Aug. 24, 1965 A. C. SCHELL 3,202,997

SCANNING CORNER ARRAY ANTENNA

Filed Oct. 16, 1961 5 Sheets-Sheet 1

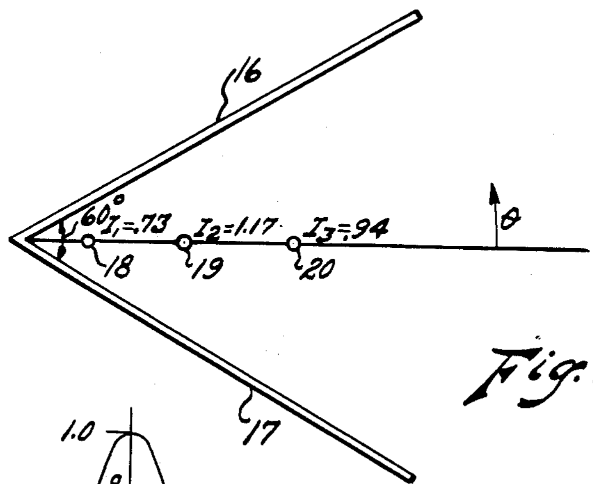

Fig. 1

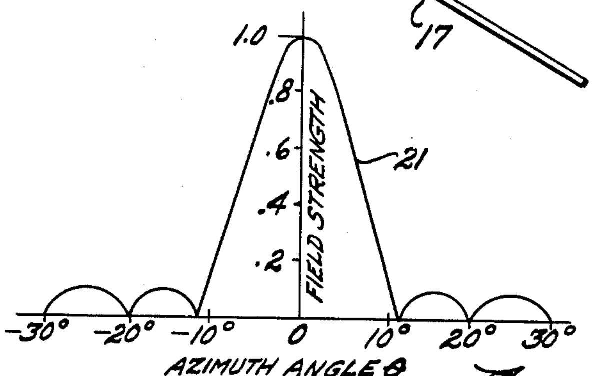

Fig. 2

