The Double-Helix Antenna and Its Variants, a New Class of Tunable Endfire Antennas

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Abstract—**Endfire antennas develop maximum gain when the phase velocity of the surface wave traveling along the structure is adjusted to its optimum value determined as a function of antenna length and operating frequency. These antennas usually have a relatively small pattern bandwidth and, if maximum gain is desired, can be used over only a small frequency range.**

The antennas described in this paper inaugurate a new class of antennas that are tunable for maximum gain in the endfire direction over a wide frequency range; tuning is accomplished by changing the phase velocity continuously or in prescribed steps. Such antennas include certain configurations of the double helix (a novel type of endfire antenna) and its artificial and natural dielectric variants. Useful structures are obtained through parallel displacement of two juxtaposed elements or angular displacement of a scissors arrangement.

Model measurements show that maximum gain can be obtained over a frequency range of more than 2:1. Tuning effects are illustrated in detail by means of near-field plots of a tuned dielectric antenna.

Introduction

THE GAIN of an endfire antenna depends on the phase velocity of the surface wave and on the length of the antenna structure along which the wave travels. For a given length there is an optimum phase velocity that produces maximum gain.[1–3] Some endfire antennas have a relatively small bandwidth, which could be substantially increased if the phase velocity could be changed with frequency.

For the endfire antenna with linear elements, like a Yagi, the phase velocity is primarily a function of the height and spacing of the elements.[4] In the conventional helix it is a function of the circumference and spacing of the turns.[5] In the dielectric-rod antenna it is a function of the dielectric constant[6] as well as of the dimensions of the rod. Effecting continuous changes in the phase velocity would be rather difficult with a Yagi because it would require simultaneous readjustment of the height and/or spacing of all elements. To adjust the phase velocity on a helix would be even more difficult because only the spacing of the turns could be changed. On a dielectric-rod antenna the phase velocity could not be adjusted at all.

The antennas described inaugurate a new class of tunable endfire antennas in which the phase velocity can be changed continuously or in prescribed increments to maximize gain over a wide frequency range.

Double-Helix Configuration

Simple deformation of a conventional helix, by pinching all turns from two opposite points on the circumference, produces a double helix whose cross section is a figure eight. Figure 1(a), where the arrows indicate the points and directions of pinching, shows the cross sections before and after deformation. A wire wrapped in overlapping figure eights produces a double helix as shown in Fig. 1(b). Two helixes, each of about half the diameter of a conventional helix, constitute a double helix when laterally juxtaposed as shown in Fig. 1(c). Neither of the helixes in this unit can individually act as an endfire antenna;[5] together, they can form a maximum-gain endfire antenna.

Double-helix antennas are linearly polarized in the direction of the long axis of the figure eight. Any double-helix antenna can be energized by a feed having the same polarization as the double helix, with a linear or plane reflector behind it.

The various types of double-helix antennas will be fully described in a later paper. This paper deals only with double-helix antennas which allow tuning over a wide frequency range, and is, therefore, restricted to structures consisting of two separate helixes.

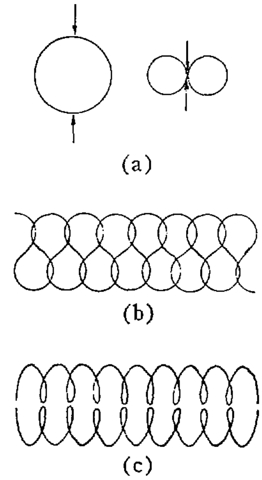

Fig. 1. Various types of double helixes.

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[2] Reid, D. G., The gain of an idealized yagi array, *J. IEE*, vol 93, pt 3A, Mar 1946, pp 564–566.

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[4] Ehrenspeck, H. W., and H. Poehler, A new method for obtaining maximum gain from Yagi antennas, *IRE Trans. on Antennas and Propagation*, vol AP-7, Oct 1959, pp 379–386.

[5] Kraus, J. D., *Antennas*, New York: McGraw-Hill, 1950, ch. 7, pp 175–179, 187–194.

[6] Zucker, F. J., Surface- and leaky-wave antennas, in *Antennas Engineering Handbook*, H. Jasik, Ed. New York, N. Y.: McGraw-Hill, 1961, ch. 16, pp 23–24.

