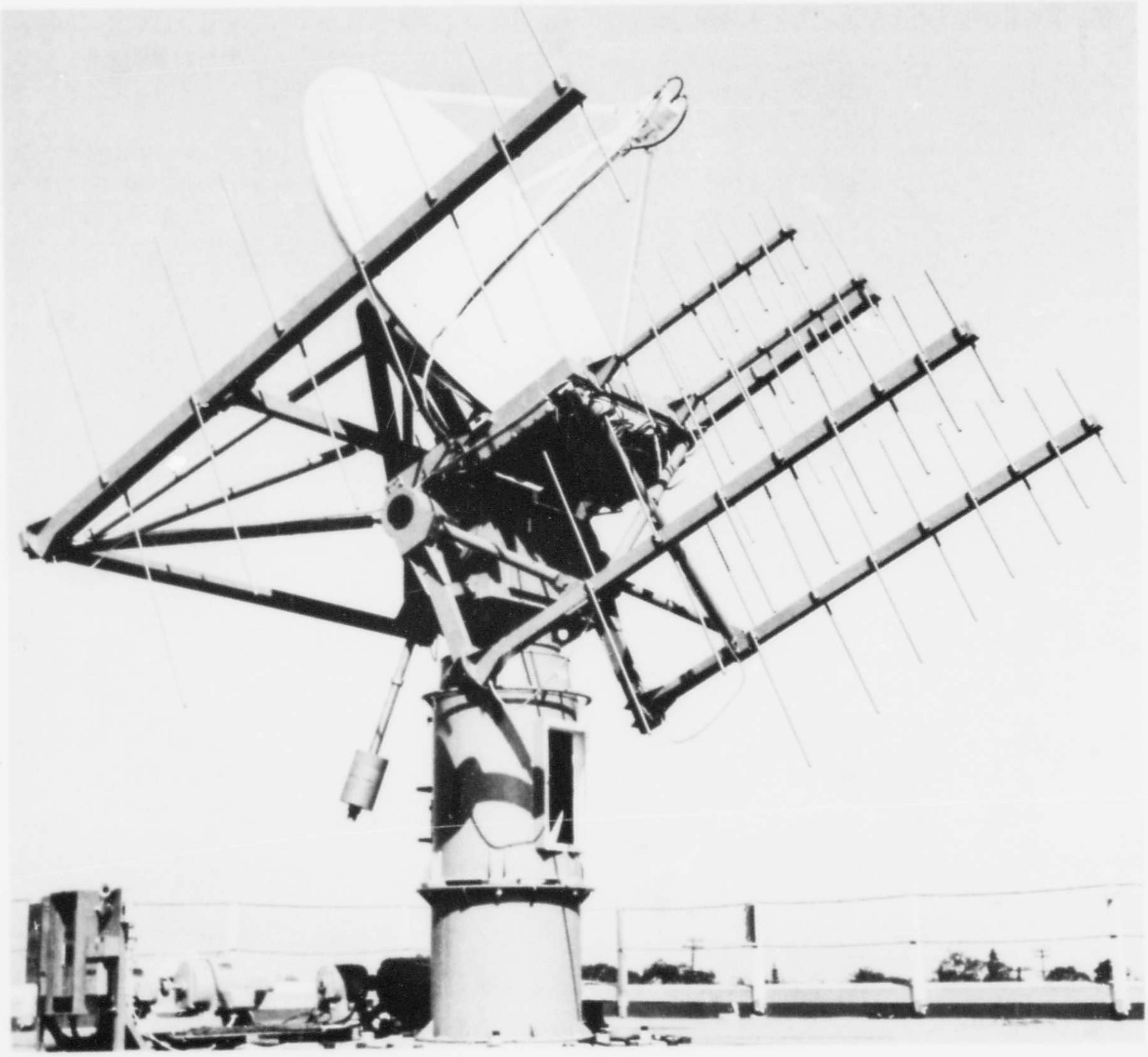
3.2 Boom Construction and Impedance

The initial boom concept used for the crossed-dipole log-periodic antenna, incorporated four right-angle metal strips with dielectric spacers as shown in Figure 33b. The general performance of this antenna was unsatisfactory because it



65091001

Figure 30. Array of Log-Periodic Dipole Antennas with Cylindrical Rod Beam



66092823

Figure 31. Array of Square-Boom Log-Periodic Dipole Antennas

66111151

Figure 32. Circularly Polarized Log-Periodic Dipole Antenna Employing Square-Boom Construction

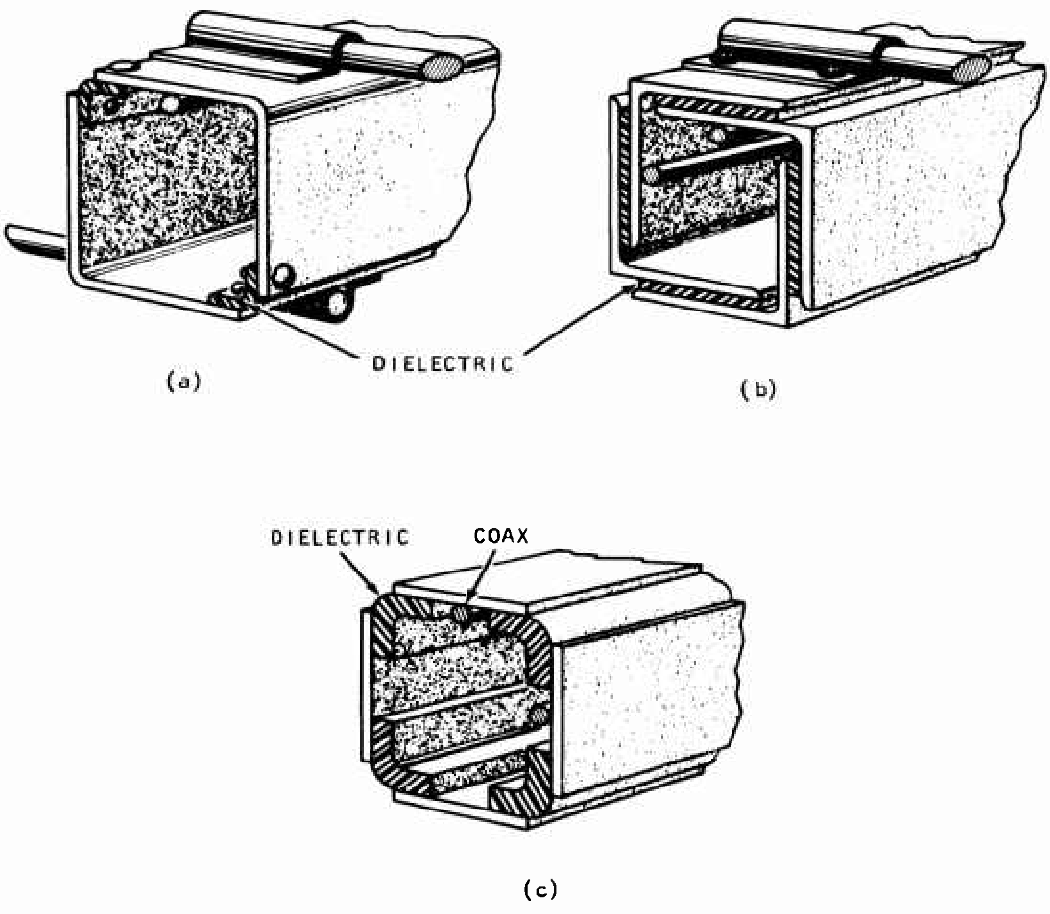


Figure 33. Methods of Square-Boom Construction

3.2 (Continued)