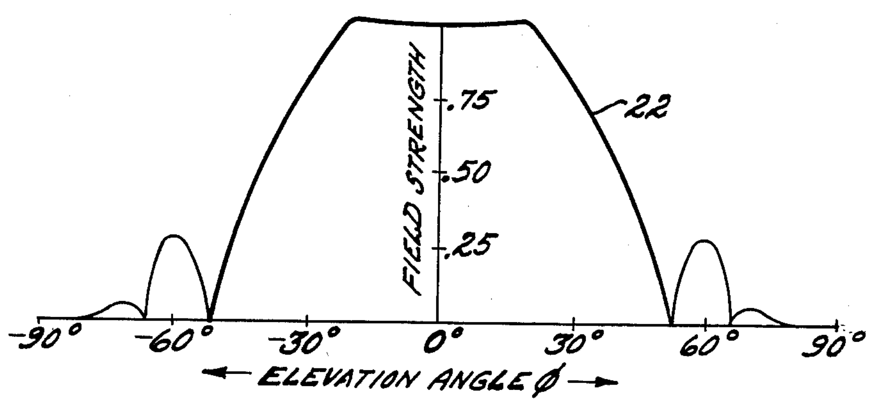

Fig. 3

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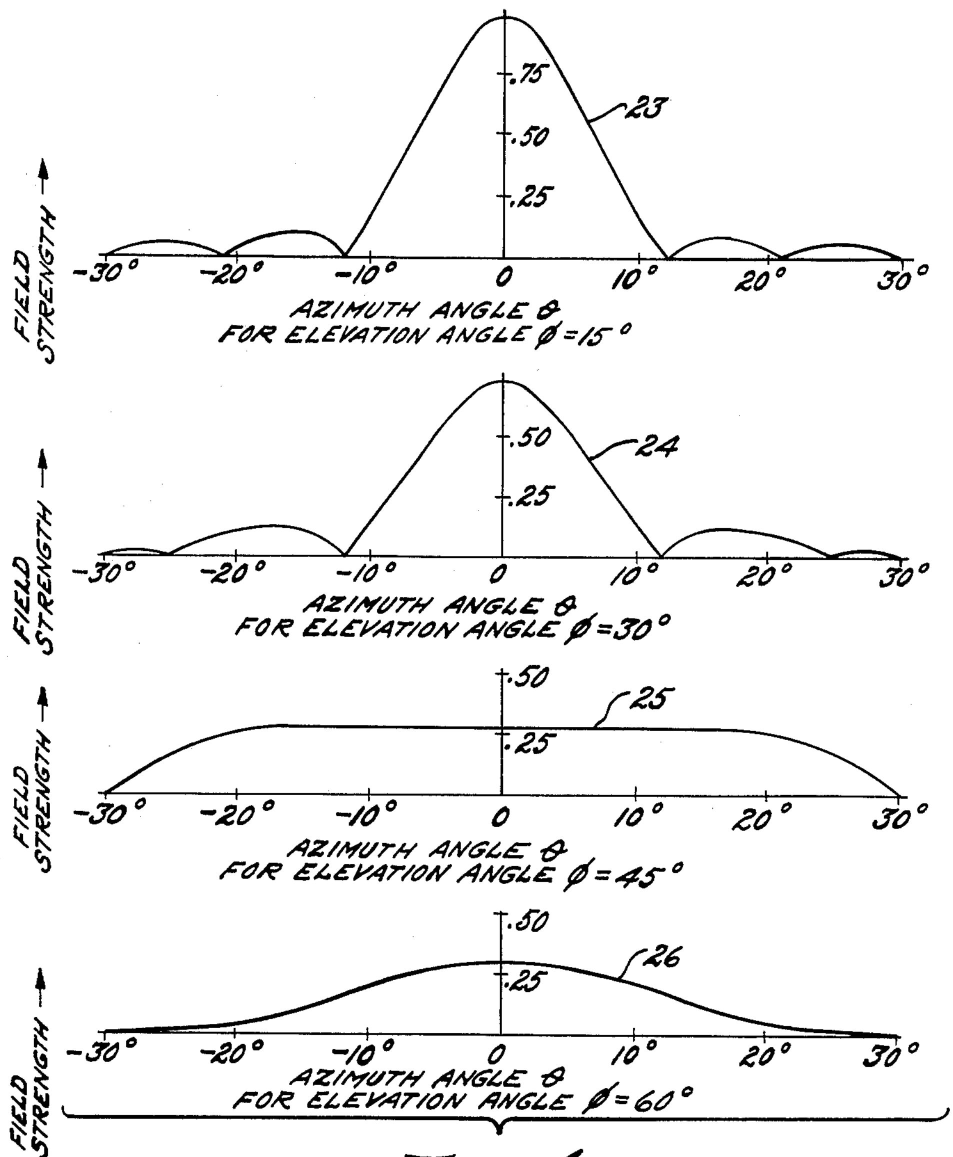

Fig. 4

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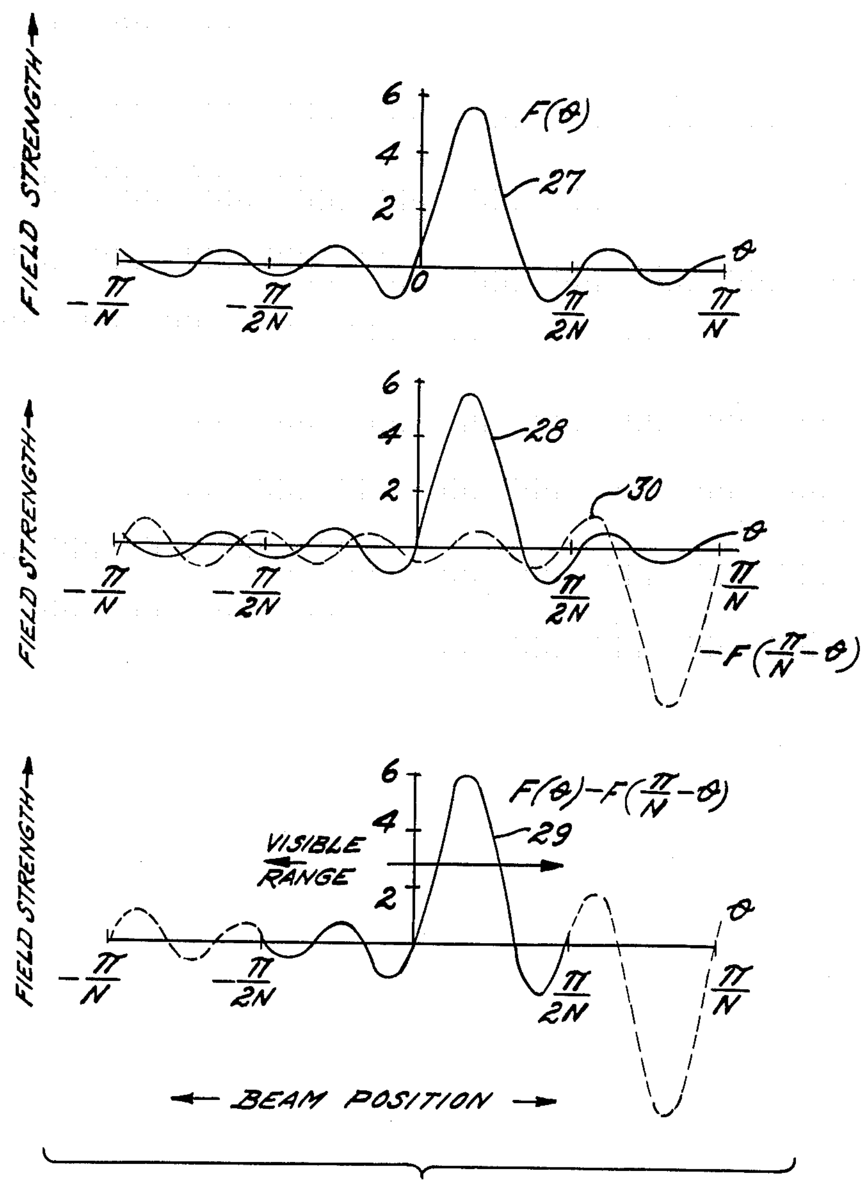

