LOGARITHMICALLY PERIODIC ANTENNA DESIGNS

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Summary

Research on new types of broadband logarithmically periodic antenna structures is reported. The antennas have pattern and impedance characteristics which are essentially independent of frequency over theoretically unlimited bandwidths. Bandwidths of ten to one are readily achieved in practice. Structures are described which provide linearly polarized omnidirectional, bidirectional and unidirectional patterns as well as circularly polarized bidirectional and unidirectional patterns.

Introduction

The subject of this paper is a class of antennas, called logarithmically periodic antenna structures, for which the pattern and impedance are essentially independent of frequency over theoretically unlimited bandwidths. Research on one particular type of these structures which provided a linearly polarized bidirectional beam was previously reported.[1] Since that time, various types of these structures have been discovered which provide linearly polarized unidirectional and omnidirectional patterns as well as circularly polarized unidirectional patterns. The proven versatility and wide bandwidth of these structures leads to the conclusion that the applications are practically unlimited. Obvious applications are to high-frequency and ECM antennas as well as to primary feeds for reflector and lens-type antennas.

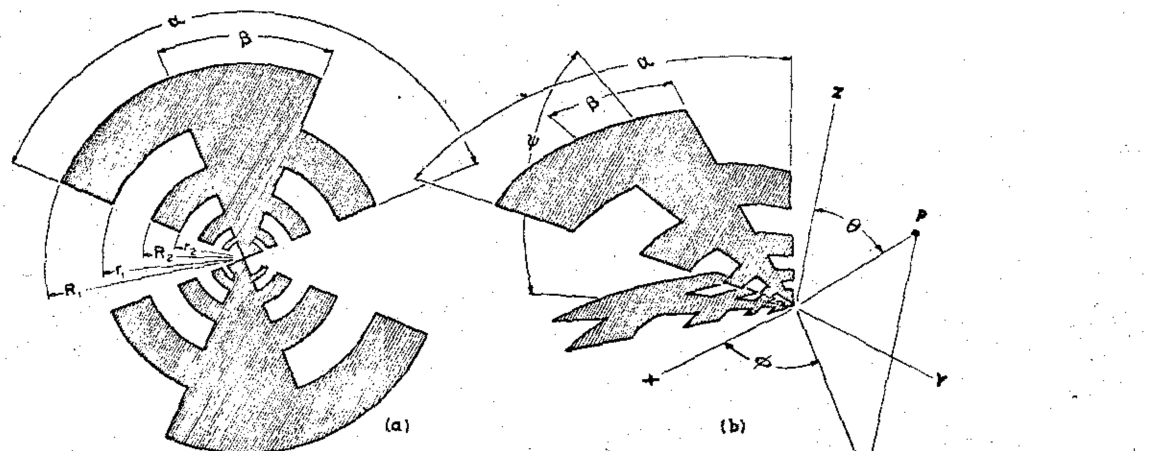
The only other known class of frequency independent antennas is the angular antenna described by V. H. Rumsey.[2] Common examples are the discone, biconical, and bow-tie antennas which have bandwidths of approximately 2 or 3 to 1 for which the pattern is essentially independent of frequency. The so-called "end effect" limits the bandwidth of these antennas. An example of a recent type of angular antenna which apparently has negligible "end effect" is the equiangular or logarithmic spiral antenna[3] which has a frequency independent bandwidth of better than 10 to 1.

Referring to figure 1, the geometry of logarithmically periodic antenna structures is defined so that the pattern and impedance repeat periodically with the logarithm of the frequency. For planar structures, this is accomplished by defining their shape such that θ equals a periodic function of ln r where r and θ are the polar coordinates in the plane. Then if ln τ is the period of ln r, the operation of a structure of infinite extent would be the same for any two frequencies related by some integral power of τ. For the simple structure in figure 1a:

$$\tau = \frac{R_{N+1}}{R_N}$$

If the shape of the structure and the factor τ can be made such that the variation of the pattern and impedance over one period is small, then this will hold true for all periods, the result being an extremely broadband antenna. For finite structures, it has been found that since the end effect is negligible, wide bandwidths are readily obtained.

The two halves of the antenna are fed at the vertices either with a balanced two-wire line or with a coaxial line running up one half of the structure with the outer conductor bonded to the structure. For the structure of figure 1a, it is found that the lower and higher frequency limits are obtained when the longest and shortest teeth respectively are approximately 1/4 wavelength long. By probing the structure, it is found that the currents on the structure die off quite rapidly after progressing past the region where a tooth 1/4 wavelength long is positioned. This accounts for the negligible end effect. This antenna has a horizontally polarized bidirectional pattern with approximately equal and constant principal



$\tau = \frac{R_{N+1}}{R_N}$	$\alpha = 135°$
	$\beta = 45°$
$\sigma = \frac{r_N}{R_N}$	$\tau = .5$

Fig. 1 Parameters and coordinate system for circular-tooth structures.

plane beamwidths over a frequency band of 10 to 1 or more and has a constant input impedance of approximately 170 ohms. The axes of the lobes are perpendicular to the plane of the structure. It was originally believed that it was necessary to make these structures identical to their complement in order to obtain a frequency independent input impedance. However, the results reported in this paper demonstrate that this equi-complementary condition is sufficient but not always necessary. Several frequency independent antennas will be introduced where the deviation from the equi-complementary condition is quite severe.

The fact that the electrical characteristics of logarithmically periodic structures repeat every period greatly simplifies the experimental investigation of them because it is only necessary to measure these characteristics over a half or single period in most cases. The operation over other periods may be readily predicted provided the end effect is negligible and that all dimensions are made proportional to their distance from the vertex.

As illustrated in figure 1b, D. E. Isbell[4] found that by bending the curved tooth structure about a horizontal axis, a unidirectional pattern pointing in the direction of the positive y axis could be obtained. Some control of the principal plane beamwidths and front-to-back ratio was obtained by varying the parameters α, β, ψ, and τ. Typical E-plane and H-plane beamwidths of 60° and 90° and a front-to-back ratio on the order of 10 to 15 db were obtained. It was found that the characteristic impedance of the structure decreased as the angle ψ was decreased, but that the VSWR referred to this characteristic impedance increased rather rapidly to 3.5:1 for $\psi = 30°$.

A great number of logarithmically periodic antenna configurations are possible. The investigation reported in this paper was conducted to study impedance, pattern, and polarization characteristics of a variety of structures. Another objective of the investigation was to devise practical forms of this type of antenna. Since large, circular tooth structures would be difficult to construct, the possibility of simplifying this basic structure by straightening the teeth and by making wire approximations of the teeth was investigated and is reported in the following sections.

Trapezoidal Tooth Sheet Structures

Figure 2 shows a sketch of a general trapezoidal tooth structure and gives a definition of the coordinate system and various parameters that will be used throughout this paper to describe the various structures. Figure 3 is a photograph of a printed circuit board form of this type of structure which was used for the experimental investigation. By comparing a structure cut from sheet metal in a conventional way to an identical structure etched on teflon dielectric printed circuit