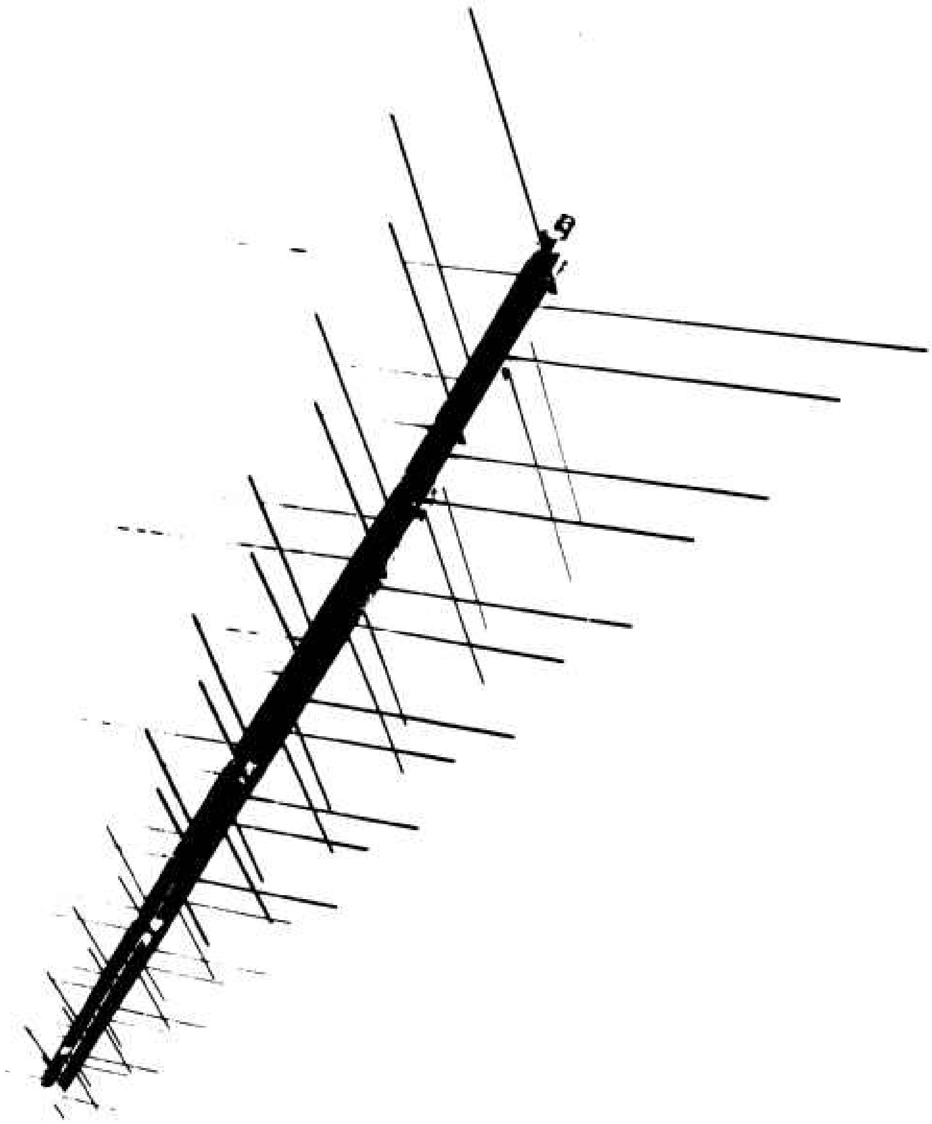
exhibited a high VSWR, low gain and a pattern shape that was a function of frequency. When the unloaded boom impedance was measured, it was found to be approximately 35 ohms. Previous investigations of log-periodic dipole antennas at Sylvania established that a feeder impedance of at least 50 ohms is necessary to obtain sufficient coupling to the dipole elements. In models having feeder impedances less than 50 ohms, appreciable amount of power remains on the feeder at the large end of the antenna. Since the feeder is shorted at the large end, this power is reflected back through the antenna and manifests itself as a high VSWR and a general pattern deterioration. It was concluded that in order to obtain successful performance from this type of boom structure, the feeder impedance must be at least 50 ohms.

3.3 Characteristic Impedance of Transmission Line

The most direct method of increasing the boom impedance is to increase the spacing between opposite metal plates by increasing the thickness of the dielectric separating them. However, it was felt that an alternate method should be used, because any increase in the amount of dielectric material considerably increases the weight of the antenna.

An alternate method is to use four flat metal strips as shown in Figure 33c. These strips are fastened together by thin right-angle dielectric strips (not necessarily continuous) and the elements are welded or bolted to the metal strips. The impedance can then be varied simply by varying the width of the metal strips or the spacing between opposite strips. Thus, an impedance increase can be accomplished with a negligible weight increase and with no loss of mechanical strength.

To investigate the characteristics of the impedance as a function of the transmission line separation, the model shown in Figure 34 was used. This model was constructed so that the spacing (b) between the transmission lines could be varied easily. Dielectric blocks spaced periodically along the line were used for line supports. The transmission line impedance was measured with the elements removed, using the time domain reflectometer (TRD). Essentially the TRD excites the system with a pulse and measures the amplitude and time delay of reflections from the test line. The impedance of the line is then calculated from a



66110101

Figure 34. Square-Boom Log-Periodic Dipole Antenna

3.3 (Continued)

knowledge of these parameters. To determine the accuracy of this method of measuring impedance, one pair of parallel plates was removed from the structure and the impedance of the remaining parallel-plate line was measured as a function of plate separation. These measured values were then compared with previously calculated values.[1] It was necessary to perform this measurement check on the parallel-plate line because the calculation of the line impedance for the "square boom" configuration is beyond the scope of this report.

The results of the above measurements are graphically displayed in Figure 35 where it is seen that the calculated and measured impedance values of the parallel-plate transmission line are in close agreement. The impedance of the square boom was found to be much less than the corresponding parallel-plate line impedance when the corner spacing between plates (d) is small. As the spacing (d) is increased, the square-boom impedance begins to approach that of the equivalent parallel-plate line. Thus the square-boom configuration effectively shunts the transmission line with a large capacitance, the magnitude of which is proportional to the spacing (d). The next parameter of interest is the impedance variation obtained from the right-angle dielectric strips used in the antenna construction. To electrically simulate this construction, 1/4-inch square plexiglass strips (relative dielectric constant of 2.6) were placed along the entire length of the line. These strips were placed in each of the four inside corners of the lines. The above size was chosen because it was considered to be representative of the mechanical configuration offering maximum effect on the microwave performance. For d = 0.166 inch, the addition of the dielectric resulted in a 10-ohm decrease of the characteristic impedance. Thus the dielectric loading of the transmission line by thin right-angle dielectric strips does not significantly alter the impedance of the unloaded transmission line.

For the transmission line configuration used for these measurements the width of the plates (w) was tapered, but the corner spacing (d) was kept constant. The ratio (w/b) thus increased linearly along the test line, and a corresponding

1. Wheeler, H. A. "Transmission line properties of Parallel Strips Separated by a Dielectric Strip", IEEE Transactions on Microwave Theory Antenna Techniques, March-May 1965.