Fig. 5

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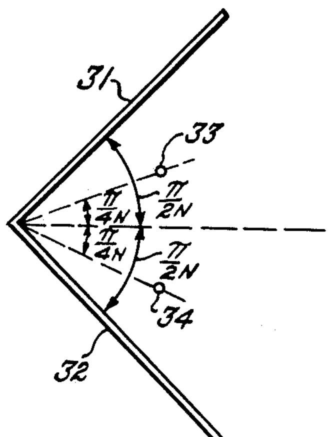

Fig. 6

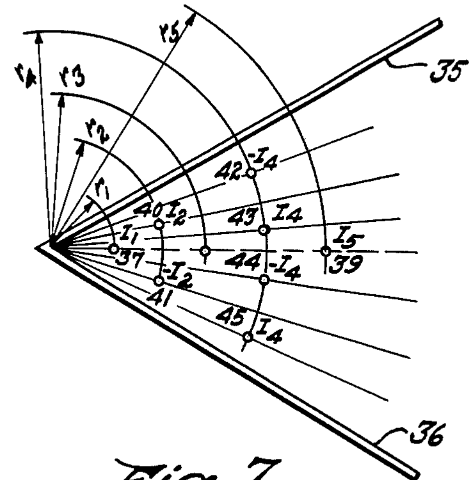

Fig. 7

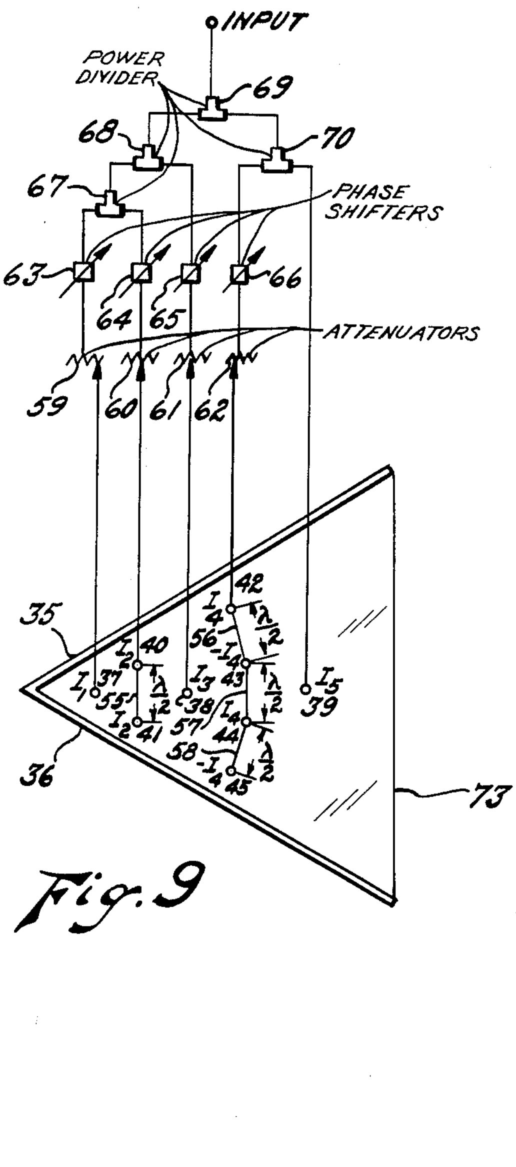

Fig. 9

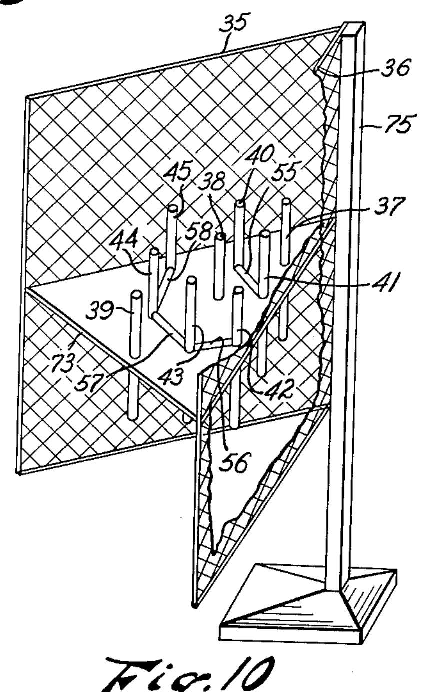

Fig. 10

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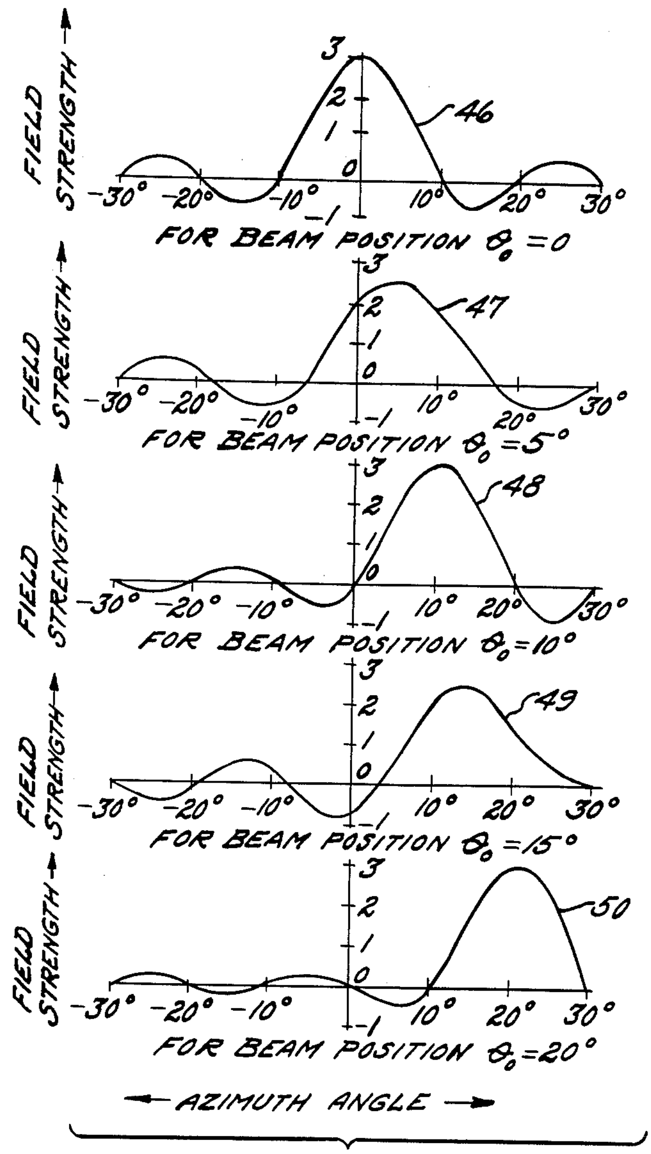

Fig. 8

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3,202,997

SCANNING CORNER ARRAY ANTENNA

Allan C. Schell, Medford, Mass., assignor to the United States of America as represented by the Secretary of the Air Force

Filed Oct. 16, 1961, Ser. No. 145,519
8 Claims. (Cl. 343—814)
(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the United States Government for governmental purposes without payment to me of any royalty thereon.

This invention relates generally to apparatus for radiating and receiving ultra high frequency electromagnetic waves, and more particularly to a directive, corner reflector antenna system whereby scanning within the corner may be accomplished without physical movement of the reflector structure.

The corner reflector antenna has many characteristics which make it an attractive means for transmitting electromagnetic waves. These characteristics include high gain, low back radiation, good directivity, wide bandwidth, and constructional simplicity. The use of such an antenna, however, has been limited to applications where the dimensions of the reflector aperture approximate one or two wavelengths, and the corner angle is either sixty or ninety degrees. A further vexing, and heretofore unsolved problem, is the mechanical difficulty encountered in scanning with this type of antenna. Due to the large size of the corner antenna, especially at frequencies on the lower end of the radio spectrum, physical movement of the antenna structure is extremely difficult.

Because of the limited utility of the conventional corner reflector antenna, various alternate schemes are resorted to whenever more directivity and gain are desired, or whenever specifications call for a particular beam configuration. The most common of said alternate schemes are the horn antenna, the parabolic reflector antenna, and the dipole array