The Tunable Double-Helix Antenna

Tuning

The phase velocity of the double-helix combination depends not only on the physical dimensions of the helixes but also on the coupling between them. Changing the gap changes the phase velocity, so long as the coupling remains strong enough, and the double helix can thus be continuously tuned for maximum gain. In Fig. 2, where R marks the reflector and F the feed dipole, (a) is a sketch of the double-helix antenna before tuning; (b) and (c) are after tuning. Figure 2(b) shows a parallel displacement d of both helixes. In this case the phase velocity is constant along the double-helix structure, which allows tuning over the widest possible frequency range. In Fig. 2(c), the helixes form a small angle α whose vertex is at the feed end. In this case the phase velocity increases toward the radiating end, which provides better matching to free space and yields a slight increase in gain. If, in addition, the two helixes decrease in diameter toward the radiating antenna end, the resulting amplitude and phase distribution produces a radiation pattern with extremely low sidelobes and backlobes, as shown later.

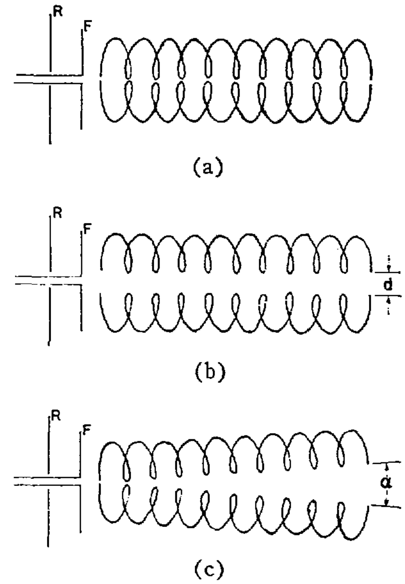

Fig. 2. Tuning methods for double-helix antenna. (a) Untuned. (b) Parallel displacement. (c) Angular displacement.

Construction

With a two-helix configuration, as in Fig. 2(a) or (b), the lowest phase velocity is always obtained when the gap between the two parts is at its narrowest. Antennas of this class are tunable if maximum gain at the lowest operating frequency is obtained at the narrowest spacing. Optimum design at any prescribed center frequency depends on phase-velocity curves determined for a useful range of parameters.

Experimentally determined phase-velocity curves are presented in Fig. 3. Although not completely covering all possible double-helix arrangements, these curves furnish enough information on the two most important parameters, helix diameter and turn spacing, to enable construction of double-helix antennas with maximum gain. The tunability range depends on whether tuning is according to Fig. 2(b) or (c); it is widest for the former.

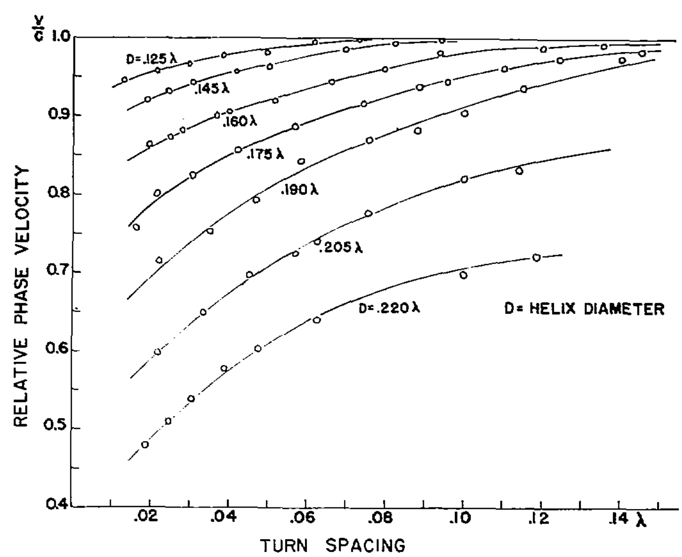

Fig. 3. Phase velocity of double helix and image helix as a function of turn spacing and diameter.

Model Measurements

Figure 4 is a sketch of an experimental S-band model of a double-helix antenna tuned according to Fig. 2(c). All dimensions are given relative to a frequency of 3000 Mc/s ($\lambda = 10.0$ cm). The feed-dipole F is in front of a plane circular reflector R of about 0.5λ diameter; L marks the length of the double helix, and S_T the spacing between turns. The spacing d_E between the open ends of the double helix was changed from zero to $\lambda/4$ to $\lambda/2$, consequently changing the angle α from zero to 5° to 10°.