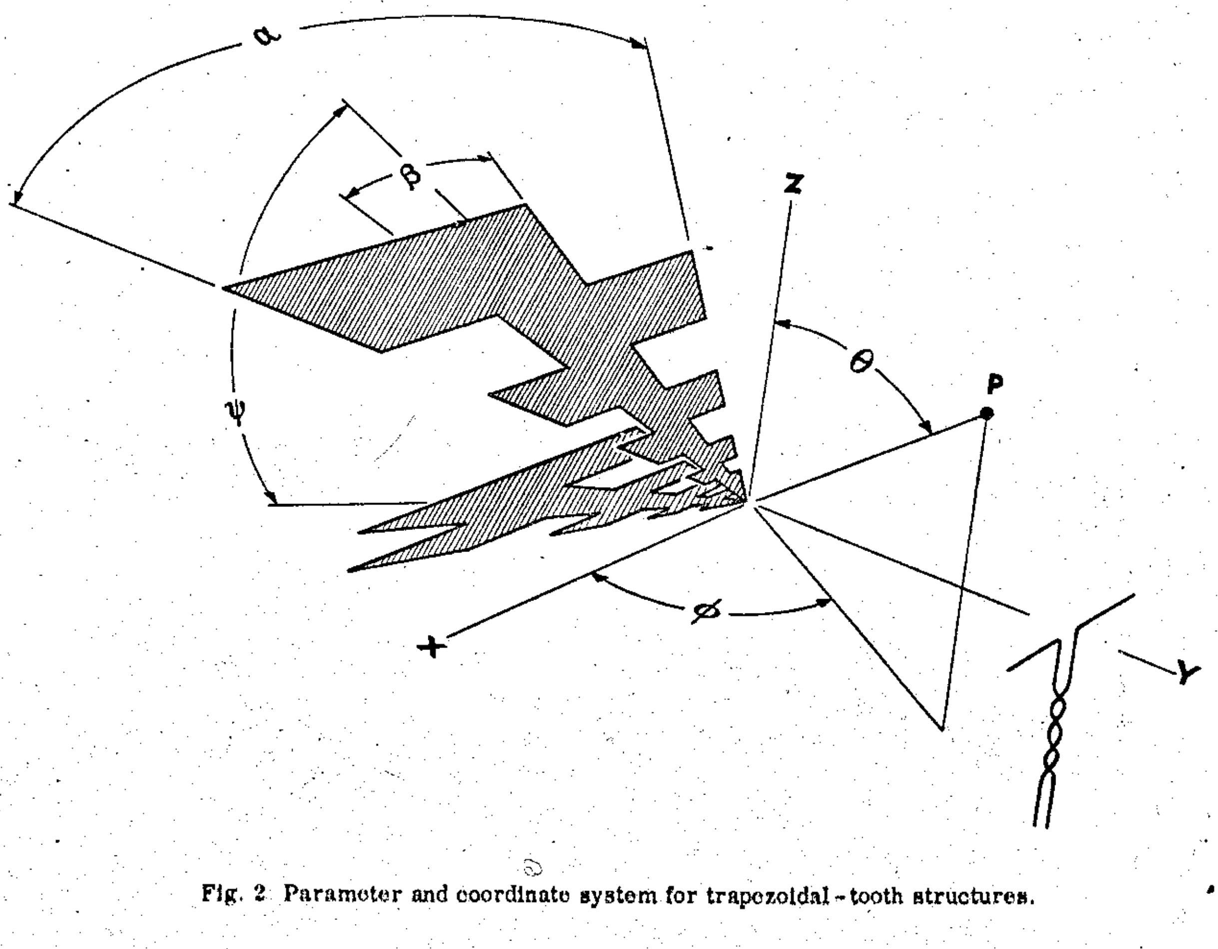


Fig. 2 Parameter and coordinate system for trapezoidal-tooth structures.

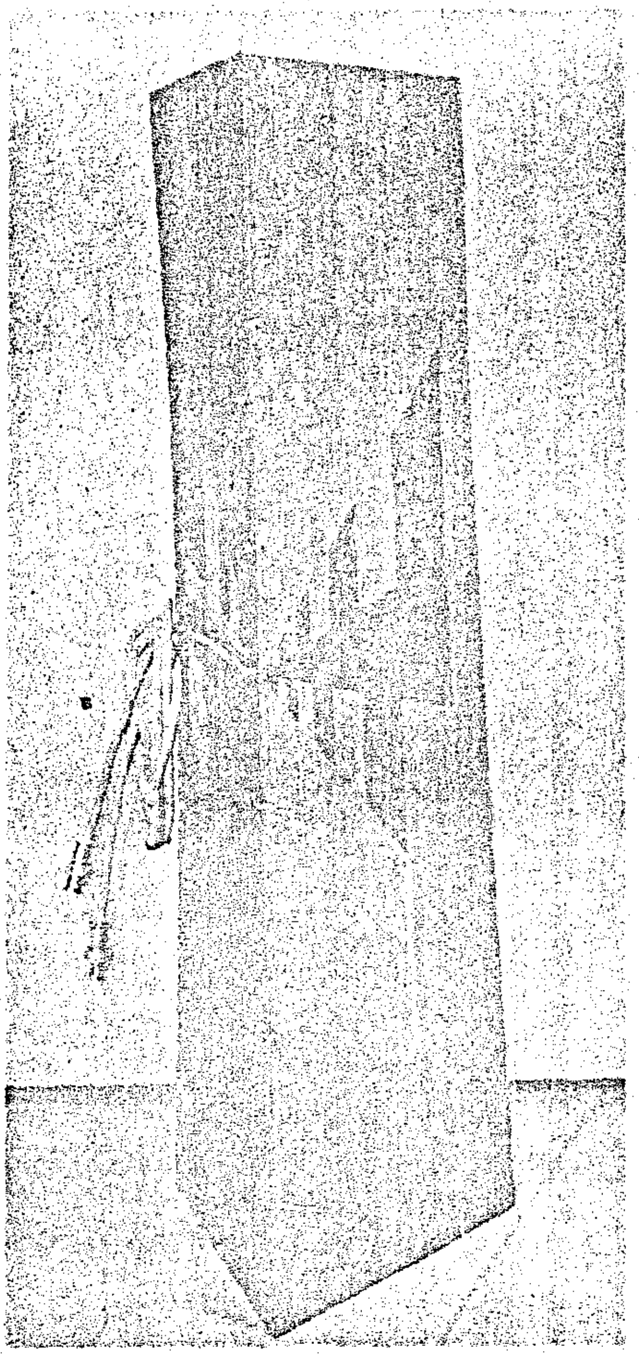


Fig. 3 A printed, nonplanar, trapezoidal-tooth structure bent about the X axis.

board, it was found that the printed circuit board models could be used up to about 3000 mc without the presence of the dielectric becoming too objectionable. As a point of interest, the undesired metal can be removed either by an etching process or by cutting around the outline of the structure with a sharp instrument and then peeling the metal away. Two models of planar structures (with $\psi = 180°$) were constructed with the following parameters: $\alpha = 90°$, $\beta = 30°$ for one and

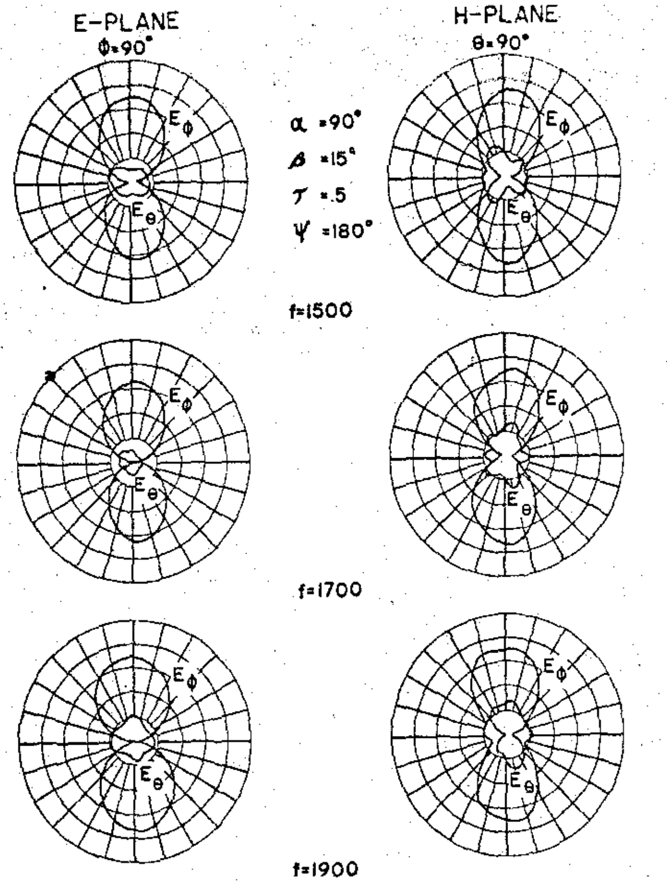


Fig. 4 Patterns for planar trapezoidal-tooth structure.

$\beta = 15°$ for the other, $\tau = 0.5$, and R_1, the perpendicular distance from the vertex of one-half the structure to the longest element, is 12.75 cm. Patterns were taken over about a two to one frequency range (900 to 2100 mc). Figure 4 shows typical patterns for this type of structure. In general, both structures gave essentially frequency independent, linearly polarized, bidirectional patterns. Over the frequency range stated above, the E-plane (pattern in the xy plane of figure 1b) half-power beamwidth varied from 65° to 80° with an average beamwidth of 71°, and the H-plane (pattern in the yz plane of figure 1b) half-power beamwidth varied from 60° to 69° with an average beamwidth of 62°. Of the two antennas tested, the one having the narrower center section ($\beta = 15°$) demonstrated slightly less variation of beamwidth with frequency.