antenna. All are more difficult to construct than the corner reflector antenna, and are consequently more expensive. The horn antenna has the additional disadvantages of being inflexible, and extremely large at low frequencies. The dipole array antenna is subject to high back radiation and is, therefore, unsatisfactory for most military applications. The consequent increase in physical size of each of these antennae with the reduction of frequency, as in the case of the corner reflector antenna, accentuates the problem of moving the large structure for scanning purposes.

In my co-pending patent application entitled "Corner Array Antenna," Serial No. 24,184, now abandoned, I have disclosed a novel corner reflector antenna in which there is placed a plurality of dipole feed elements disposed at discrete points along the bisector of the corner angle. The design of a corner antennae of greatly enhanced utility having any desired beam configuration is made possible by the principles taught therein. The present invention is a further improvement on the corner angle reflector antenna, whereby the problem of scanning with large cumbersome antenna structure is effectively resolved.

It is accordingly the primary object of my invention to provide a corner reflector antenna capable of scanning within the area defined by the reflecting surfaces without physical movement of the antenna structure.

It is another object of my invention to provide an ultra high frequency antenna of simple construction having high gain, a high degree of directivity, wide bandwidth, a steerable beam, and low back radiation, said antenna being adaptable to a wide range of applications.

It is still another object of my invention to provide a novel corner reflector antenna having a wider range of application and greater utility than has heretofore been possible.

It is a still further object of my invention to provide a corner reflector antenna having a high degree of directivity and gain.

It is a still further object of my invention to provide a corner reflector antenna adapted to produce substantially any specified beam configuration in combination with means for sweeping said beam within the confines of said reflecting surfaces.