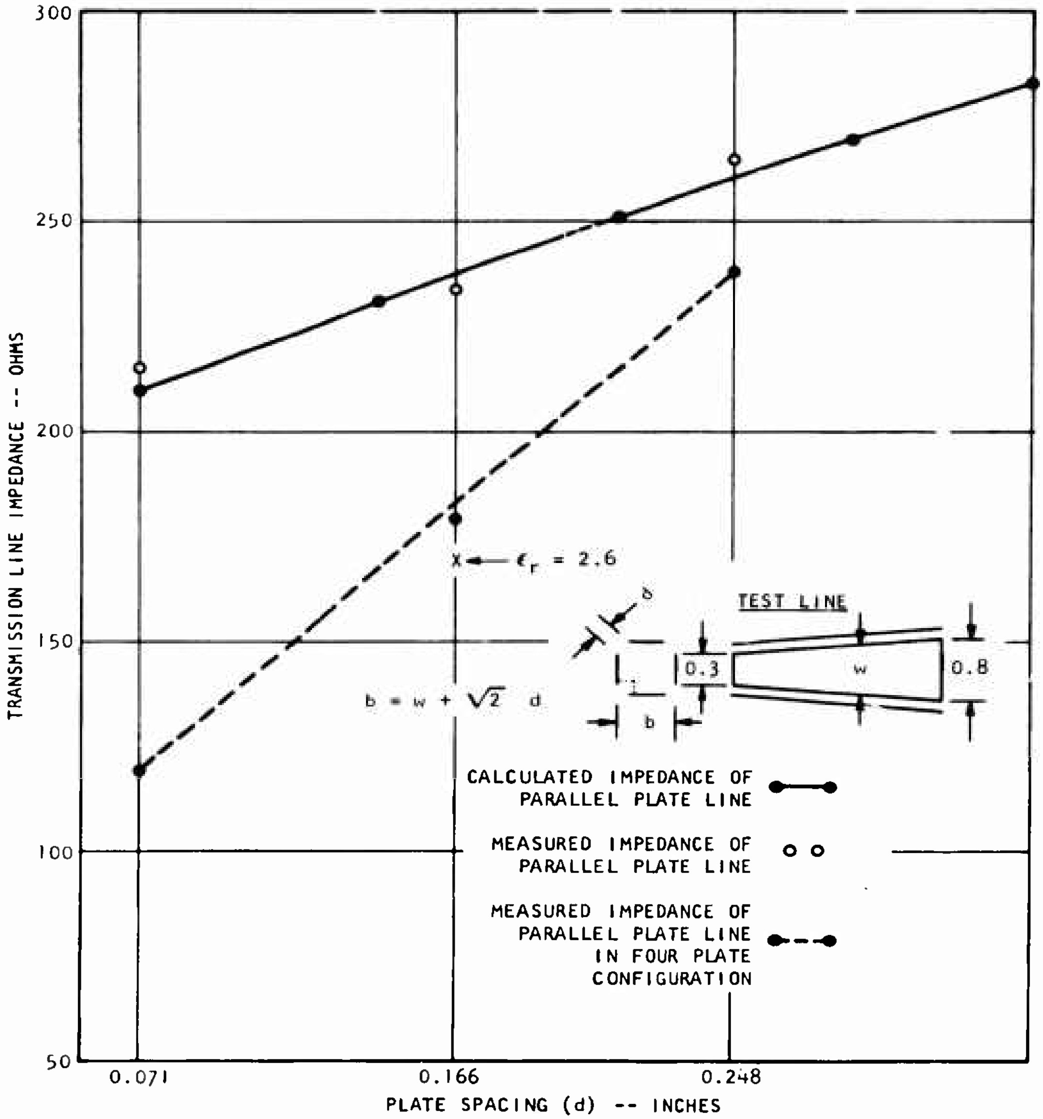


Figure 35. Unloaded Transmission Line Impedance of Parallel-Plane Line (Square-Boom Configuration).

3.3 (Continued)

decrease in impedance should have occurred. Although the impedance change predicted by parallel-plate theory for the above variation in the (w/b) ratio was approximately 15 ohms, this change was not observed experimentally for the square-boom. In other words, the loading effect of the square-boom tends to mask small variations in the w/b ratio, thereby allowing construction tolerances to be slightly relaxed.

3.4 Antenna Performance

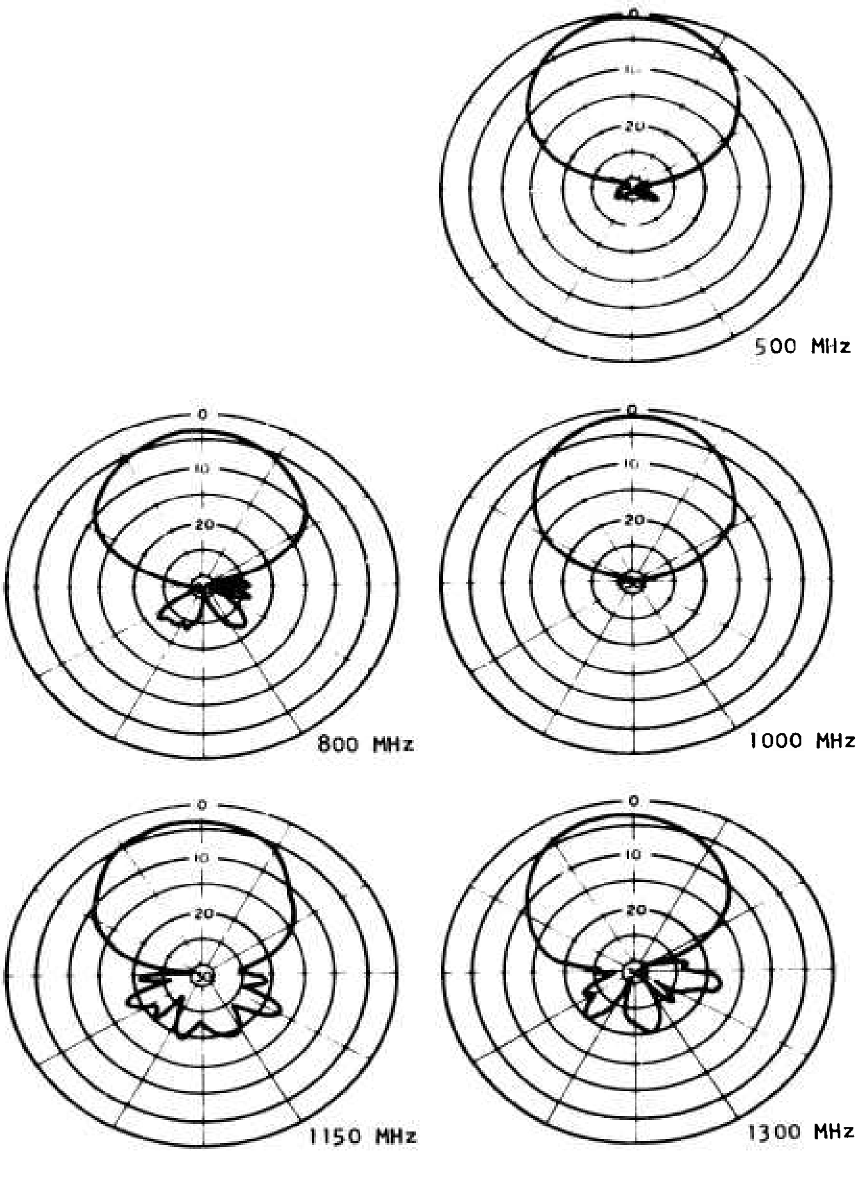
To evaluate the performance of the square-boom antenna, the model shown in Figure 34 was constructed using an unloaded transmission line impedance of 225 ohms. The performance of this model was compared with several additional models having widely different design parameters. These design parameters are summarized in Table 1. Antenna models 1 through 3 have essentially the same element design parameters, but their boom impedances differ. Antennas 1 and 4 have similar boom impedances but the design parameters of the elements are different.

The E- and H-plane patterns were recorded with the antenna mounted in an environment that simulated free space. For pattern purposes the antennas were operated in the linearly polarized mode so that the performance of the antenna could be evaluated better. The radiation patterns of the antennas are given in Figures 36 through 42. These patterns show that the pattern stability and front-to-back ratio of Model No. 1 is superior to the other models. In general the patterns of Model No. 4 are very unsatisfactory at the upper frequencies. Investigation of log-periodic dipole (LPD) antennas has shown that when only part of the energy traveling along the boom is radiated by the 1/2-wavelength elements, the energy remaining on the boom is usually radiated by the longer elements operating in the 3/2-wavelength mode. The combination of energy from these two radiating regions may be evidenced by side lobes on the pattern. Above 200 MHz, the patterns of antenna Model No. 3 clearly exhibit these lobes, which indicate that the energy on the transmission line is not completely coupled to the proper dipole elements. Notice also that the back lobe of this antenna is high at the lower frequencies. At the upper frequencies the patterns for antenna Models No. 2 and No. 3 also begin to show the effects of radiation from the 3/2-wavelength elements, although these patterns are generally very satisfactory.

TABLE 1

SUMMARY OF DESIGN PARAMETERS OF EXPERIMENTAL MODELS

Design Parameter	Model No. 1	Model No. 2	Model No. 3	Model No. 4
Frequency Range	275-1300 MHz	275-1300 MHz	100-1000 MHz	50-250 MHz
τ	0.9	0.9	0.86	0.875
σ	0.792	0.792	0.1	0.050
2α	35°	35°	39°	65.4°
Antenna Length	32.5 in.	32.5 in.	92 in.	86 in.
Number of Elements	19	19	22	16
Boom Construction				
(a) Taper	0.3 in. to 0.8 in.	0.3 in. to 0.8 in.	0.75 in. to 3 in.	None
(b) Thickness	1/32 in.	1/32 in.	1/8 in.	1/16 in.
(c) Spacing (d)	0.25 in.	0.07 in.	0.125 in.	0.24 in.
Theoretical Directivity	8.6 db	8.6 db	8.0 db	7.7 db