Patterns were taken for a nonplanar structure with $\psi = 60°$ over a 5:1 frequency range. Typical patterns are shown in figure 5. The E-plane patterns were unidirectional with beamwidths that varied from 60° to 75° with an average beamwidth of 65° and the H-plane patterns had beamwidths that varied from 80° to 110° with an average beamwidth of 85°. The front-to-back ratio, due to the cross polarization E_θ, had an average value of about 9 db; the front-to-back ratio, due to the major polarization E_ϕ, had an average value of about 13 db.

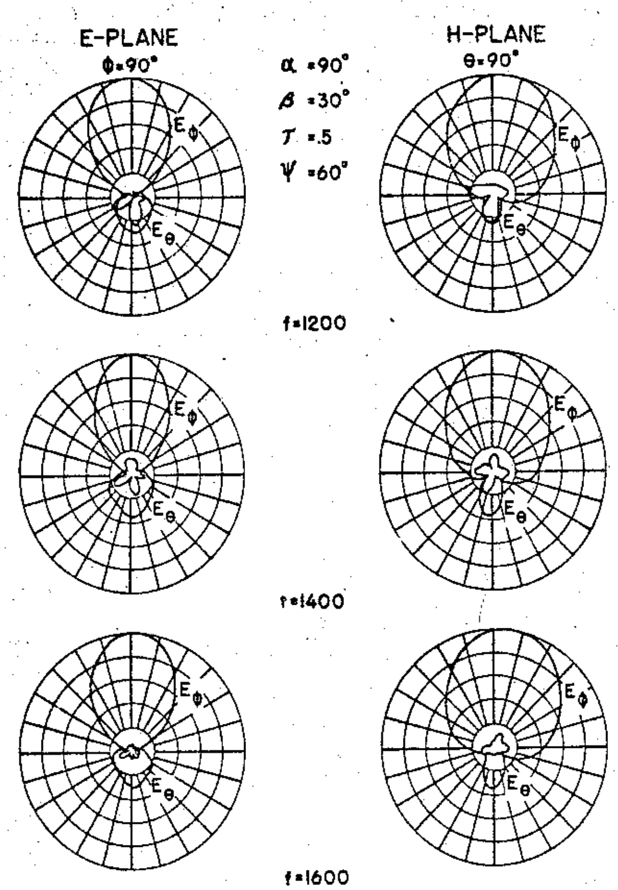


Fig. 5 Patterns for nonplanar (bent about horizontal axis) trapezoidal-tooth structure.

TABLE 1: VARIATION OF Z_0 AND VSWR WITH ψ ANGLE FOR A PRINTED, TRAPEZOIDAL TOOTH STRUCTURE

ψ Angle	Z_0	VSWR (Referred to Z_0)
180	170	1.4
60	105	1.6

Table 1 shows how the impedance of this particular structure compared with the corresponding planar structure. The input impedance Z_0 was reduced from 170 ohms to about 105 ohms and the VSWR's referred to their respective input impedances were about the same. Thus, the impedance characteristic of a nonplanar trapezoidal tooth structure is considerably better than that of a curved tooth structure.

Another possible nonplanar structure is where the original planar structure is bent about its vertical axis to an included acute angle χ. A structure of this type is shown in figure 6. Patterns and impedance were measured for a variation in χ from 180° to 60° in 30° steps. It was found that the E-plane patterns showed a definite tendency toward varying from bidirectional at $\chi = 180°$ to omnidirectional at $\chi = 60°$; the H-plane patterns remained bidirectional over the same range.

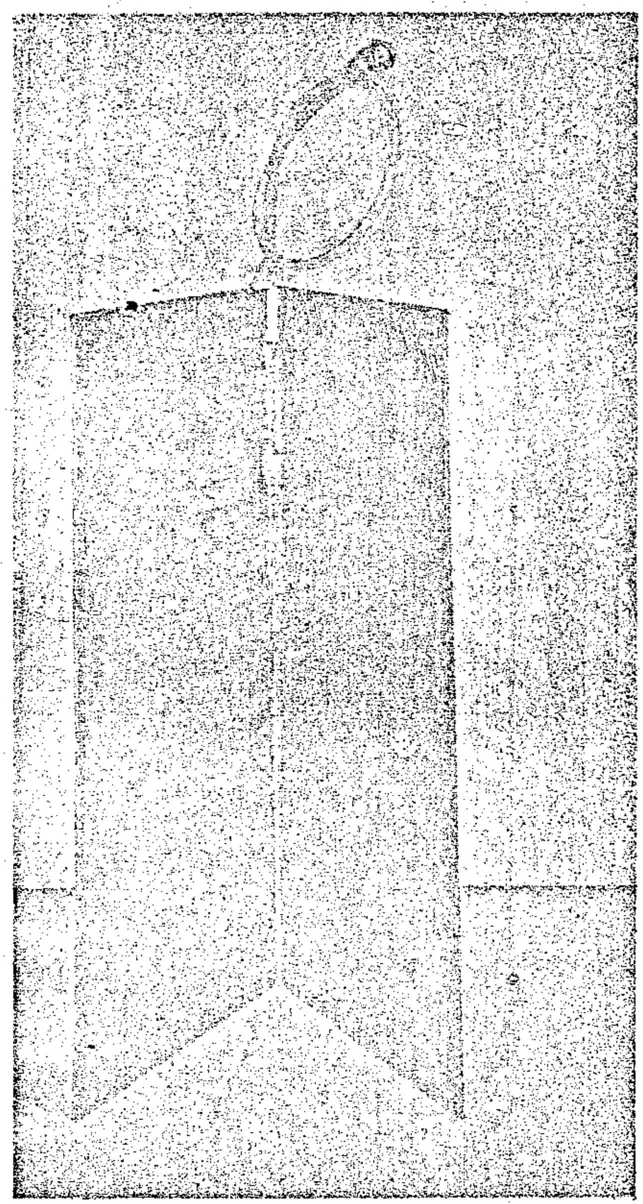


Fig. 6 A printed, nonplanar, trapezoidal-tooth structure bent about the Z axis.

Typical patterns for $\chi = 90°$ are shown in figure 7. In general, the patterns varied considerably with frequency.

TABLE 2: VARIATION OF Z_0 AND VSWR WITH VARIOUS χ ANGLES FOR A PRINTED, TRAPEZOIDAL TOOTH STRUCTURE

χ Angle	Z_0	VSWR (Referred to Z_0)
180	170	1.4
120	180	1.35
90	200	1.4
60	210	1.9

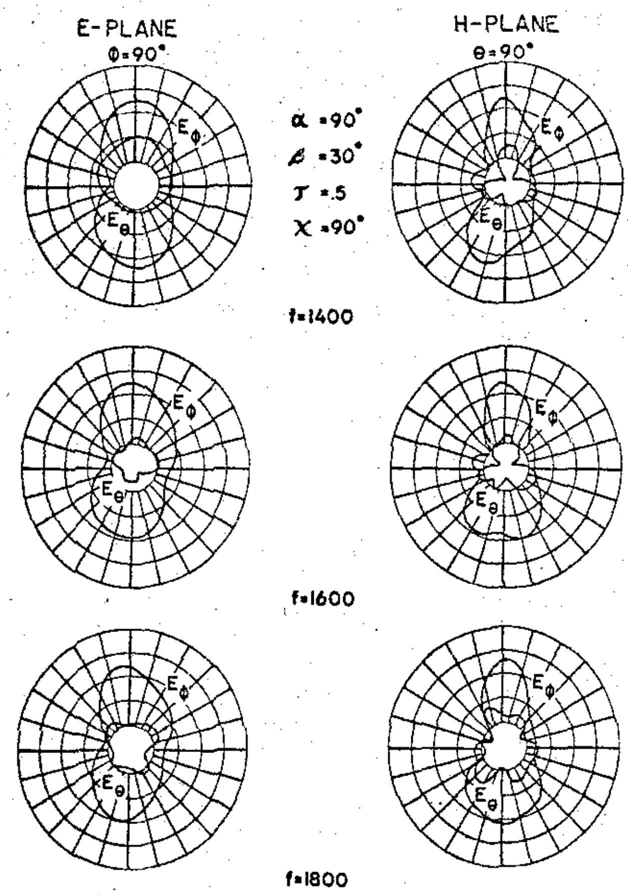
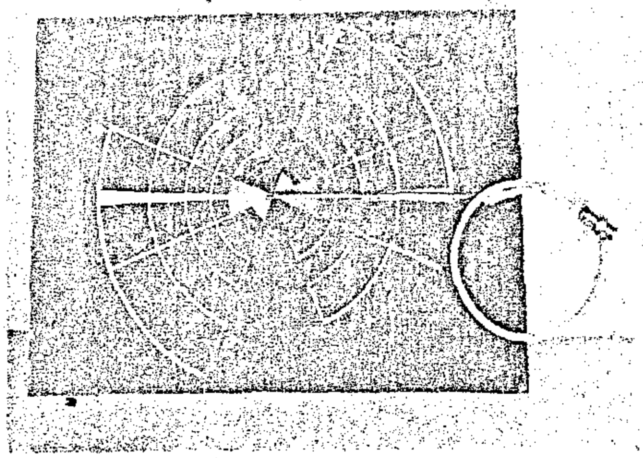
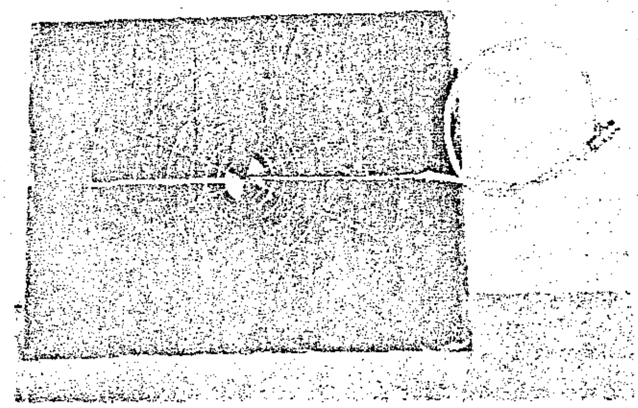


