

April 11, 1961

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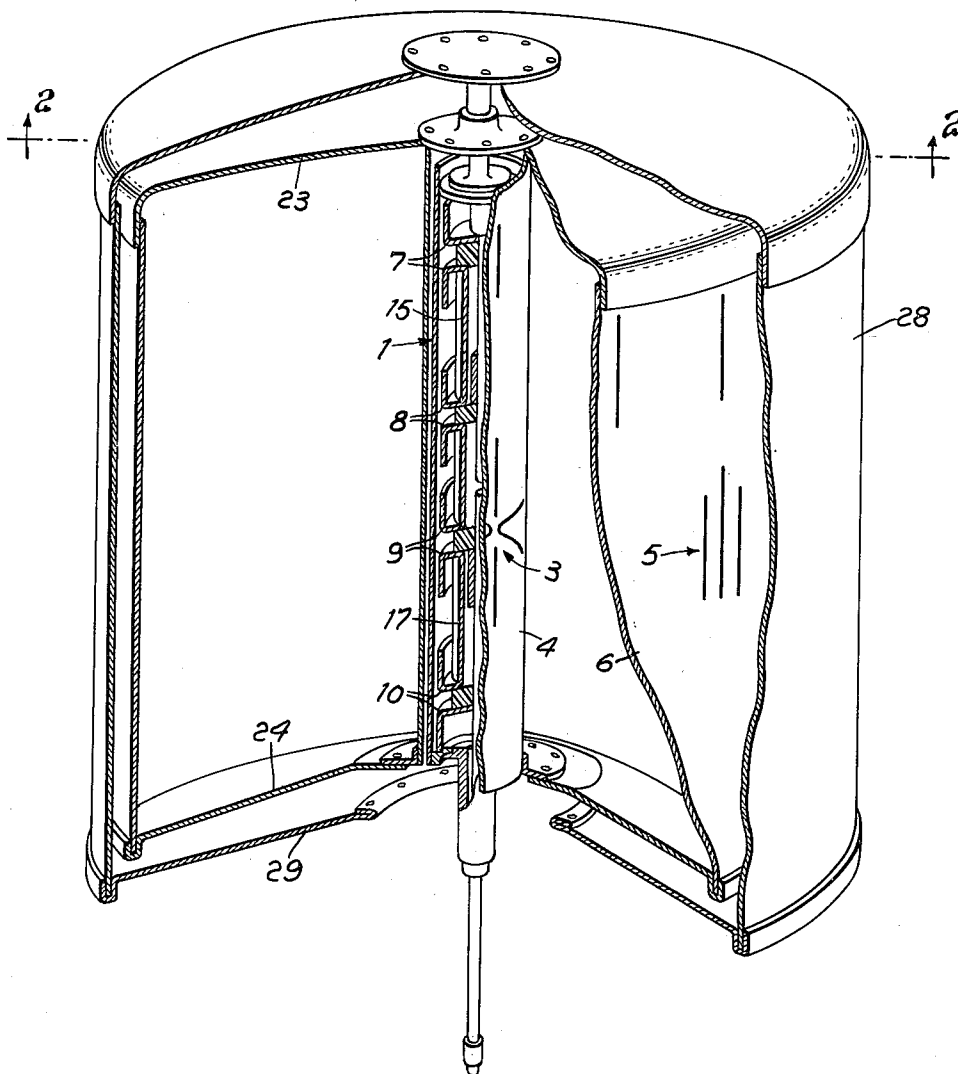
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OMNIDIRECTIONAL BEACON ANTENNA