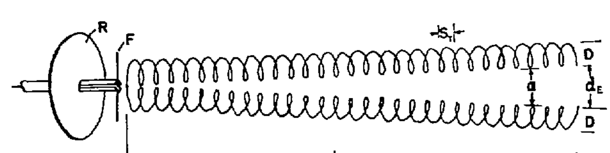

Fig. 4. Sketch of experimental model of tunable double-helix antenna.

Two horizontal plane patterns of special interest are shown in Fig. 5. The pattern of the narrowly spaced double-helix antenna before tuning (broken line) has deteriorated at 3275 Mc/s. In the pattern after tuning (solid line), the half-power beamwidth has decreased from 68° to 27°, and the gain in the endfire direction has increased by 10 dB. At the same time the first sidelobe has decreased from about −10.5 dB to −16.3 dB. In Fig. 6 the half-power beamwidth is given as a function of frequency, with the two tuning steps applied over

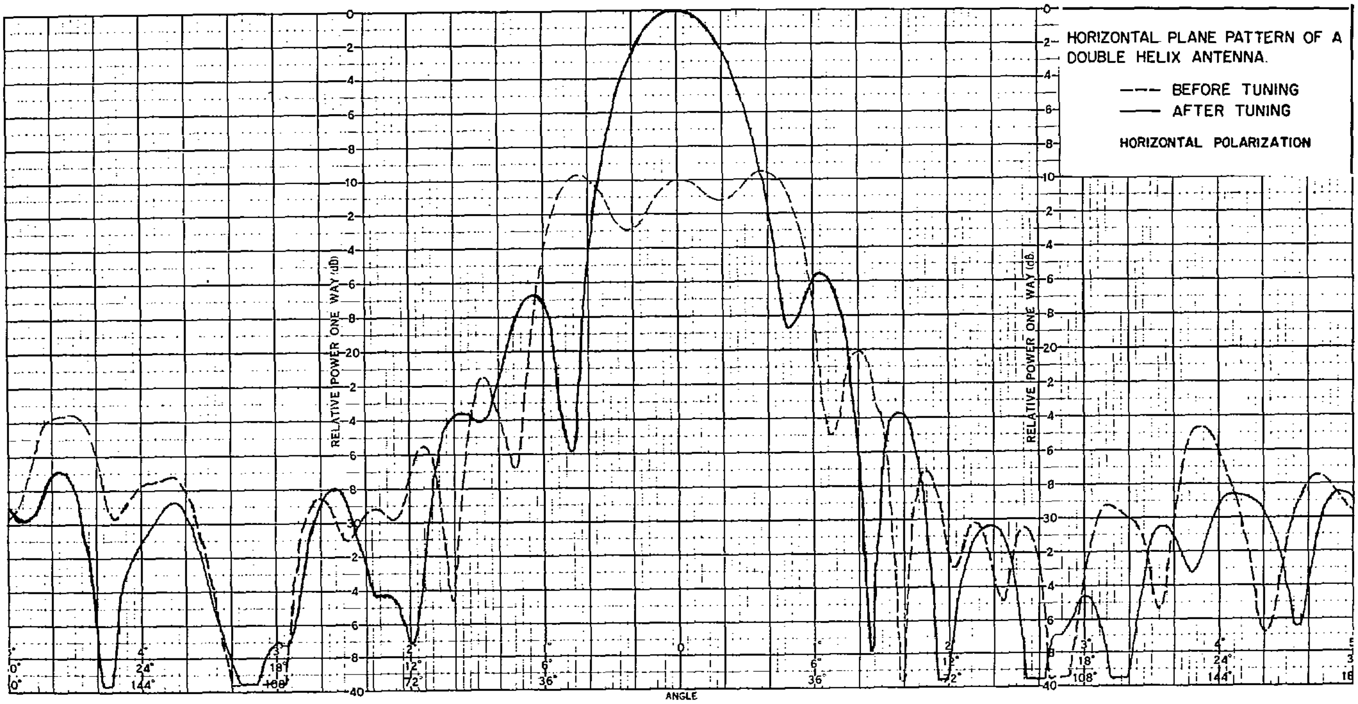

Fig. 5. Horizontal plane patterns of a double-helix antenna before tuning (- - -) and after tuning (——). Operating frequency 3275 Mc/s; horizontal polarization; tuning by angular displacement.