Fig. 7 Patterns for nonplanar (bent about vertical axis) trapezoidal-tooth structure.



(a) With Tapered Elements



(b) With Uniform Elements

Fig. 8 Planar, printed, wire-like, circular-tooth structure.

The variation of impedance with the angle χ was rather interesting, as can be seen in table 2. The average input impedance Z_0 increased as the χ angle was decreased. This was just the reverse of the effect that the reduction in ψ produced.

Wire Structures

Wire, Curved Tooth, Planar Structure

The approximation of sheet structures with wire structures was first investigated for a circular tooth structure. Two different approximations are shown in figure 8 and as can be seen, all the metal was removed except for narrow strips outlining the teeth. A still closer observation will indicate that the horizontal metal strips in figure 8a vary in width proportional to the distance from the center of the structure and the vertical members are triangular in shape. This is necessary in order to make the structure logarithmically periodic. Figure 8b is a structure identical to that of figure 8a, except that all members are of uniform width.

The average input impedance of the structure in figure 8b was slightly lower than that in figure 8a, 110 ohms for figure 8b as compared to 150 ohms for figure 8a. As an interesting comparison, the impedance of a similar basic circular tooth structure was about 150 ohms.

In general, the patterns for the two cases were very similar. In both cases, the patterns were essentially independent of frequency, with the structure having tapered elements being slightly less frequency sensitive. The beamwidths in both the above cases were slightly wider than the beamwidth of the corresponding basic circular tooth structure.

Nonplanar, Wire, Trapezoidal Tooth Structure

Since the circular tooth structures with only the outline of the teeth being made of metal performed almost as well as the basic circular tooth structure, this technique was used in constructing the trapezoidal tooth structures. In figures 9a and 9b are two typical types of wire, nonplanar, trapezoidal tooth structures. The only difference is that in figure 9a, the β angle has

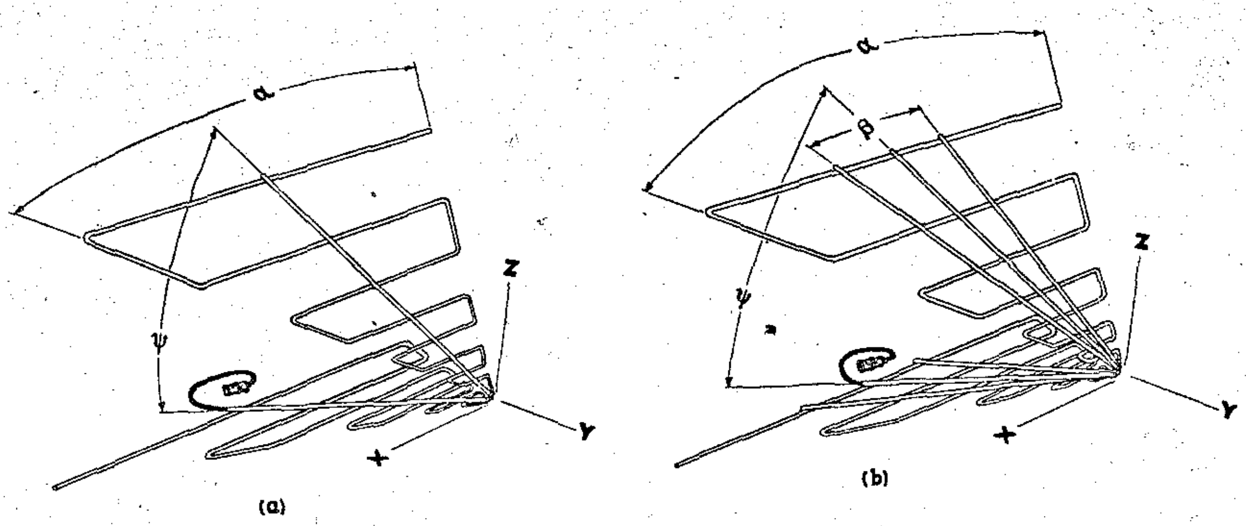


Fig. 9 Types of nonplanar, wire, trapezoidal-tooth structures.

been decreased to zero. Figure 10 is a photograph of a typical model used in the investigation of this type of structure. (In the photograph, the dielectric rod between the halves of the antenna was used for support only and is not part of the antenna.)

A considerable number of models of this type of structure with various values of the parameters α, ψ, and τ were constructed and tested. In general, the patterns of these structures were quite independent of frequency, especially those with the larger values of τ. Variations of the beamwidth of only several percent over a period of operation were common.

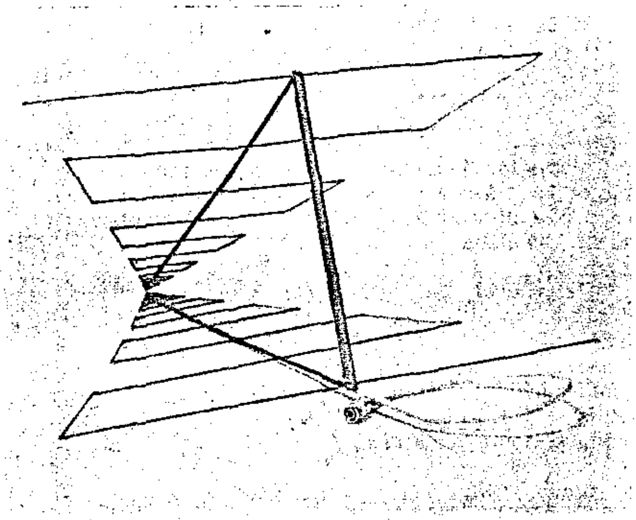


Fig. 10 A typical, wire, nonplanar, trapezoidal-tooth structure.

Figure 11 shows the patterns over a half-period for the antenna shown in figure 10. This particular antenna had an average E-plane beamwidth of 67°, an average H-plane beamwidth of 106° and an average front-to-back ratio of 15 db.

Table 3 shows how the beamwidth, gain, and front-to-back ratio are functions of the parameters of the antenna for several structures. From the table, it can be seen that both E-plane and H-plane beamwidths decrease as the design ratio of τ is increased. For example, take $\psi = 45°$, $\alpha = 60°$; then as τ was varied from 0.4 to 0.707, the E-plane beamwidth decreased from 86° to 64°, and the H-plane beamwidth decreased from 112° to 79°. It can then be concluded that if high gain is required, a large design ratio is desirable. It was found that the spacing between two adjacent transverse elements should not be greater than 0.3 of the length of the longer element. Otherwise, the pattern starts breaking up. Also, from the table it can be seen that the H-plane beamwidth increased with a decrease in ψ angle for any one design ratio, while the E-plane pattern is essentially independent of the ψ angle. Also, the front-to-back ratio, in general, increased with a decrease in ψ angle. The α angle had a second-order effect on the beamwidth; with an increase in α, a decrease in E-plane beamwidth and an increase in H-plane beamwidth resulted.

In using the information in table 3 to design an antenna with relatively high gain, high front-to-back ratio, not too great complexity (the number of elements increases as the design ratio increases), one must make a compromise as to what parameters to choose. For example, antenna number 14 has $\alpha = 60°$, $\beta = 0$, $\psi = 45°$, and $\tau = 0.6$. The gain is 6.5 db over a dipole and the front-to-back ratio is 15.8 db.