E-PLANE

Figure 36. E-Plane Patterns for Antenna Model No. 1

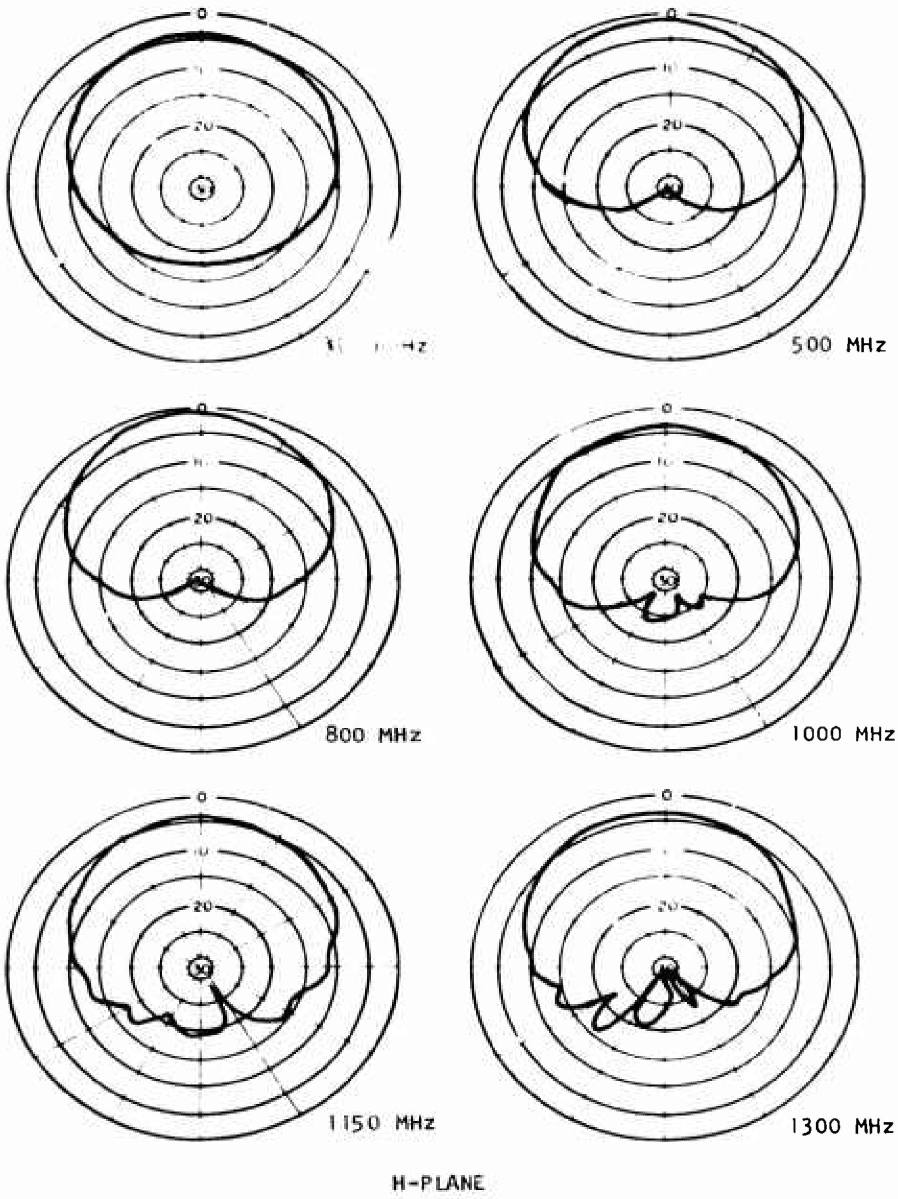


Figure 37. H-Plane Patterns for Antenna Model No. 1

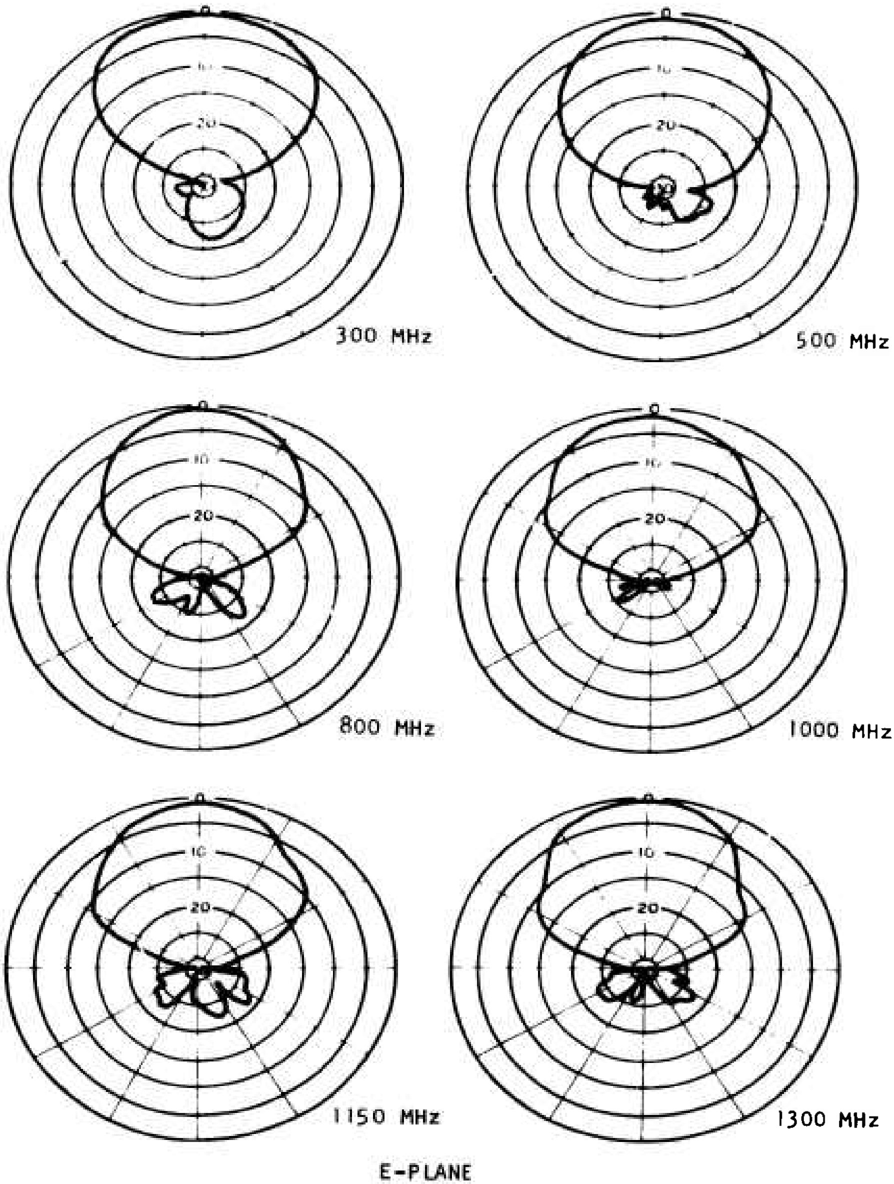


Figure 38. E-Plane Patterns for Antenna Model No. 2

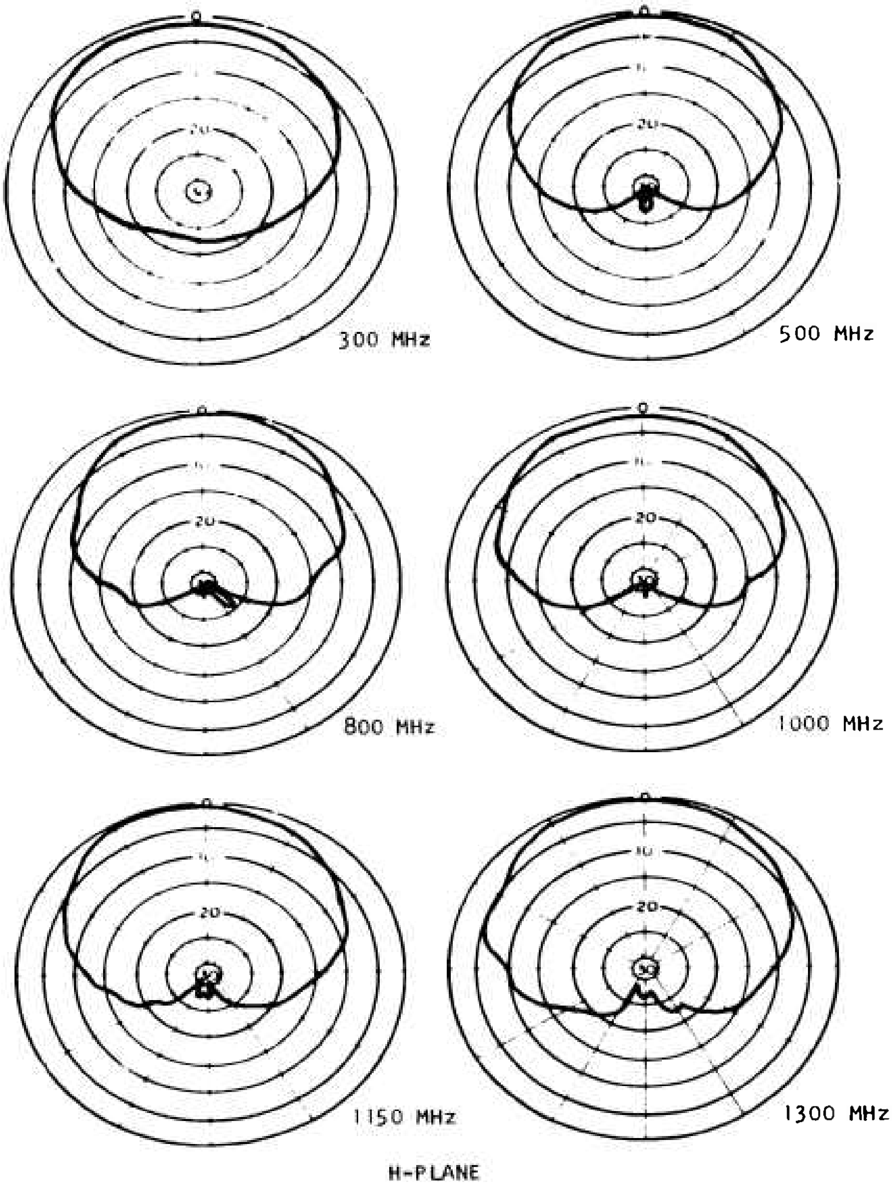


Figure 39. H-Plane Patterns for Antenna Model No. 2

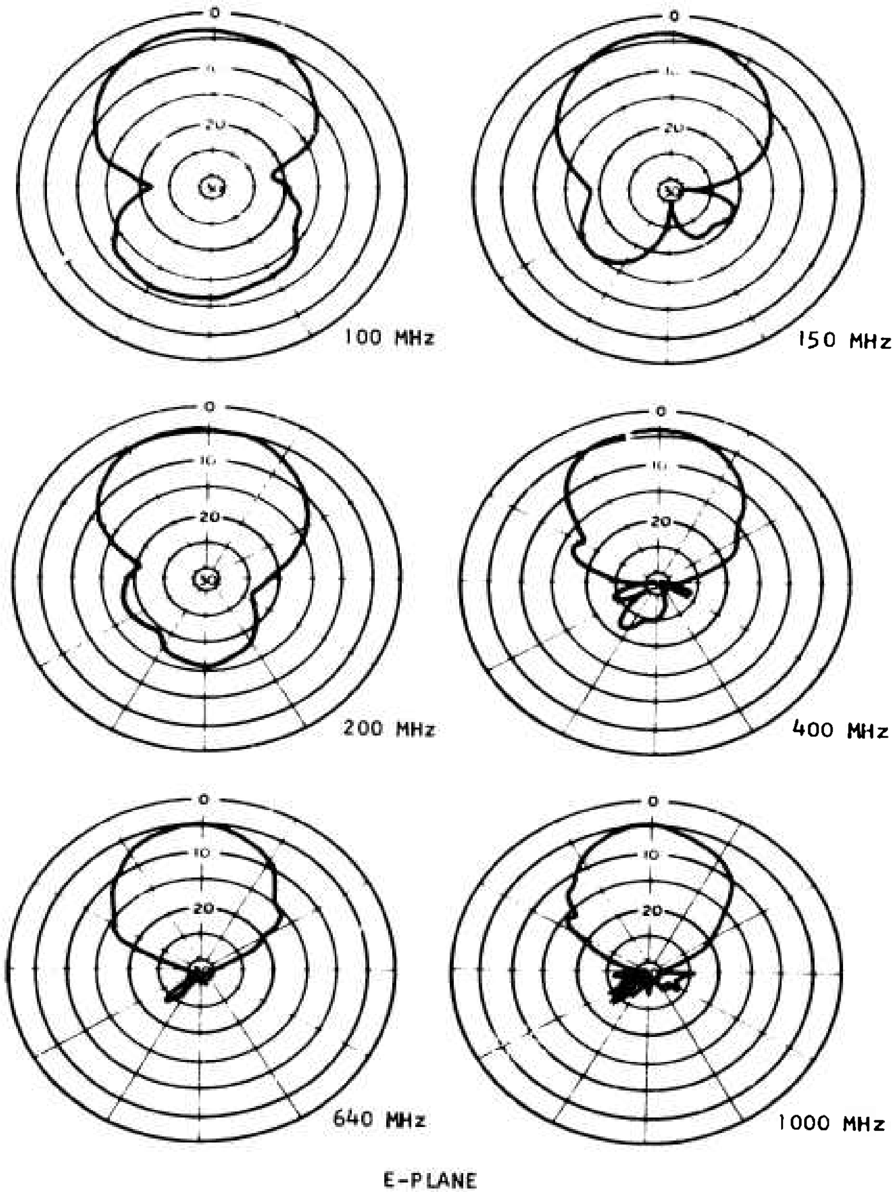


Figure 40. E-Plane Patterns for Antenna Model No. 3

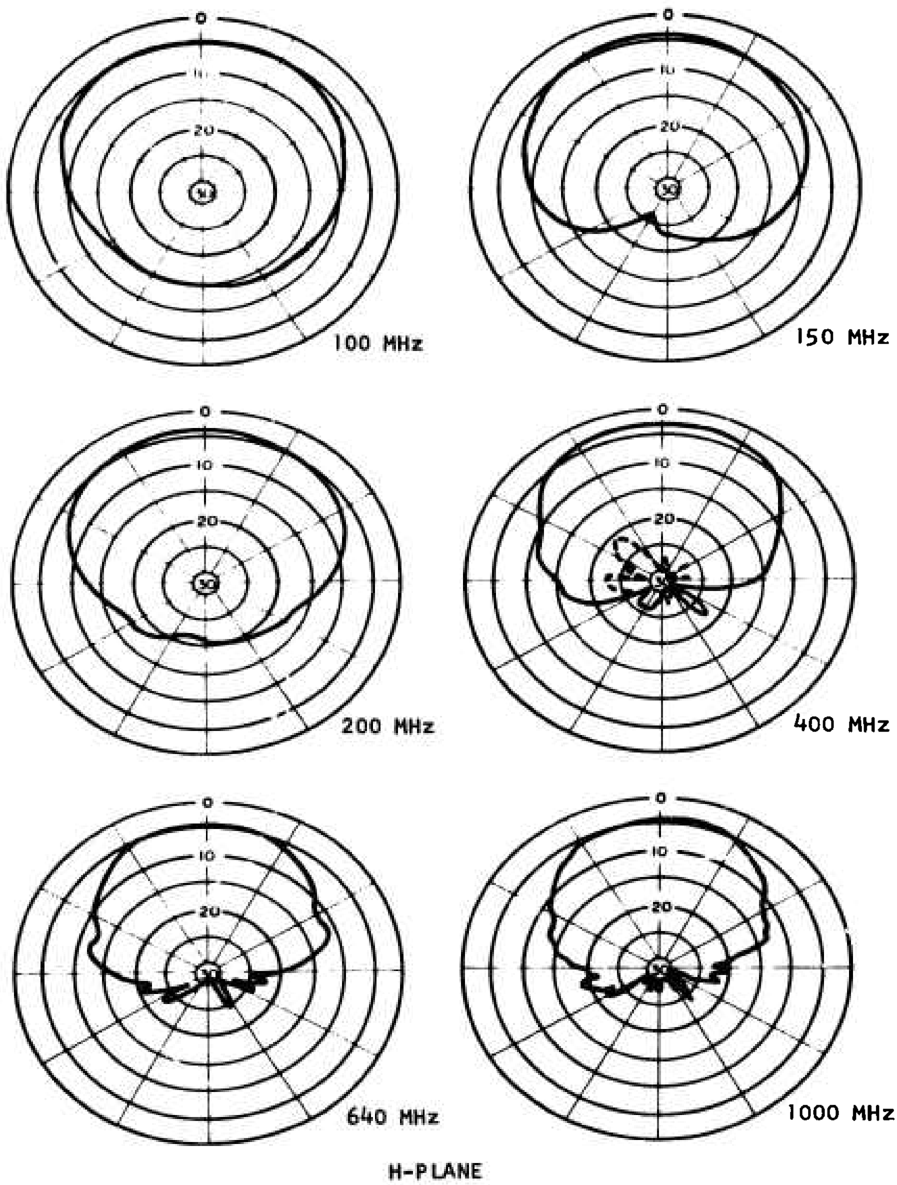


Figure 41. H-Plane Patterns for Antenna Model No. 3

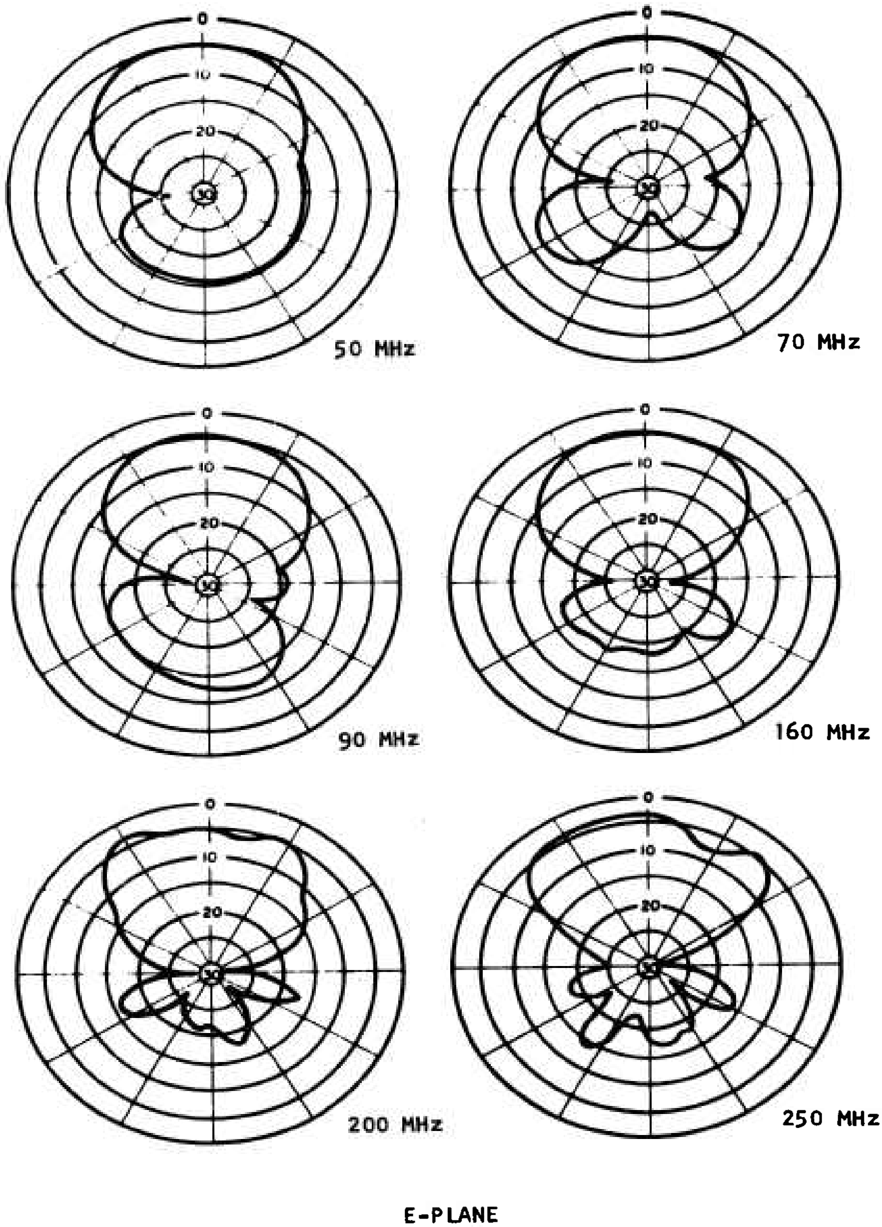


Figure 42. E-Plane Patterns for Antenna Model No. 4

3.4 (Continued)

The frequency behavior of the pattern beamwidth at the 3-db and 10-db points of the antennas are presented in Figures 43 through 46. The log periodicity and wide bandwidth stability are clearly evident. These curves again demonstrate the superior performance of antenna No. 1.