It is a still further object of my invention to provide an ultra high frequency electromagnetic wave antenna comprising a corner reflector structure in combination with a multiple dipole feed.

It is a still further object of my invention to provide means for radiating a high frequency electromagnetic wave, said wave having a narrow beam width, low sidelobe pattern commensurate with the size of the antenna.

These and other objects and advantages of the present invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 illustrates a 60° corner angle reflector antenna having a plurality of dipole feed elements disposed at discrete points along the bisector of said corner angle;

FIG. 2 illustrates the field pattern produced by said 60° corner angle reflector antenna;

FIG. 3 illustrates the vertical field pattern produced by said 60° corner angle reflector antenna;

FIG. 4 illustrates azimuthal field patterns produced by said 60° corner angle reflector antenna taken at elevation angles of $\phi=15°$, $\phi=30°$, $\phi=45°$ and $\phi=60°$;

FIG. 5 illustrates the components of an off-axis beam in a corner angle reflector antenna for the values $F(\theta)$,

$$-F\left(\frac{\pi}{N}-\theta\right) \text{ and } F(\theta)-F\left(\frac{\pi}{N}-\theta\right)$$

FIG. 6 illustrates a corner angle reflector antenna adapted to produce a field pattern having sine terms;

FIG. 7 illustrates a 60° corner angle reflector antenna adapted to steer the beam produced thereby within said corner angle;

FIG. 8 illustrates the radiation pattern of said steerable beam at beam position $\theta=0$, $\theta=5°$, $\theta=10°$, $\theta=15°$, and $\theta=20°$;

FIG. 9 illustrate apparatus for controlling the directivity of said beam; and

FIG. 10 illustrates an isometric view of one embodiment of my invention.

My aforementioned co-pending patent application presents the analysis of the corner antenna field pattern as a consideration of the reflections of a plane wave incident upon the corner. A means for obtaining narrow-beam-width low-sidelobe patterns commensurate with the size of the antenna, said means involving the use of a number of feed elements located along the bisector of the corner angle, is disclosed therein. These elements produce higher-order terms of angular variation of the radiation pattern, and allow the synthesis of desired symmetric functions.

My present invention discloses, as an improvement thereon a novel means for producing sine terms in the radiation pattern of a corner reflector antenna. I have discovered that, by the proper combination of sine and cosine terms, it is possible to produce a narrow beam at substantially any angle within the corner angle. The sidelobes can be kept low during the beam-steering. This technique affords a method of electronic steering of a low-sidelobe narrow beam within the sector angle.

The equations and their solutions for the electromagnetic fields generated by the subject corner reflector antennae disclosed herein are expressions representing the inter-relationship of beam configuration, reflector geometry, number and position of feed elements, phase and magnitude of the current on feed elements, and frequency. General and specific application of these expressions will be illustrated whereby the several objects of my invention are accomplished.

In the following calculations of field patterns, the reflecting surfaces of the corner are considered to be planar, perfectly conducting, and infinite in extent. The angle between the two planes comprising the corner is chosen to be a submultiple of 180°, or π/N radians. The polarization of the transmitted or received wave is such that the electric field vector is parallel to the line of intersection of the two planes, denoted by the z direction. Symbolically, the corner angle is π/N, the distance from the apex to the feed elements is r, the elevation angle is ϕ, the azimuth angles is θ, k is $2\pi/\lambda$, and $J_n(kr)$ is the Nth order Bessel function.

Under these conditions, the far field produced by a single current element located at a point on the bisector of the corner angle is

$$E_z=NI_0\sum_{m=0}^{\infty}J^{(2m+1)N}J_{(2m+1)N}(kr\cos\phi)\cos(2m+1)N\theta \quad (1)$$

The extent to which a particular current generates one of the terms of this series is determined by the value of the corresponding Bessel function, and this is related to the distance of the elements from the apex in wavelengths.

By placing several radiators along the bisector of the corner angle, it is possible to produce a radiation pattern of the form

$$E_z-\sum_{m=0}^{\infty}A_mI_m\cos(2m+1)N\theta \quad (2)$$

in the range $-\pi/2N\leqslant\theta\leqslant\pi/2N$. In this manner, radiation functions even in θ, such as a narrow beam pointed along the corner angle bisector, can be synthesized. An estimate of the size of the conducting planes for a given beamwidth of a uniform illumination pattern is

$$Y_a=\frac{51}{BW} \quad (3)$$

where Y_a is the width of the aperture, measured in wavelengths between the edges of the ground planes, and BW is the beamwidth in degrees.

An array designed according to these principles is shown together with its radiation pattern in FIGS. 1 and 2. Reflector surfaces 16 and 17 are disposed at an angle of 60°, and the currents on dipoles 18, 19 and 20 are

$$I_1=0.73\text{ amps}, I_2=-1.17\text{ amps, and } I_3=0.94\text{ amps}$$

respectively. Said dipoles are located on the bisector of said corner angle at the distances

$$r_1=0.64\lambda, r_2=1.58\lambda, \text{and } r_3=2.74\lambda$$

from the intersection of said reflecting surfaces.