These pattern characteristics compare very favorably with those of a three-element Yagi antenna. Admittedly, this type of structure is somewhat more complex to construct than a Yagi, insofar as the number of elements required is greater, and it is necessary to use either a tapered coax line or a balanced open wire transmission line transformer in order to match the impedance of the structure to conventional transmission lines. It has, however, the added advantage of having

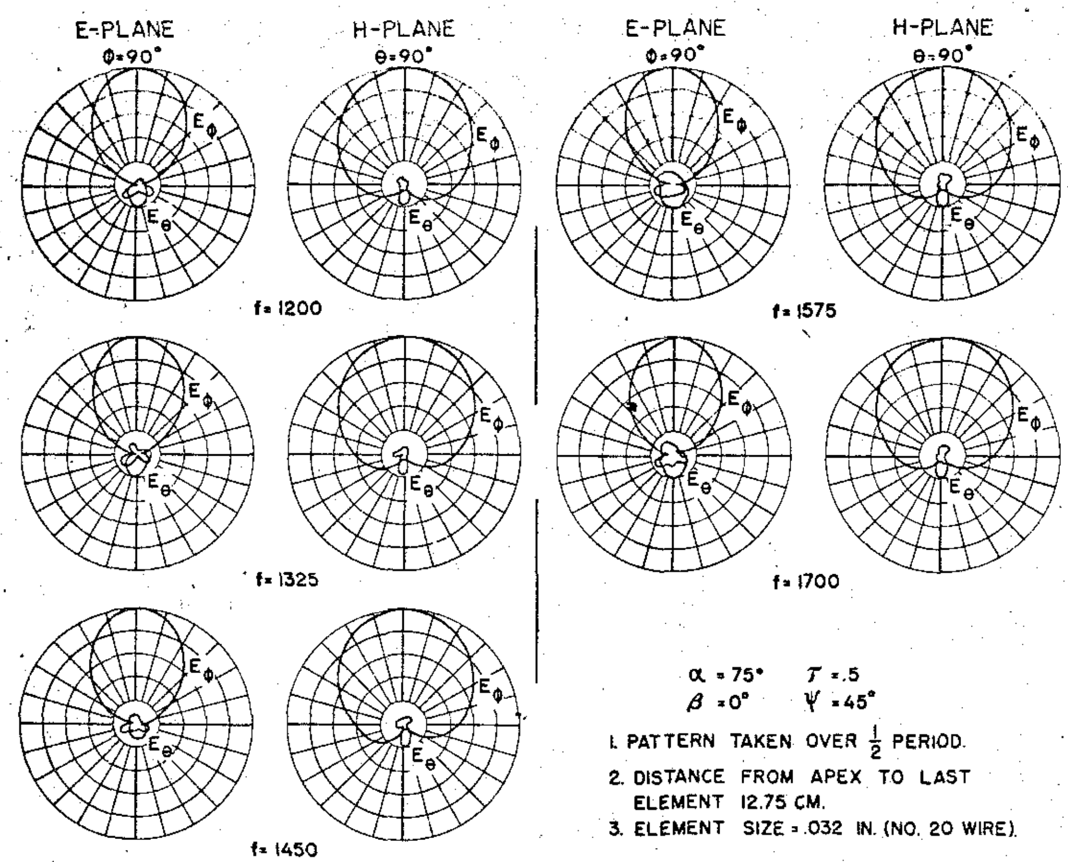


Fig. 11 Patterns for a typical, wire, nonplanar, trapezoidal – tooth structure.

TABLE 3. PATTERN CHARACTERISTICS FOR VARIOUS WIRE, TRAPEZOIDAL TOOTH STRUCTURES

ANT	α	PARAMETERS τ	ψ	AVE. HALF POWER BEAM WIDTHS IN DB E PLANE	H PLANE	APPROX. GAIN/DIPOLE IN DB	MAX. SIDE LOBE LEVELS IN DB
1	75	.4	30	74	155	3.5	12.4
2	75	.4	45	72	125	4.5	11.4
3	75	.4	60	73	103	5.3	8.6
4	60	.4	30	85	153	3.0	12.0
5	60	.4	45	86	112	4.2	8.6
6	60	.4	60	87	87	5.3	7.0
8	75	.5	30	66	126	4.9	17.0
9	75	.5	45	67	106	5.6	14.9
10	75	.5	60	68	93	6.1	12.75
11	60	.5	30	70	118	4.9	17.7
12	60	.5	45	71	95	5.8	14.0
13	60	.5	60	71	77	6.7	9.9
14	60	.6	45	67	85	6.5	15.8
15	60	.707	45	64	79	7.0	15.8
16	45	.707	45	66	66	7.7	12.3

essentially frequency independent impedance and pattern characteristics over a ten to one or more bandwidth.

The patterns of a larger antenna model, with the above design parameters (see figure 12) were measured over a ten to one frequency range (100 to 1000 mc). A slight increase in the beamwidths and a slight decrease in the front-to-back ratio was observed at about 300 mc. This effect was investigated by taking patterns of the structure and removing the elements one by one. It was found that the elements whose lengths were about 1.5 λ were responsible for these pattern changes. Thus, some end effect was noticeable for this structure at a frequency approximately three times the low frequency limit of the antenna.

TABLE 4. VARIATION OF AVERAGE IMPEDANCE AND VSWR WITH ψ ANGLE FOR A TYPICAL, WIRE, TRAPEZOIDAL TOOTH STRUCTURE

ψ Angle	Zo	VSWR (Referred to Z_O)
60	120	1.4
45	110	1.45
30	105	1.5
7	65	1.8

Fig. 12 A larger model of a (low-frequency limit of about 100 mc) wire, nonplanar, trapezoidal-tooth structure.

Table 4 shows how the impedance varies with the ψ angle for a typical wire, trapezoidal tooth structure.

The impedance of the wire, trapezoidal tooth structure (shown in figure 10) having the following parameters: $\alpha = 75°$, $\beta = 0$, $\tau = 0.5$, $\psi = 45°$, and $R_1 = 12.75$ inches, was measured over a sixteen to one frequency band (250 to 4000 mc). The impedance was good from 350 mc to 4000 mc or an eleven to one frequency band. This closely agrees with the previous definition of the low frequency limit since the width of the structure at the last element was 19.5 inches or a half wavelength at 304 mc. The actual measurements showed that the input impedance Z_0 decreased slowly and uniformly from about 150 ohms at 350 mc to about 75 ohms at the high end of the range of measurements. This change in input impedance is due to the modeling technique rather than a fault of the antenna. The elements of this particular model were of constant diameter (# 14 wire) and as the frequency was increased, the length-to-diameter ratio of the elements which were responsible for the radiation decreased. As further proof that modeling was partially responsible for this Z_0 change, the impedance of another larger model, figure 12, where the elements had been slightly tapered, was measured over a ten to one frequency range. Although the Z_0 of this structure also decreased as the frequency increased, the change was somewhat smaller. Thus, in order to obtain good frequency independence over a 10:1 bandwidth, it is necessary to model the structure accurately according to the design principles.

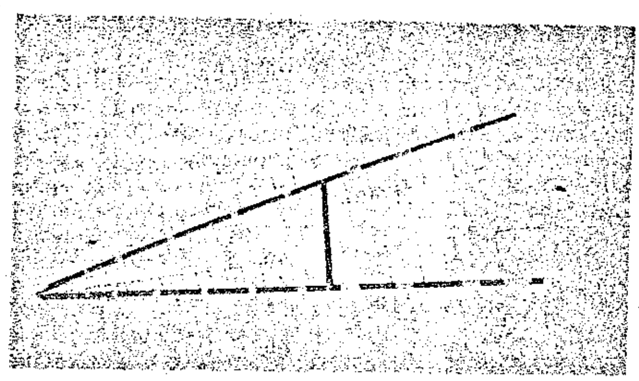


Fig. 13 A long (2λ at 1,000 mc) nonplanar, wire, trapezoidal-tooth structure.