To compare the directivity of the square-boom arrays with the conventional log-periodic dipole antennas, the directivity of antenna model No. 1 was calculated from the following formula.[2]

$$D = \frac{41,253}{\theta_E \ \theta_H}$$

where θ_E = half-power beamwidth in the E-plane

θ_H = half-power beamwidth in the H-plane

The directivity of the conventional LPD antenna was calculated from the data reported by Carrel.[3] The directivity calculated using equation (1) is 8.6-db, and the directivity predicted by Carrel for the antenna is 9.0-db. The near perfect agreement between the two results indicates that no degradation of performance is expected in the square-boom construction.

Of further interest are the design parameters used for model No. 4. According to Carrel, when σ is less than 0.05, the directivity falls off rapidly and the front-to-back ratio increases. This indicates that the poor performance observed on model No. 4 was due primarily to the choice of σ rather than to the square-boom construction. This further indicates that Carrel's work may possibly be used to predict the performance of this antenna.

The VSWR of the square-boom log-periodic dipole antennas were measured with respect to a 50-ohm line. The results of these measurements are given in Figure 47 through 49.

---

2. Kraus, "Antennas," McGraw-Hill Book Co., 1950, p. 26.
3. R. L. Carrel, "Analysis and Design of the Log-Periodic Dipole Antenna," Technical Report No. 52, Contract No. AF 33((616)-6079, University of Illinois Antenna Laboratory, Urbana, Illinois.

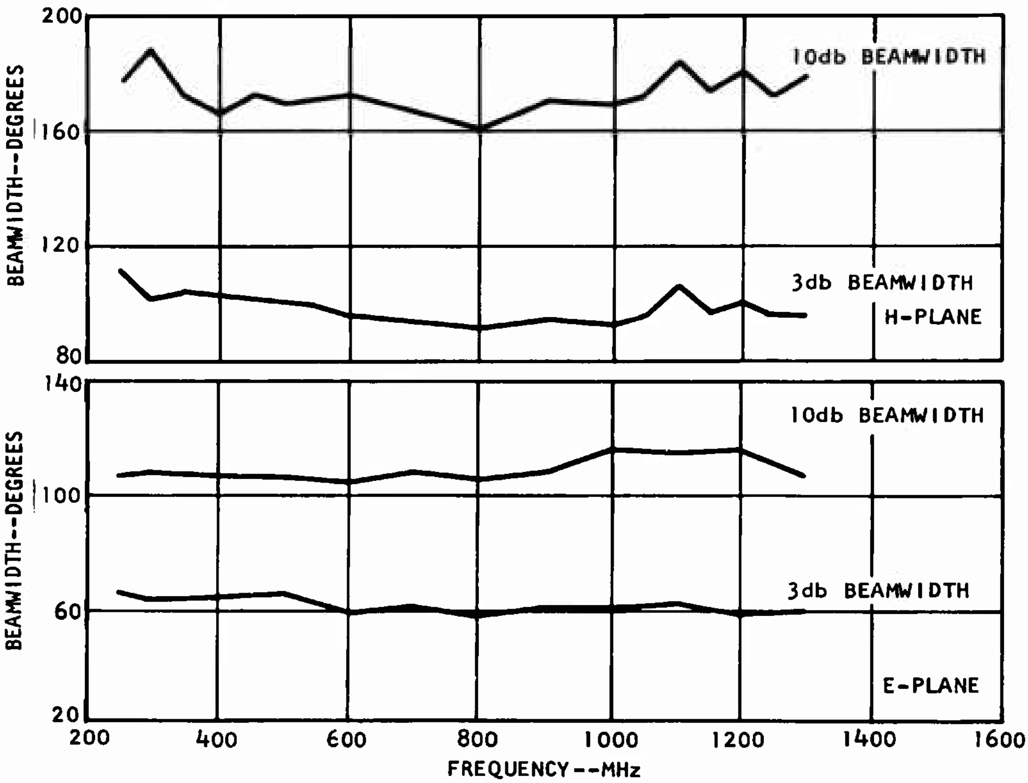


Figure 43. Frequency Versus 3-db Beamwidth (Antenna Model No. 1)