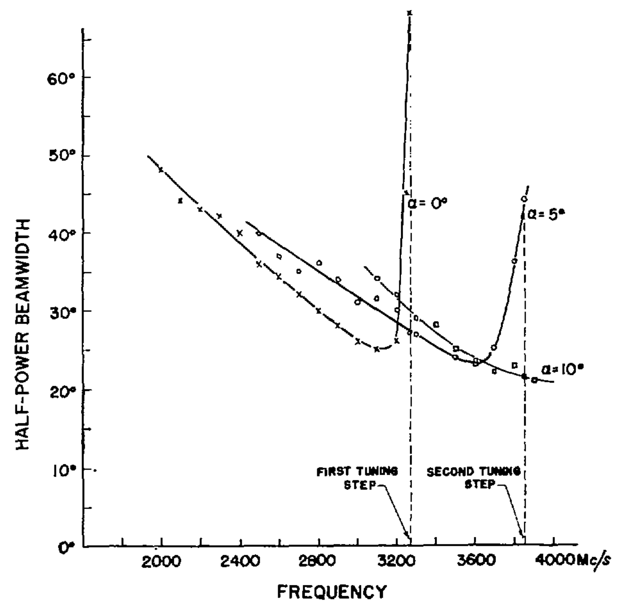

Fig. 6. Half-power beamwidth of double-helix antenna as a function of frequency (two-step tuning).

the frequency range of 2:1. Evaluation of the results shows that the frequency range of the closed double helix was about 2000 to 3000 Mc/s. At 3275 Mc/s, when the pattern had deteriorated (see broken line in Fig. 6), tuning brought the frequency range up to 3600 Mc/s. The second tuning step, at 3850 Mc/s, extended the operating frequency range to over 4000 Mc/s. The frequency limits of the transmitter used in our experiments did not permit further exploration of bandwidth. Half-power beamwidth and gain had values approximately corresponding to the length of the antenna.

Some Variants of the Tunable Double-Helix Antenna

The Image-Helix Antenna

The first variant of the tunable double helix is the image helix with a single helix about half the diameter of a conventional helix, mounted directly on (or at a very small distance above) a conducting ground plane. It acts exactly like a double helix, with its image taking the place of the second helix, but has only vertical polarization. Referring to Fig. 2(b) and (c), tuning is achieved through parallel displacement of the helix a distance $d/2$ from the ground plane or by tilting the helix at a small angle $\alpha/2$ with the ground plane.

The Scissors Antenna

The two parts of a double helix may be regarded as two artificial dielectric rods. Another variant of the double helix is, therefore, obtained by using two dielectric rods as shown in Fig. 7, where F is the feed embedded in the dielectric, R the reflector, D_1 and D_2 the rods. Like the double helix, this antenna can be tuned through parallel or angular displacement of the rods [Figs. 7(b) and (c)]. Extremely low sidelobes and backlobes can be achieved by tapering the rods in diameter [Fig. 7(d)]. The resemblance of its tapered dielectric rods to the jaws of a pair of scissors gave this antenna its name.

The Dielectric-Image Antenna

The dielectric-image antenna is analogous to the image helix and is similarly tuned for maximum gain, either by raising the dielectric rod from the conducting ground plane or tilting it at a small angle. The azimuthal radiation pattern of a tilted dielectric-image antenna 12λ long, tuned for 9070 Mc/s and measured at this frequency, is shown in Fig. 8.

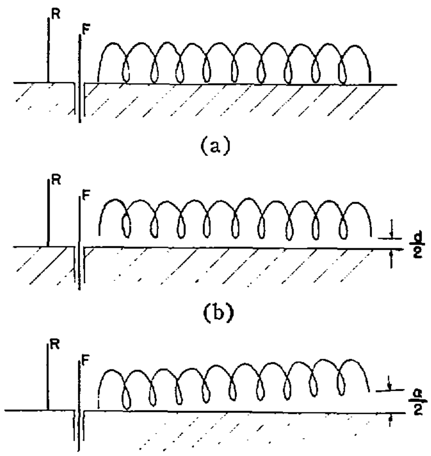

Fig. 7. Various types of tunable dielectric antennas.