From the observed trends indicated in table 3, an antenna with relatively high gain was designed. The model was constructed as shown in figure 13. The parameters for this particular model were $\alpha = 14.5°$, $\beta = 0$, $\tau = 0.85$, $\psi = 29°$ and $R_1 = 60$ cm. In order to make the vertical spacing between horizontal elements of the same length of the two half-structures about twice the length of the particular elements, ψ was set equal to 29°. R_1 was chosen equal to 60 cm in order to make the last element one half-wavelength long at 1000 mc. The patterns for this structure are shown in figure 14. The average E-plane beamwidth was 59°; the average H-plane beamwidth was 38°; and the front-to-back ratio was about 18 db. The resulting gain of this antenna then was slightly better than 10 db over a dipole, and the patterns were extremely frequency

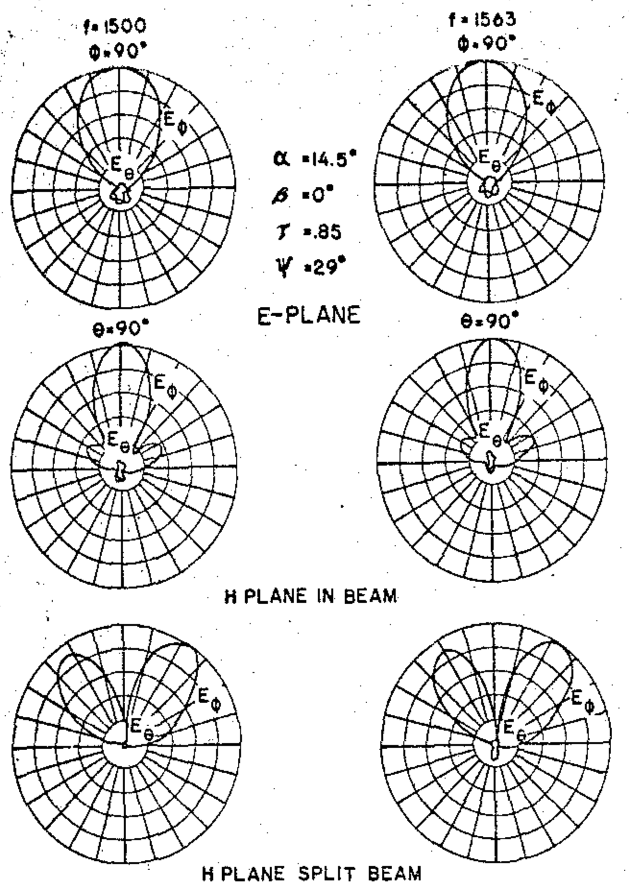


Fig. 14 Patterns for a long (2 λ at 1,000 mc) nonplanar, wire, trapezoidal-tooth structure.

independent. The H-plane split beam patterns of figure 14 were the result of turning one of the half-structures over 180°, i. e., one half-structure is then the mere image of the other. The same effect could be had by placing one of the half-structures over a ground plane at an angle 1/2 ψ to the ground plane. It can be seen that the ground plane would divide the structure symmetrically. The double lobes appear at about ± 35° from this plane of symmetry.

On the shorter structures, where the spacing between the half-structure and the ground plane was small, that is, much less than a half-wavelength, the effect of the ground plane caused the impedance to rotate around the center of a Smith chart in a periodic manner, but at a VSWR of five to eight, which is very undesirable. However, this long structure had impedance characteristics very similar to a structure in free space, with *the* Z_0 *being only one-half the* Z_0 *of an antenna in free* space. The actual Z_0 was 80 ohms with a VSWR of 1.1:1 over a period.

Wire Triangular Tooth Structures

Another step toward simplifying the construction of these logarithmically periodic structures was the triangular tooth or "Zig-Zag" structure illustrated in

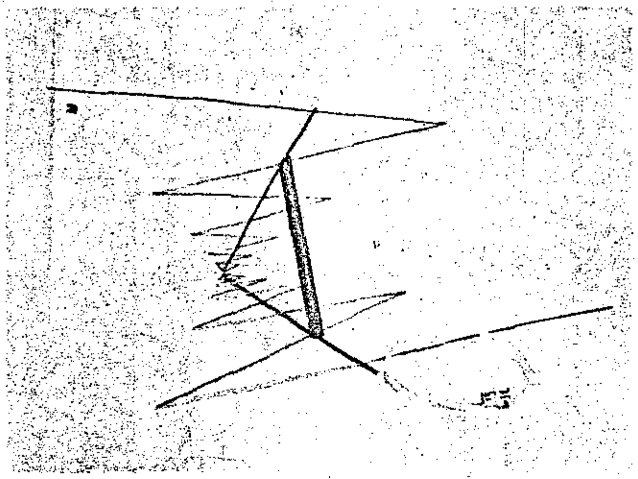


Fig. 15 A typical, wire, nonplanar, triangular-tooth structure.

figure 15. It has the same parameters as the trapezoidal tooth structure of figure 10. Figure 16 shows typical patterns for this triangular tooth structure. In general, the pattern characteristics are a slight improvement over those of the trapezoidal tooth structure. The average E-plane beamwidth was 70° as compared to 67°; the average H-plane beamwidth was 89° as compared to 106°; and the front-to-back ratio was 14.4 db as compared to 14.9 db for the trapezoidal tooth structure. *The impedance for the triangular tooth structure* was slightly lower (100 ohms with a VSWR of 1.5 over the frequency range compared) than that of the trapezoidal tooth structure.

Another model of the triangular tooth structure was constructed similar to antenna 14 in table 3 (α = 45°, β = 0, τ = 0.707 and ψ = 45°). As before, the H-plane beamwidth was slightly narrower, the E-plane beamwidth was about the same, and the front-to-back ratio was slightly greater than that of the similar trapezoidal tooth structure.

Phase Rotation Principle

The phase rotation phenomenon is a basic characteristic of these logarithmically periodic structures and has been verified experimentally. It can best be explained in the following manner: if one of these structures is fed, and if the phase of the electric field received at a distant dipole (see figure 2) is measured relative to the phase of current at the feed point of the *structure, the phase of the received signal will advance* 360° as the structure is shrunk through a period. Or,

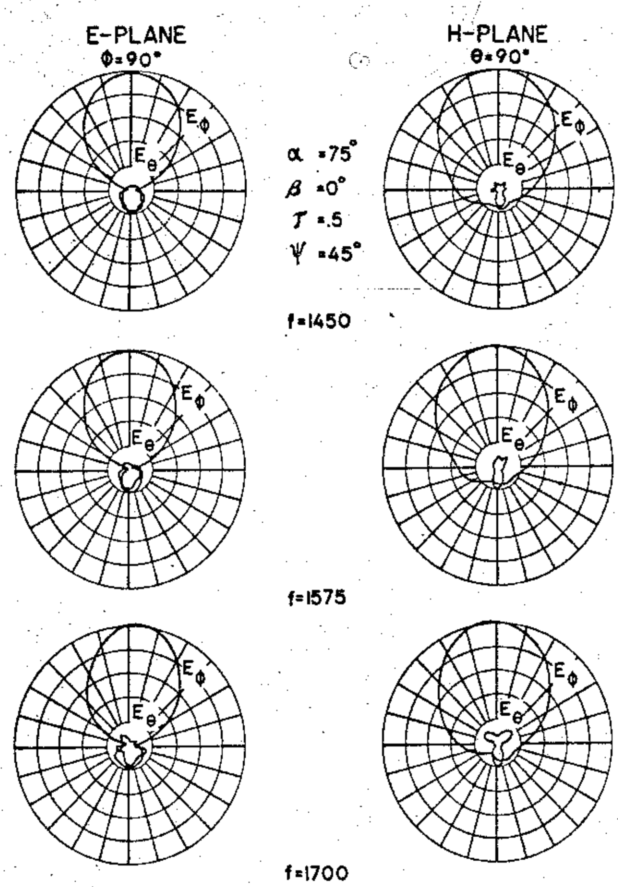


Fig. 16 Patterns for nonplanar, wire, triangular-tooth structure.

in other words, if the frequency of the exciting signal is increased by a period, and the phase is measured at the dipole while keeping the dipole at a constant electrical distance from the periodic structure, the phase will be delayed 360°, relative to the phase of the feed current. This characteristic is analagous to the pattern rotation principle[2] of angular structures.

This phenomenon is the factor which makes it possible to achieve the omnidirectional and circularly polarized logarithmically periodic structures discussed in the following sections.

Omnidirectional Structures

Often it is desirable to have a wide band antenna that gives omnidirectional patterns. The most common antenna to date that tends to meet such a requirement is the vertically polarized discone or biconical antenna. However, pattern breakup limits the bandwidth of these antennas to 2 or 3 to 1. The desirability of designing a logarithmically periodic structure with omnidirectional characteristics is readily apparent.