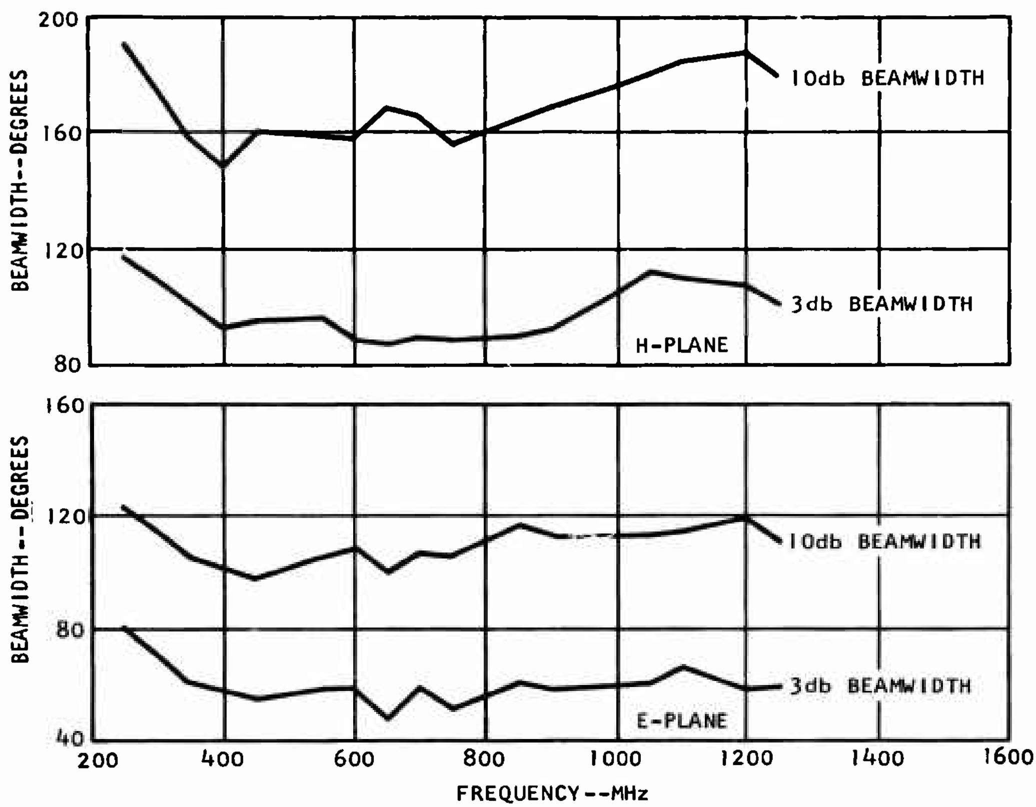


Figure 44. Frequency Versus 3-db Beamwidth (Antenna Model No. 2)

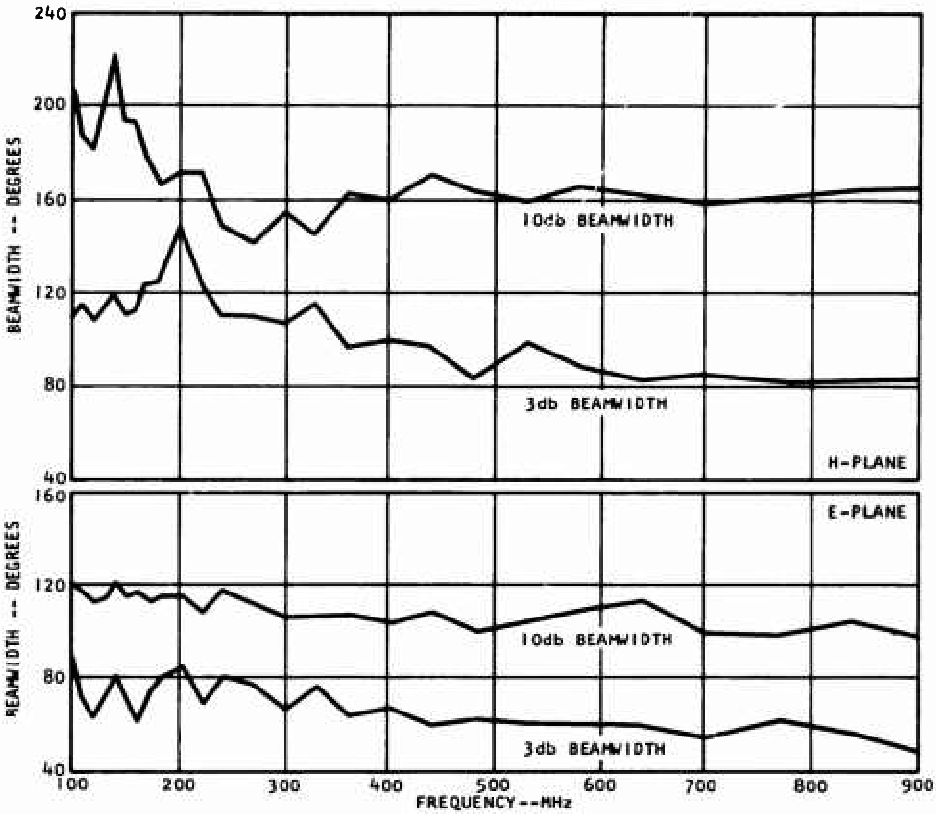


Figure 45. Frequency Versus 3-db Beamwidth (Antenna Model No. 3)

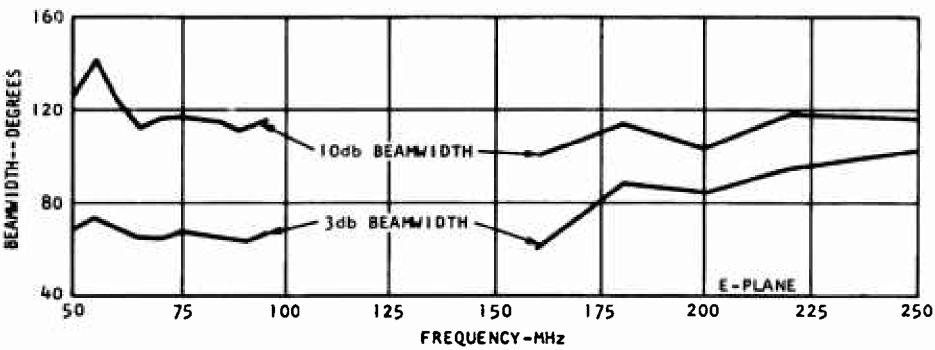


Figure 46. Frequency Versus 3-db Beamwidth (Antenna Model No. 4)