Demonstration of the Tuning Effect

The effect of tuning can be clearly seen in nearfield amplitude-phase plots.[7] Figure 9(a), (b) and (c) shows the results obtained with two 12λ dielectric-image antennas measured at 9070 Mc/s. A polystyrene rod of diameter = 0.29λ, located directly on the ground plane [Fig. 9(a)], is tilted for tuning to maximum gain [Fig. 9(b)]. A tapered dielectric rod having a rectangular cross section of 0.20λ by 0.50λ at the feed side and 0.20λ by 0.25λ at the termination, is also tilted for maximum-gain tuning [Fig. 9(c)]. Each of these dielectric rods (crosshatched in the figures) is in physical contact with the feed, which is λ/4 in front of a reflector. The lines perpendicular to the longitudinal axis of the rod are lines of constant phase, 360° apart. The lines that run parallel to the axis within the wave channel and then spread out beyond the virtual aperture (V.A.) are lines of constant amplitude, decreasing in steps of 5 dB away from the rod. The width of the V.A. in Fig. 9(a), based on the assumption[8] that power levels more than 20 dB below the maximum make no essential contribution to the radiation pattern, is about 2λ. Figure 9(b) shows that tuning has increased it to 3.3λ. The result is an essential gain increase, also noticeable in these plots.

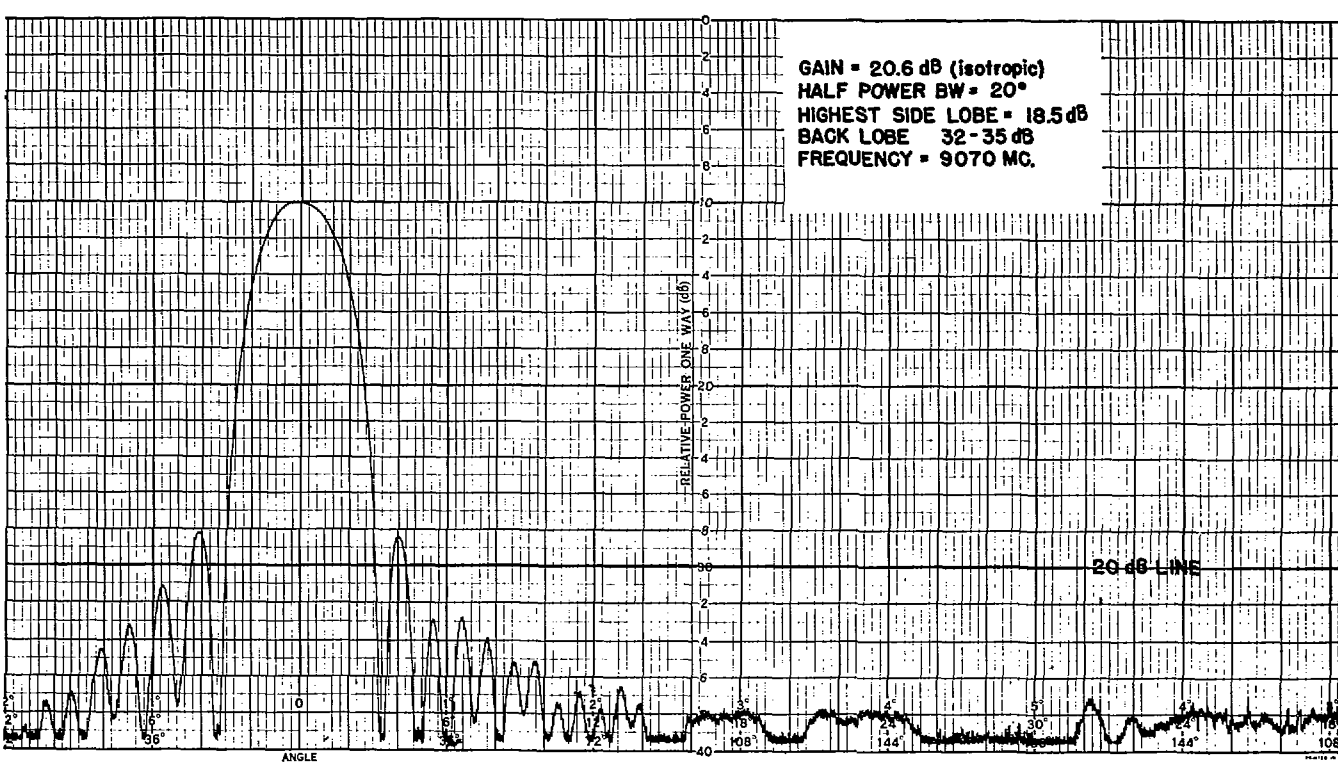

Fig. 8. Horizontal plane pattern of 12-λ dielectric-image antenna tuned by angular displacement.