Since two dipoles arranged in a turnstile and fed ninety degrees out of phase give omnidirectional patterns, it was decided to arrange two planar, sheet metal structures (which have approximate dipole patterns) in a turnstile as shown in figure 17a. Since the planar sheets were actually soldered together where they crossed, it is obvious that the two sheet structures could not be identical or the same result would occur as when feeding two crossed dipoles in phase (a bidirectional pattern with maximum lobes occurring at an angle of 45°). Therefore, one of the structures was made $\tau^{1/N}$ times the size of the other (where N is the number of arms of the structure) in order to obtain the 90° phasing.

An easy way to visualize such a structure is to imagine two cones placed apex to apex on a common

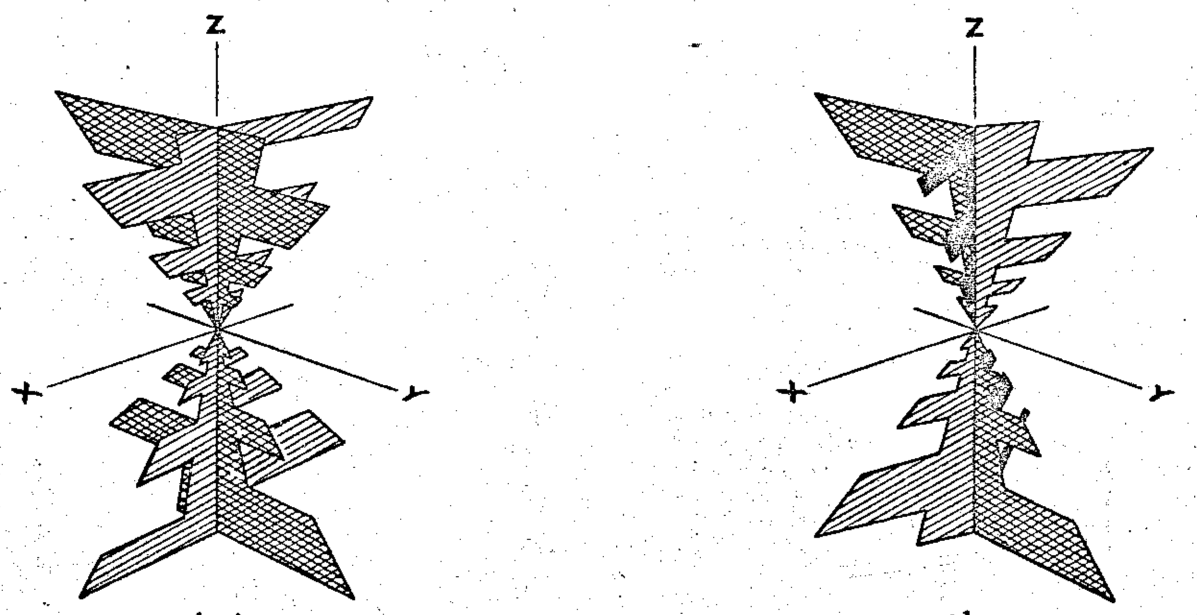


Fig. 17 Types of omnidirectional structures.

axis. Starting at the apex of each cone, an equiangular spiral is placed on the slant side of the cone with the axis of the spiral coinciding with the axis of the cone. The spiral on one cone is made to rotate clockwise; the spiral on the other cone is made to rotate counterclockwise as the two cones are viewed simultaneously from the point where their respective apexes meet. Actually, these spirals are the openings of grooves which become progressively wider and deeper as they spiral away from the apexes of the cones. The outlines of four arms of a four-arm structure would be the lines of intersection of the cones and two planes perpendicular to each other and intersecting on the axis of the cones. When the cone concept is used, it is possible to visualize a number of different structures. Figure 17b is an example of a structure with three arms.

Figure 18 is a photograph of a circular tooth structure constructed as stated above. The design ratio τ of this particular structure is 0.7. Of the various structures constructed and tested, it was found that the structure with a design ratio of 0.5 had the best pattern characteristics. Typical patterns of this structure are shown in figure 19. The $\theta = 90°$, ϕ variable patterns are omnidirectional within ±1.5 db over the frequency range of one period; the $\phi = 90°$, θ variable patterns are bidirectional and have an average beamwidth of about 65°. The characteristic impedance was 100 ohms with a normalized VSWR of 1.2 to 1.

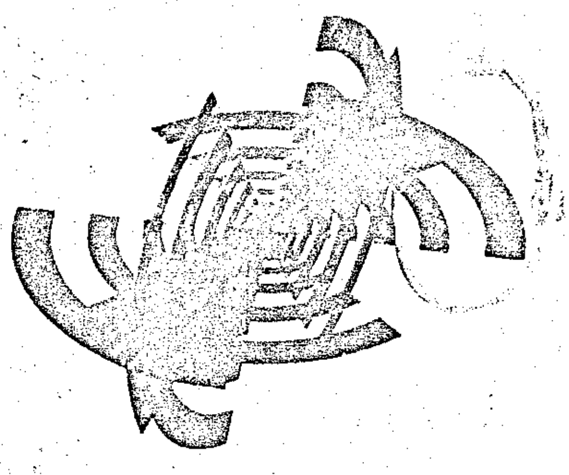


Fig. 18 A typical, four-armed, sheet, circular-tooth, omnidirectional structure.

A limited investigation of the effect of varying the α angle while holding β fixed at 45° for a structure having a design ratio of 0.7 (figure 18) was made. As α was reduced from 135° to 115°, the E-plane patterns were unchanged while the H-plane beamwidth increased slightly from 68° to 75°. When α was reduced to 95°, the E-plane pattern was omnidirectional within ±3 db, and the H-plane pattern beamwidths were about 90°. The impedance did not change appreciably as α was reduced.

The trapezoidal tooth structure shown in figure 17a ($\alpha = 90°$, $\beta = 30°$, $\tau = 0.5$) did not have as uniform

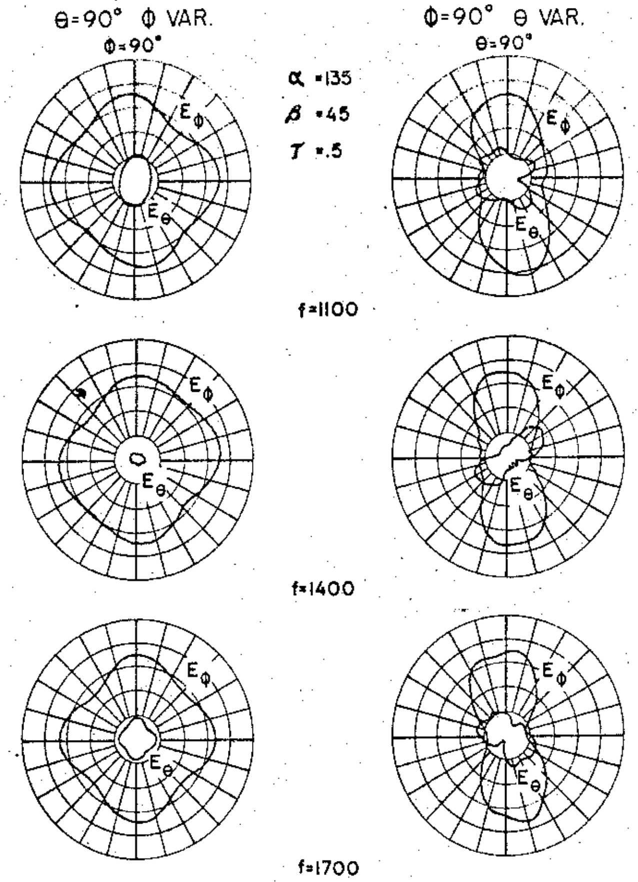


Fig. 19 Patterns for omnidirectional curved-tooth structure.

or as frequency independent omnidirectional characteristics as did the similar circular tooth structure. As a comparison, the trapezoidal tooth structure was omnidirectional within ±2.1 db as compared to ±1.5 db for the circular tooth structure; and the H-plane, bidirectional patterns were on an average 55° as compared to 65°. The impedance was 140 ohms and 100 ohms for the trapezoidal and circular tooth structures, respectively. Both had a normalized VSWR of 1.2 to 1.

The only other type of sheet metal omnidirectional structure tested was a three-armed circular tooth structure (see figure 17b for a similar trapezoidal tooth structure). The structure was omnidirectional within ±3 db and the patterns were more frequency dependent than the structure having four arms. It appears that the more arms a structure has (within reason), the more omnidirectional it will be.

One wire, trapezoidal tooth, omnidirectional structure was constructed and tested (see figure 20). The E-plane patterns varied somewhat in their omnidirectional characteristics with frequency, but on an average, they were omnidirectional within ±2.1 db; the H-plane patterns were bidirectional with an average beamwidth of 60°. The input impedance was 135 ohms with a normalized VSWR of 1.3 to 1. In view of the relative simplicity, this structure could be used as an hf antenna. The wire structure could be easily strung up between four wooden poles.