These elements produce a beam with 20-db uniform sidelobes in the H or azimuthal ($\phi=0$) plane. It is necessary, however, to examine the radiation pattern at various elevation angles in order to be sure that there are no large high-angle lobes. The complete description of the field is given by the equation

$$E_n(\phi,\theta)\approx\{[.73J_3(4\cos\phi)-1.17J_3(9.9\cos\phi)+.94J_3(17.2\cos\phi)]\cos 3\theta+[1.17J_9(9.9\cos\phi)-.94J_9(17.2\cos\phi)]\cos 9\theta+.94J_{15}(17.2\cos\phi)\cos 15\theta\}\frac{\cos\left(\frac{\pi}{2}\sin\theta\right)}{\cos\phi} \quad (4)$$

Curve 22 of FIG. 3 presents a vertical cut through the radiation pattern of $\theta=0$ to show the behavior of the main beam as a function of elevation angle. This pattern illustrates the directivity obtained in the vertical plane as the result of adding elements for horizontal plane beamwidth reduction. The use of a number of elements along the bisector of the corner angle benefits principally the azimuthal or θ plane pattern, but it should be remembered that the element positions may be chosen such that a desirable elevation pattern is also obtained.

The corner array thus has directivity in both planes and should not be considered a two-dimensional device. If additional colinear elements are used to narrow the elevation beamwidth, use should be made of the inherent properties of the corner. A considerable reduction in the number of necessary elements may result.

Azimuthal cuts through the radiation pattern for various elevation angles give additional information. First, any large, high-angle lobes can be found. Second, the frequency dependence of the pattern is shown. Apart from the element pattern, the elevation angle behavior of the corner array is contained in the Bessel function argument $kr\cos\phi$. Thus, azimuthal plots for a range of values of ϕ with k held constant may also represent plots at a particular ϕ for different values of k (or λ). The azimuth patterns for $\phi=0°$, 15°, 30°, 45°, and 60° with $\lambda=\lambda_0$ may also be viewed as plots of the azimuthal pattern at $\phi=0$ or $\lambda=\lambda_0$, $1.04\lambda_0$, $1.16\lambda_0$, 1.414λ and 2λ. The azimuthal patterns of the array in FIG. 1 are shown for elevation angles of $\phi=15°$, 30°, 45°, and 60° by curves 23, 24, 25, and 26, respectively of FIG. 4. The effect of the higher-order terms decreases with elevation angle; the pattern at $\phi=45°$, while reduced in magnitude, has broadened because of the phase reversal of the field component produced by the second element. The element impedances are of course also a function of frequency.

The radiation patterns described thus far contain only odd cosine functions of $N\theta$, that is, they are of the form

$$\sum_{m=0}^{M}A_m\cos(2m+1)N\theta$$

To produce sine terms in the radiation pattern it is necessary to position elements off the corner angle bisector.

The expression for the corner antenna field is valid only in the range $-\pi/2N\leqslant\theta\leqslant\pi/2N$. The argument of the first term in the series, $\cos N\theta$, varies between −90° and +90°. The restriction of zero field at the conducting surfaces prohibits even cosine terms in $N\theta$ from appearing; such terms would not be zero at $\pm\pi/2N$. Similarly, any sine terms that are produced must have arguments that are even multiples of $N\theta$ because odd multiples would not go to zero at the conducting planes. The terms of angular variation of the radiation pattern are therefore odd cosines and even sines. These may be written as

$$E_z(\theta)=\sum_{m\text{ odd}}A_m\cos mN\theta+\sum_{m\text{ even}}B_m\sin mN\theta$$

$$E_z(\theta)=\sum_{n=0}^{N_1}A_n\cos(2n+1)N\theta+\sum_{n=1}^{N_2}B_n\sin 2nN\theta \quad (5)$$

In general, it is desirable to synthesize patterns that can be put in the form

$$F(\theta)\sum_{n=0}^{N}(C_n\cos nN\theta+D_n\sin nN\theta) \quad (6)$$

Harmonics other than those of $N\theta$ need not be considered, since the pattern exists only in the sector π/N. If this function is reversed and displaced by π/N, it may be written

$$F(\pi/N\theta)-\sum_{n=0}^{N}C_n\cos nN(\pi/N-\theta)+D_n\sin nN(\pi/N-\theta)]$$
$$-=\sum_{\text{odd}}C_n\cos nN\theta+\sum_{\text{even}}C_n\cos nN\theta$$
$$+\sum_{\text{odd}}D_n\sin nN\theta-\sum_{\text{even}}D_n\sin nN\theta \quad (7)$$

Taking the difference

$$F'(\theta)=\tfrac{1}{2}[F(\theta)-F(\pi/N-\theta)]$$

gives the result:

$$F'(\theta)=\sum_{\text{odd}} C_n \cos nN\theta+\sum_{\text{even}} D_n \sin nN\theta \quad (8)$$