[7] Barrett, R. M. and M. H. Barnes, Automatic antenna wavefront plotter, *Electronics*, vol 25, Jan 1952, pp 120–125.

[8] Ehrenspeck, H. W., and W. J. Kearns, Two-dimensional endfire array with increased gain and sidelobe reduction, Tech Rept AFRC-58-132, AD 152 372, USAF Cambridge Research Center, Bedford, Mass., Apr 1958.

(a)

(b)

(c)

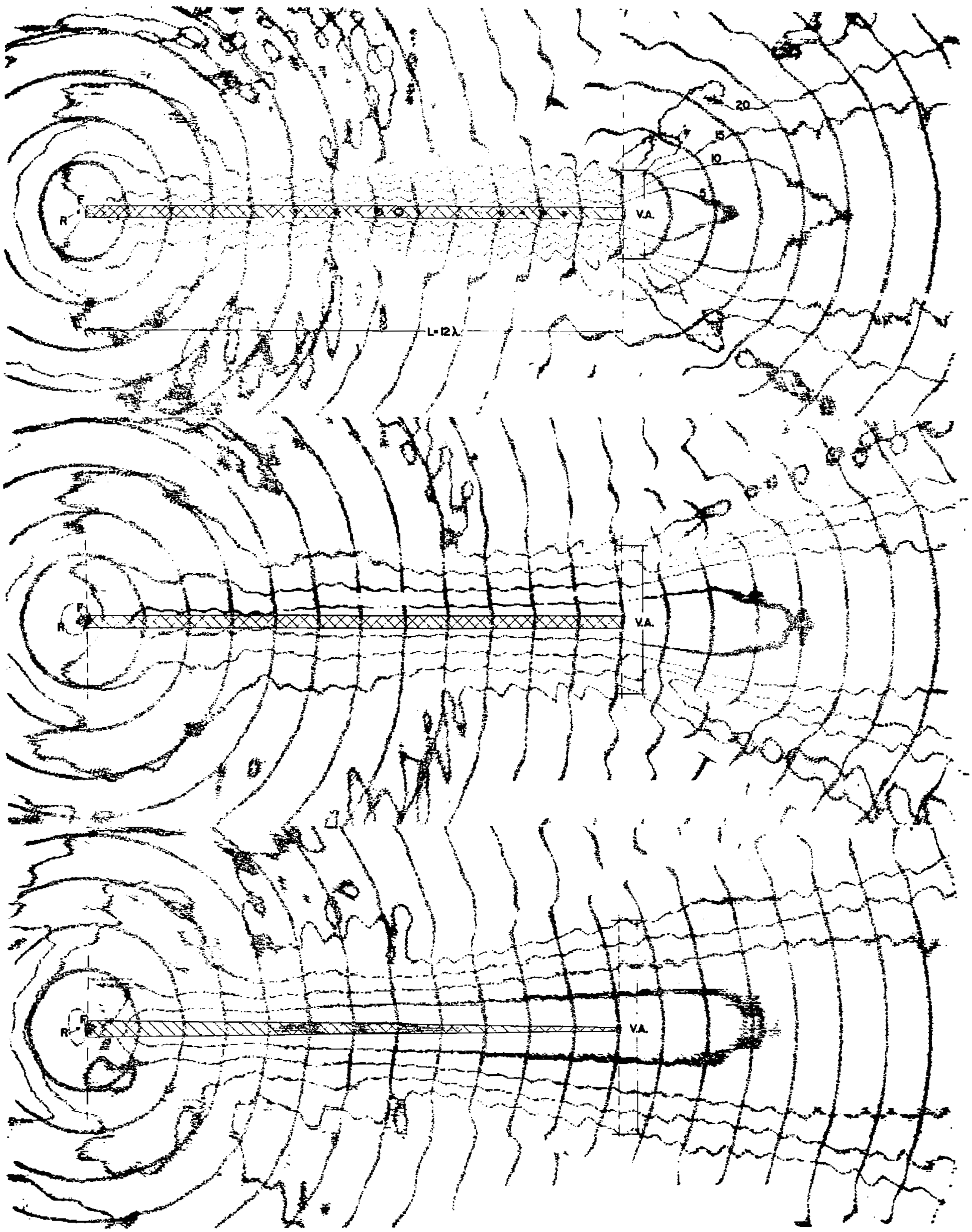

Fig. 9. Amplitude-phase plots of two types of tunable dielectric-image antennas. (a) Uniform dielectric rod before turning. (b) Uniform dielectric rod tuned for maximum gain. (c) Tapered dielectric rod tuned for maximum gain.

Still more interesting is the amplitude-phase plot of the tapered dielectric rod [Fig. 9(c)], tilted at an angle $\alpha/2$ with respect to the ground plane. The improved matching obtained by tuning is indicated by a lower VSWR on the surface-wave structure, a nearly complete disappearance of the discontinuity at the radiating end, and an increase of the V.A. from 3.3λ to 4.9λ. This qualitatively explains the high gain and low sidelobes and backlobes in Fig. 8.

Comments

Comparing the various types in this new class of tunable endfire antennas, it is apparent that the double-helix and image-helix structures will have more practical applications than the equivalent dielectric structures, since they are made of wire or tubing and, therefore, can be used at much lower frequencies than structures of bulky dielectric materials.

The image-helix structure may find wide use as a ground antenna because it extends only about 0.15λ above ground and its mechanical construction is very sturdy. Gain figures of 20 dB above dipole can be achieved without difficulty.

So far as dielectric-rod antennas go, the special broadband design of a single dielectric rod reported by Parker and Anderson[9] had a bandwidth (as defined by an acceptable sidelobe level of at least 10 dB below maximum) that was at best 2:1. The gain was the usual optimum gain of a properly designed dielectric rod at the low end of the frequency band, and it was about 3 dB below optimum at the high end. Our tunable design covers a bandwidth of more than 2:1, and the gain is optimum over the entire frequency range of the antenna.

Acknowledgment

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[9] Parker, C. F., and R. J. Anderson, Constant beamwidth broadband antennas, *1957 IRE Nat'l Conv. Rec.*, pt 1, pp 87–98.