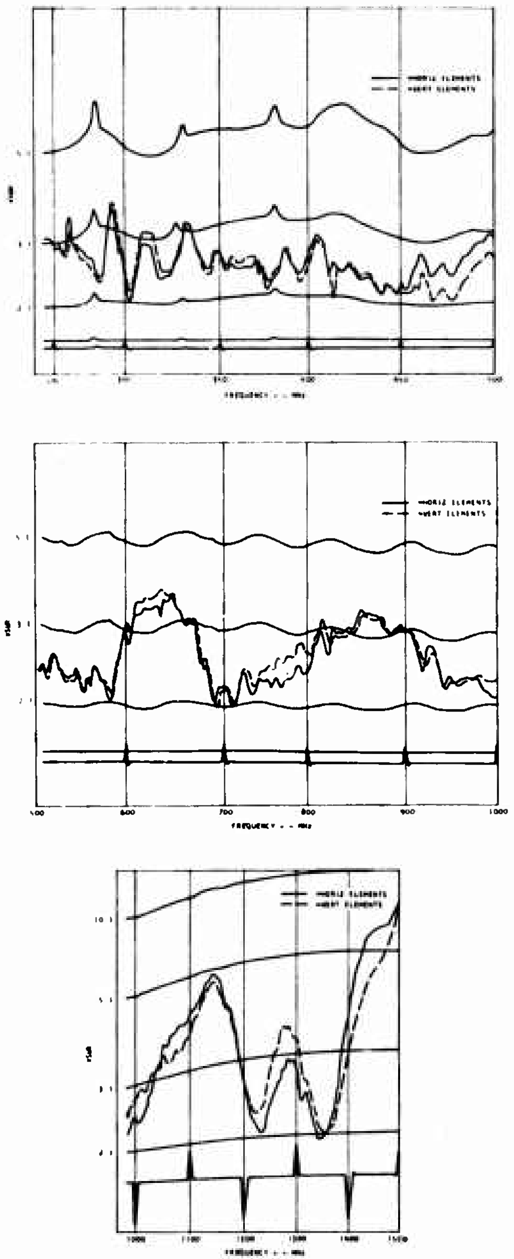


Figure 47. VSWR Versus Frequency for Antenna Model No. 1

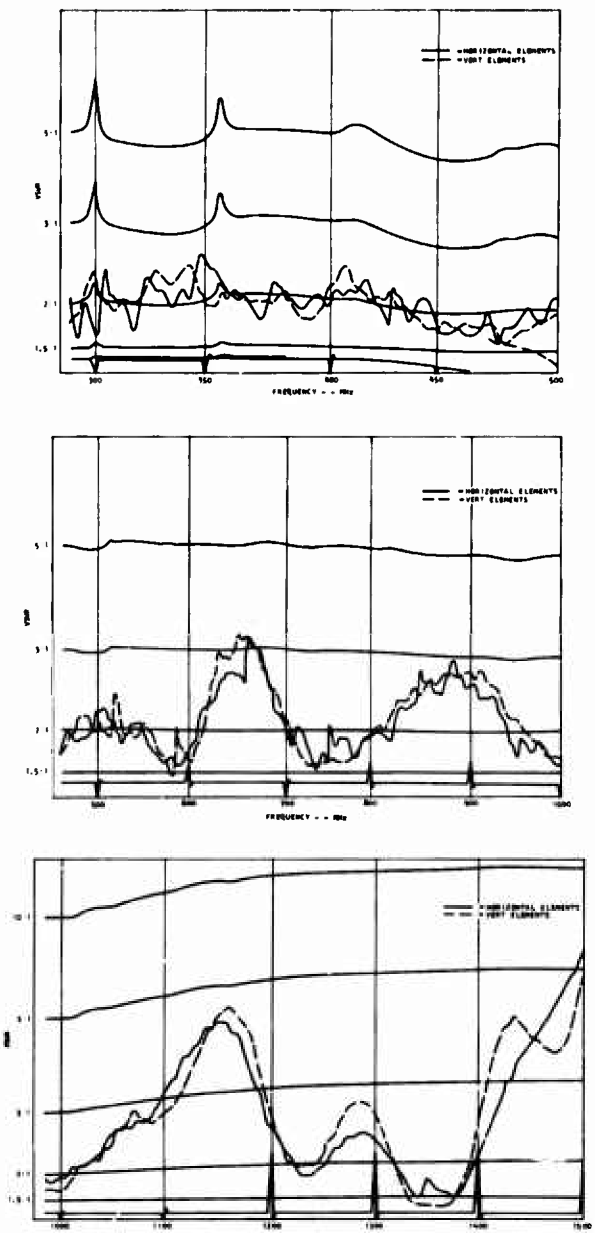
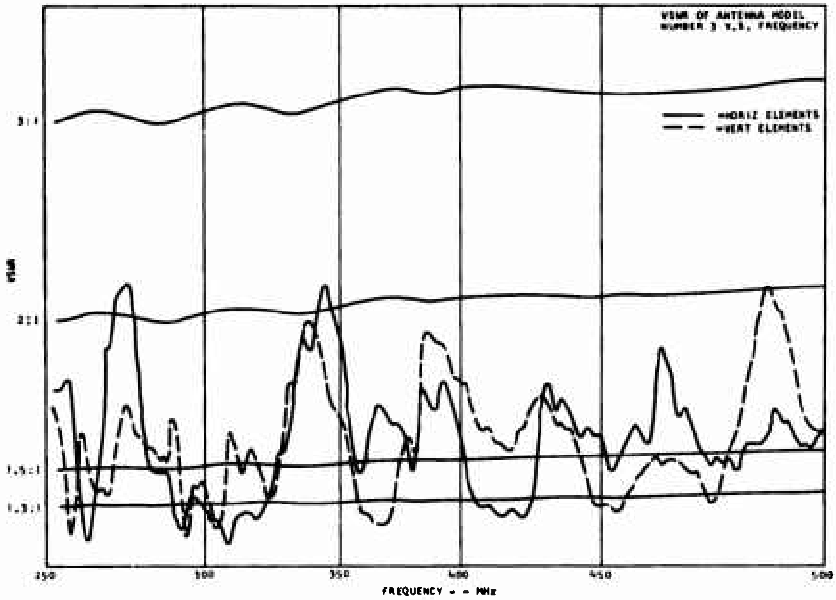


Figure 48. VSWR Versus Frequency for Antenna Model No. 2



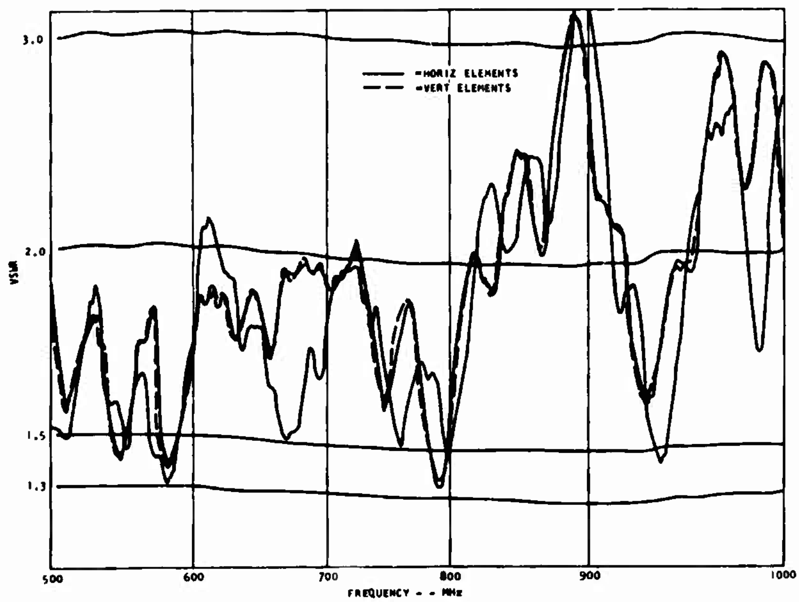


Figure 49. VSWR Versus Frequency for Antenna Model No. 3

3.4 (Continued)

In general the VSWR plots are typical of the log-periodic dipole antenna because the VSWR oscillates about a mean value that is determined by the design parameters of the antenna. For model No. 1 the mean input VSWR is approximately 3:1, corresponding to a nominal input impedance of 150 ohms. This is a 35 percent reduction in the 225-ohm unloaded impedance of the transmission line. When this antenna was modified to have an unloaded impedance of 125 ohms (model No. 2), the mean VSWR was approximately 2:1, which is equivalent to a nominal impedance of 100 ohms – a much smaller impedance reduction due to element loading. This indicates that a lower design limit exists for the input VSWR of this antenna when referred to 50 ohms.

The input VSWR of antenna No. 3 was slightly less than the VSWR of model No. 2 although the spacing (d) chosen for this antenna should result in a slightly higher VSWR. This was caused by using right-angle dielectric strips with a relative dielectric constant of 5.7. Evaluation of the VSWR curves for this antenna show that with a properly designed transformer, a VSWR of possibly 2:1 may be obtained over the bandwidth of the antenna.

3.5 Conclusions

The purpose of this work was to determine how various design parameters affected the radiation patterns, pattern stability, directivity, and input VSWR of the square-boom log-periodic antenna. Four antennas with widely different design parameters were investigated in the 50 MHz to 1300 MHz frequency range.

It was found that the radiation performance of the antenna and the frequency stability improves as the characteristic impedance of the transmission line is increased. For unloaded transmission line impedances less than 125 ohms, the patterns begin to exhibit a lobe-like structure at the upper operating frequencies. This phenomena was caused by energy remaining on the feeder and being reradiated by the 3/2-wavelength elements. The curve of Figure 35 may be used to design for a particular feeder impedance. However, when this impedance curve is used, it is necessary to correct for the impedance reduction caused by the dielectric used in the antenna construction. It was also found that the limits imposed by Carrel on the design parameters of the log-periodic dipole antenna should be observed.

3.5 (Continued)

Carrel's work may also be used to estimate the performance of a particular square-boom configuration, provided the transmission line impedance is above the minimum specified above.

It was found that the amplitude of the cross-polarized component increased with increasing frequency. For the models tested, the magnitude of the cross-polarized radiation was approximately 13 db below the on-axis gain at the highest operating frequency and it decreased to values greater than -20 db at the lower operating frequencies.

Although the performance of this antenna improved as the boom impedance was increased, a corresponding increase occurred in the VSWR referenced to 50 ohms. Thus if both good performance and low VSWR are design criteria, it will be necessary to determine a compromise or to employ a suitable transformer.

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) Sylvania Electronic Defense Laboratories P.O. Box 205 Mountain View, California 94040	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

LOG-PERIODIC ANTENNA TECHNIQUES

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

Technical Memorandum

5. AUTHOR(S) (Last name, first name, initial)

Bullock, Louis G.
Elfving, Claes T.
Miller, Stuart K.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April 1967	64	3

8a. CONTRACT OR GRANT NO. DA 28-043 AMC-01829(E) b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) EDL-M1016 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U.S. Army Electronics Command Fort Monmouth, New Jersey

13. ABSTRACT

This report describes several investigations conducted during the past year in the area of log-periodic antennas. The work on inductively loaded, foreshortened log-periodic antennas included measurement of patterns and gains of antenna models which were foreshortened by various amounts. Capacitive top-loading of monopole antennas was also investigated to develop other techniques for log-periodic antenna foreshortening. Finally, a new, flat plate boom configuration for stronger and less expensive construction of log-periodic dipole array antennas is described.

DD FORM 1 JAN 64 1473

14. KEY WORDS	LINK A		LINK B		LINK C		KEY WORDS (Cont)	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT		ROLE	WT	ROLE	WT	ROLE	WT
Antenna													
Techniques													
Log													
Periodic													
Foreshortening													
Inductively-loaded													
Capacitively-loaded													
Boom													
Tubing													
Square-boom													