From this it is possible to develop a workable beam synthesis. Given a complete Fourier series approximation of a desired function, the pattern obtained from the corner will be the difference between the complete series of argument θ and the same series with the argument reversed and shifted by π/N. For example, consider the beam represented by curve 27 of FIG. 5. It may be represented by

$$F(\theta)=\sum_{n=1}^{N} A_n \cos nN(\theta-\theta_0)$$

$$=\sum_{n=1}^{N} A_n \cos nN\theta_0 \cos nN\theta+\sum_{n=1}^{N} A_n \sin nN\theta_0 \sin nN\theta \quad (9)$$

Forming the difference

$$F'(\theta)=\tfrac{1}{2}F(\theta)-F(\pi/N-\theta)=$$

$$=\tfrac{1}{2}\sum_{n=1}^{N} A_n \cos nN(\theta-\theta_0)-\sum_{n=1}^{N} A_n \cos nN(\pi/N+\theta_0-\theta)$$

$$\sum_{\text{odd}} A_n \cos nN\theta_0 \cos nN\theta+\sum_{\text{even}} A_n \sin nN\theta_0 \sin nN\theta \quad (10)$$

the feeding coefficients A_n are seen to be altered by cos $nN\theta_0$ or sin $nN\theta_0$ for the odd and even cases. The two patterns $F(\theta)$ and $-F(\pi/N-\theta)$ are represented by curves 28 and 30, respectively and the result $F'(\theta)$ is represented by curve 29 of FIG. 5. This function is zero at $\pm\pi/2N$.

A narrow beam with low sidelobes at an angle θ_0 from the bisector of the corner, satisfying the conditions imposed by the reflecting surfaces of the corner, can in this manner be obtained. By proper adjustment of the currents that produce the various terms a beam can be steered within the corner angle.

The current and radiation pattern relations having thus been determined, it is possible to position the various sine and cosine-generating elements. The odd cosine terms may be produced as previously described, that is, elements may be located along the bisector of the corner angle in such a manner as to produce the even part of the desired function. Elements placed along the bisector do not change the symmetry of the device and therefore generate no sine terms; however, if two elements of opposite polarity are symmetrically disposed on each side of the corner angle bisector, only sine terms will result. The production of sine terms within the corner is accomplished with element pairs and may therefore be done without involving the cosine-generating elements. The first sine term needed is sin $2N\theta$, and this suggests a corner of $\pi/2N$ radians. FIGURE 6 shows a method of producing the sin $2N\theta$ term. Each of the two elements 33 and 34 is located on the bisector of one of the angles formed by reflector surfaces 31 and 32, and the corner angle bisector. The resultant pattern is the same as that of a corner angle of $\pi/2N$, oriented at an angle of $\pi/4N$ to the $\theta=0$ axis. Since two elements are used, this pattern exists in the entire corner of π/N. This may be written as

$$E_z=J_{2N}(kr \cos \phi) \cos 2N(\theta-\pi/4N)$$

$$-J_{2N}(kr \cos \phi) \cos 2N(\theta+\pi/4N)$$

$$=2J_{2N}(kr \cos \phi) \sin 2N\theta \quad (11)$$

The next term of the series that is excited by elements 33, 34 is sin $6N\theta$; another set of elements is therefore necessary to produce a sin $4N\theta$ term. This may be done by using four additional elements located at $\pm\pi/8N$, $\pm 3\pi/8N$, with adjacent elements oppositely phased.

Such a scheme has the distinct advantage that no other lower-order terms are produced, that is, four elements properly located along an arc generate sin $4N\theta$, sin $12N\theta$, . . ., and the feeding coefficients for these elements need not involve other terms.

The foregoing theory and concepts may now be applied to the design of a scanning corner array antenna in accordance with the principles and objects of my invention, a specific embodiment of which is illustrated in FIG. 7.

The antenna design is developed from a determination of the Fourier components of the corner reflector fields. The corner angle specified is 60°, and five terms of the antenna pattern are to be generated. These are cos 3θ, sin 6θ, cos 9θ, sin 12θ, and cos 15θ. As the beam is steered within the sector, the feed currents must be varied according to the beam angle. The elements of the array as illustrated in FIG. 7 comprise reflector surfaces 35 and 36, and dipole feed elements 37 through 45. The distance r from the apex is chosen for each dipole feed element so that the Bessel function associated with the particular field component is near a maximum, and the other terms are small. In the present example $r_1=.64\lambda$, $r_2=1.20\lambda$, $r_3=1.58\lambda$, $r_4=2.23\lambda$ and $r_5=2.79\lambda$. The angular variation of the field pattern associated with each element is such that I_1, I_3 and I_5 excite cos 3θ, cos 9θ, and cos 15θ terms respectively, I_2 excites the sin 6θ term, and I_4 excites the sin 12θ term. The elements that produce the sin 12θ pattern are interconnected so that only one cable is used for the control of this component. The same is true of the sin 6θ pair. The manner in which the feed currents are varied in order to produce a beam oriented at different angles is given in the following feed coefficient table. The radiation patterns corresponding to these beam positions are illustrated by curves 46 through 50 of FIG. 8.