Circularly Polarized Antennas

A limited investigation of circularly polarized, unidirectional logarithmically periodic broadband structures was performed. The most successful of the various techniques tried was that of taking the planar structure shown in figure 21 and placing the quarter-structures, one on each slant side of a pyramid. The angle between opposite slant sides of the pyramid is the ψ angle of the structure.

As can be observed from the figure, one structure is $\tau^{1/4}$ the size of the other. A very well-defined circularly polarized beam (at $\phi = 90°$, $\theta = 90°$) is obtained. The enlarged view of the feed point shows that, in general, two adjacent quarter-structures are fed against the remaining two quarter-structures; two and three are being fed against four and one. The sense of the circular polarization can be reversed by simply switching the feed point, or by feeding three and four against one and two.

Four experimental patterns over approximately a half-period are shown in figure 22. As can be seen, the axial ratio r as measured on the beam axis varied from 1.05 to 2 over this range. Since the patterns for the linearly polarized components (E_θ and E_ϕ) are very similar, it is expected that good circular polarization is obtained over most of the beam.

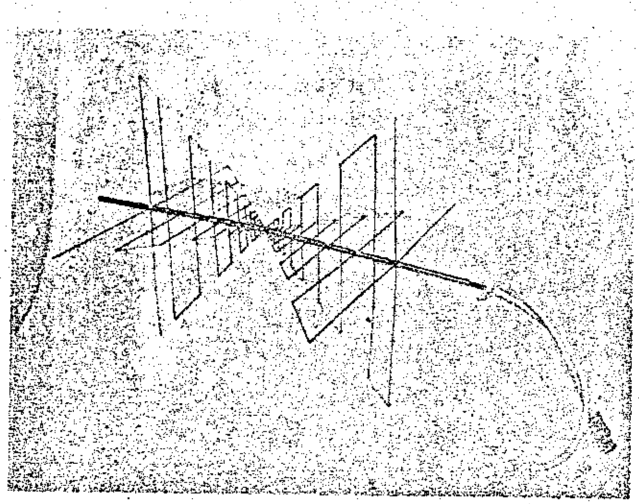


Fig. 20 A typical, four-armed, wire, trapezoidal-tooth, omnidirectional structure.

Unfortunately, it is not possible to use one-half of any of the above structures over a ground plane (and fed against the ground plane) without having large variations of pattern and impedance over a period of frequency.

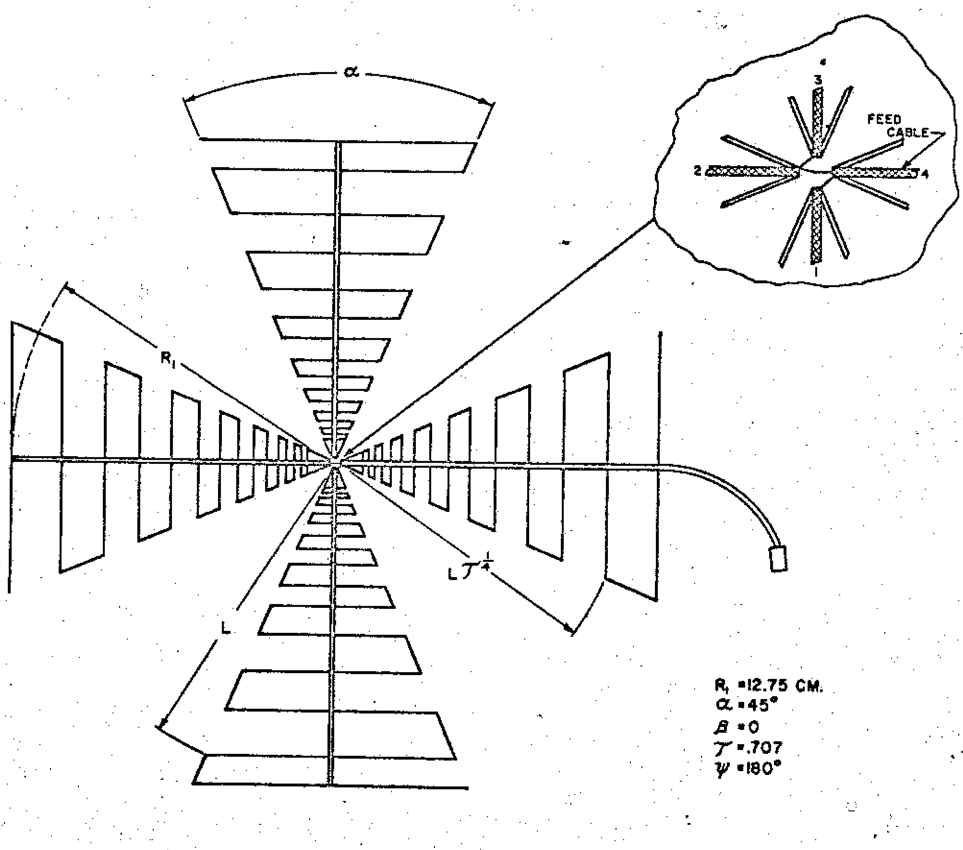


Fig. 21 Wire, trapezoidal-tooth, circular-polarized structure.

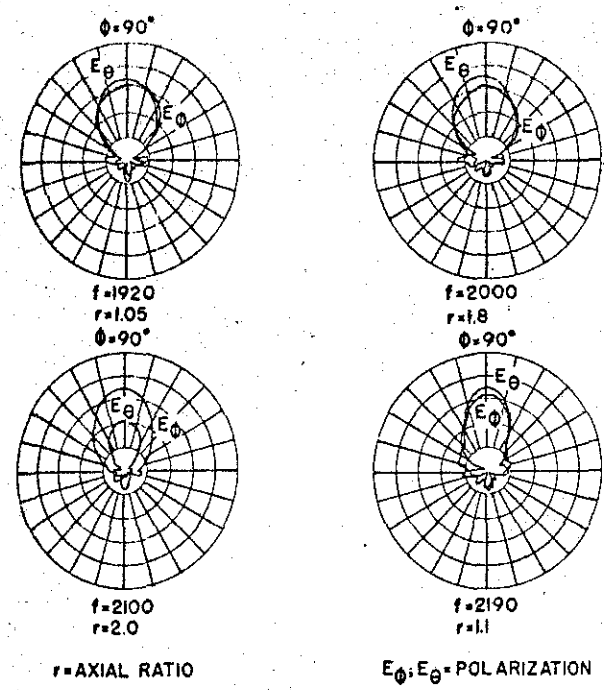


Fig. 22 XY plane patterns of circular-polarized pyramidal structure.

Current Distribution Measurements

An attempt was made to measure the magnitude and phase of the currents flowing on the elements of a typical nonplanar, wire, trapezoidal tooth structure. The current distribution was very complex and the results were not too conclusive. However, it was observed that, as the magnitude of the currents was measured from the vertex out toward the longer transverse elements, a point of maximum current magnitude was reached. From this point, the magnitude of the current decreased to more than 30 db below its value at the maximum point. The transverse elements at this low current point were much longer than a half wavelength of the operating frequency. This tends to demonstrate that end effects are negligible on these structures, which must be the case for wide band operation. As would be expected, the point of maximum current magnitude shifted toward the vertex of the structure as the frequency was increased.

Conclusions

Many types of logarithmically periodic antenna structures have been built and tested. Most of those which gave essentially frequency independent operation have been reported here but there were many structures for which the pattern and/or impedance were quite frequency sensitive. Unfortunately, no theory has been established which even predicts the types of structures which will give frequency independent operation. The equicomplementary condition (for planar structures) is sufficient to insure frequency independent impedance but not patterns. All of the planar structures (even those that don't work) may be considered as cross sections of frequency independent three-dimensional angular structures so that this approach leads nowhere. Thus, it is felt that a theoretical investigation of this class of antennas would be most fruitful.

Nevertheless, a small amount of effort has led to the discovery of structures which give a wide variety of essentially frequency independent radiation characteristics over practically unlimited bandwidths. One of many possible applications is for flush-mounted microwave antennas. Here, unidirectional structures can be placed in cavities with the cavity having little influence on the electrical characteristics because of the unidirectional pattern.

Acknowledgment

Special thanks are due Dr. R. L. McCreary for his support and tolerance and to Forrest G. Arnold who constructed and tested many of the models.

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