On Grating Plateaux of Nonuniformly Spaced Arrays

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***Abstract*—This paper investigates the optimization and synthesis of nonuniformly spaced arrays with respect to the flattening of their grating plateaux. The analysis begins with the proof that the exponential spacing gives flat space-factor grating plateaux, using Poisson's sum and the stationary phase method. The theory then is generalized to include arrays of nonisotropic elements. It is found that results of the above analysis can be reduced to very simple forms.**

Through the use of Parseval's theorem, the theory of the space-factor gain of nonuniformly spaced arrays is also developed.

Introduction

The PATTERN of a nonuniformly spaced array is in general an almost periodic function and, as a result, the grating beams are spread out into plateaux. It was observed by Yen and Chow[1] that for uniformly illuminated elements, the envelope of the plateau is flat if the element spacing increases exponentially. In the present investigation, by requiring the array factor to have flat plateau envelopes, the exponential spacing is derived. Because of the characteristic flatness and low intensities of these plateaux, we may say that the array factor is optimized with respect to its grating plateaux. If the elements are not isotropic, the plateaux of the pattern depend on the product of the space factor and the element pattern. The latter part of this investigation is devoted to the synthesis of arrays with flat plateaux using arbitrary elements.

Although the arrays previously mentioned are optimized with respect to their grating plateaux, their main beam structures and power gain are not necessarily inferior to those of the uniformly spaced case. They will be included for the sake of completeness.

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[1] Yen, J. L., and Y. L. Chow, On large nonuniformly spaced arrays, *Canad. J. Phys.*, vol. 41, Jan 1963, pp 1–4.

The Flattening of Grating Plateaux

In order to obtain low diffraction sidelobes near the main beam, let us choose a symmetrical linear array, of which the element spacings are increasing monotonically from the array center as shown in Fig. 1. Let the