Feed coefficient table

Beam Position θ°	Cos 3θ (C_1)	Sin 6θ (D_2)	Cos 9θ (C_3)	Sin 12θ (D_4)	Cos 15θ (C_5)
0°	1.000	0.000	1.000	0.000	1.000
5°	.966	.500	.707	.866	.259
10°	.866	.866	0.000	.866	−.866
15°	.707	1.000	−.707	0.000	−.707
20°	.500	.866	−1.000	−.866	.500

The scanning corner array antenna constructed in accordance with the foregoing design antenna is shown in conjunction with its associated beam steering means in FIG 9. The antenna is supplied with plane 73 for convenience in mounting the feed elements. Of the total of nine feed elements used, dipoles 37, 38 and 39 generate the cosine terms and dipoles 40 through 45 generate the sine terms. The sine-generating elements are connected by cables 55, 56, 57 and 58 of one half wavelength so that alternate elements are 180° out of phase. Power dividers 67 through 70, attenuators 59 through 62, and trombone phase shifters 63 through 66 are used to provide control over the five inputs. Each element or set of elements used to produce a particular term in the radiation pattern is preset by comparing its amplitude and phase with that of the cos 3θ element. The signal at each set of terminals is set at the value shown in the accompanying table for the prescribed angle, and patterns are taken without adjusting parameters for minimum beamwidth or low sidelobes.

A perspective veiw of this particular embodiment of my invention is illustrated by FIG. 10 wherein reflecting surfaces 35 and 36 are shown mounted at a 60° angle on mounting structure 75. There is also shown dipole feed elements 37–45 and cables 55–58. It is to be noted that the associated beam steering means of FIG. 9 is not included with FIG. 10 as only the perspective structure of the corner antenna array is being illustrated.

There has thus been disclosed a practical scanning corner reflector antenna having high gain and a high degree of directivity wherein the several objects of my invention are accomplished. Although the particular embodiment disclosed illustrates a sixty degree, nine feed element device, it is not intended that the principles of my invention as taught herein be restricted thereto. It will be apparent to those having ordinary skill in the art that application of the principles of my invention will provide, within practical limits, scanning corner reflector antennae having any degree of gain feed elements, or any size corner angle.

Therefore, although I have described the principles of my invention in connection with specific apparatus it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. A scanning antenna comprising two intersecting plane surfaces of highly conductive material, said plane surfaces being positioned on mounting means located at the vertex of the angle formed thereby, a plurality of feed elements disposed in parallelism with said vertex, and with each other, in a series of planes diverging from and including said vertex as a common access of intersection of all said planes, all of said parallel feed elements being located at discrete points along said several diverging planes and means for varying the currents applied to each of said feed elements.

2. A corner reflector antenna in combination with a plurality of dipole feed elements, said dipole feed elements being disposed within said corner in parallelism along a series of planes having a common access of intersection at said corner, and being adapted to divert the beam produced thereby in response to the several currents applied to each of said feed elements.

3. An electromagnetic wave radiating device comprising a corner angle reflector, a first series of feed elements disposed on the bisector of said corner angle, a second series of feed elements disposed on the sub-bisectors of said corner angle all of said sub-bisectors having a common access of intersection at the vertex of said corner angle, and means for varying the phase and magnitude of the currents applied to the several elements of said first and second series of feed elements.

4. An electromagnetic wave radiating device in accordance with claim 3 wherein said corner angle reflector comprises two vertical intersecting plane surfaces of highly conductive material, and reflector mounting means.

5. An electromagnetic wave radiating device in accordance with claim 3 wherein the individual elements of said first and said second series of feed elements are disposed

at discrete distances from the apex of said corner angle such that the Bessel function associated with the field components produced thereby is substantially a maximum.

6. An electromagnetic wave radiating device in accordance with claim 3 wherein said means for varying the phase and magnitude of the currents applied to said feed elements comprises a plurality of power dividers, said power dividers being adapted to provide a separate input current for each of the several feed elements, a plurality of phase shifting devices, means for controlling said phase shifting devices in accordance with the desired radiation pattern and a plurality of attenuating elements, said attenuating elements being adapted to control the magnitude of the current applied to each of said feed elements.

7. An ultra high frequency antenna comprising a corner angle reflector, said corner angle reflector consisting of two vertically intersecting plane surfaces of highly conductive material, a first series of feed elements, said first series of feed elements being adapted to provide cosine components of the field pattern radiated thereby, a second series of feed elements, said second series of feed elements being adapted to provide sine components of the field pattern radiated thereby, all of said feed elements being located in planes having a common access of intersection at the vertex of said corner angle, and means for controlling the phase and magnitude of the several currents applied to said first and said second series of feed elements.

8. A corner angle reflector antenna comprising two intersecting plane surfaces of highly conductive material, a plurality of cosine producing feed elements, said cosine producing feed elements being disposed at discrete points on the bisector of the angle formed by the intersection of said plane surfaces, a plurality of oppositely phased pairs of sine producing feed elements, the individual elements of each of said pairs being disposed at discrete points on the sub-bisectors of said angle formed by the intersection of said plane surfaces one on either side of said bisector, the intersection of said plane surfaces being coincident with the vertex of said corner angle, and means for varying the individual currents applied to said sine and said cosine producing feed elements.

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