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6 Sheets-Sheet 1

Fig. 1



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Fig. 3

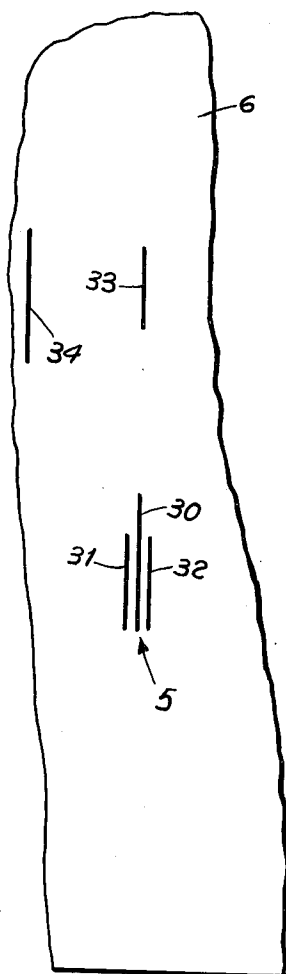


Fig. 4

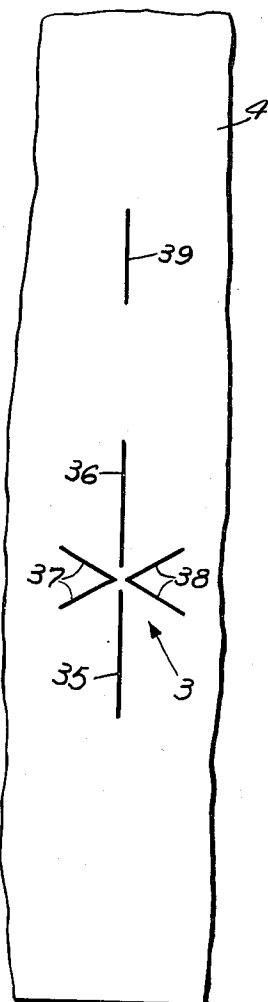
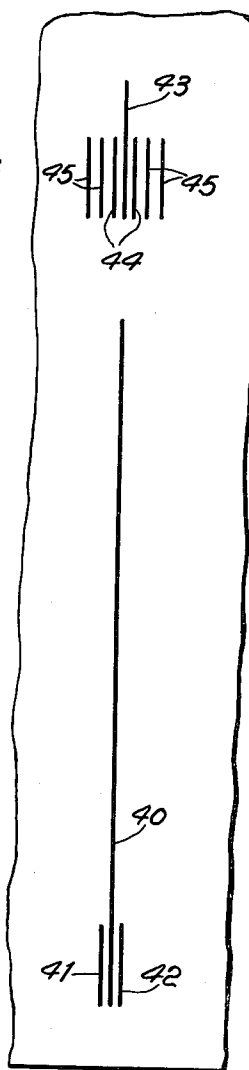


Fig. 5



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Fig. 6

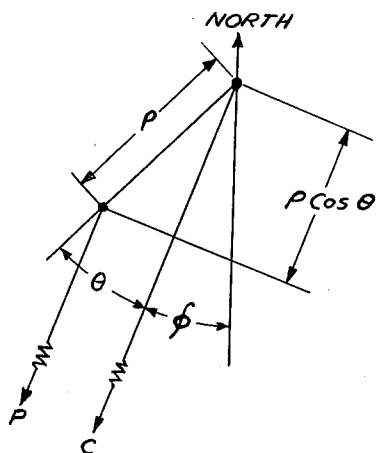


Fig. 7

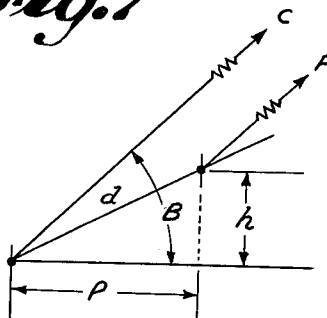


Fig. 8

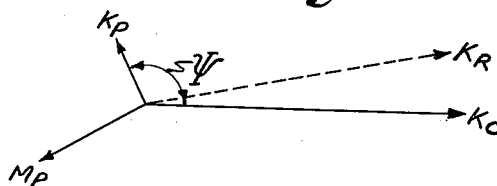
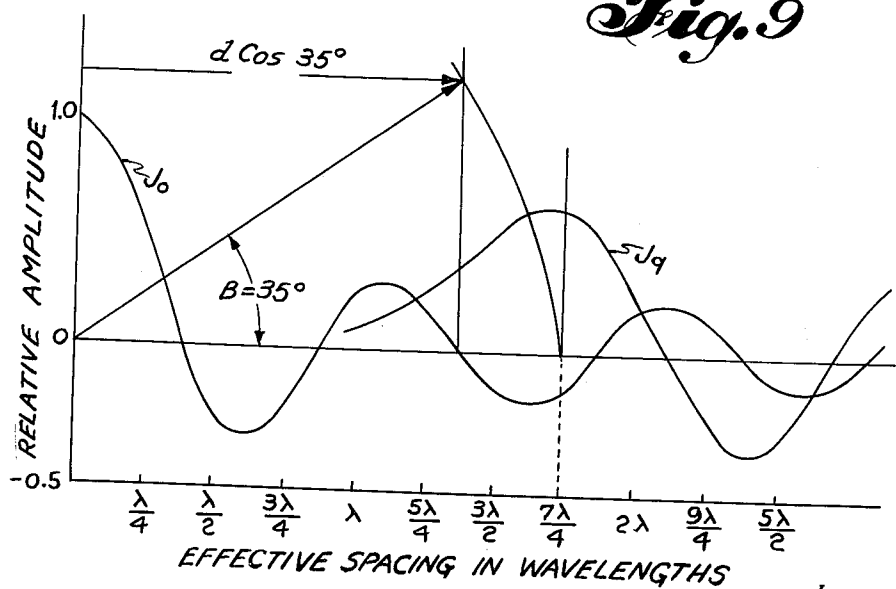


Fig. 9



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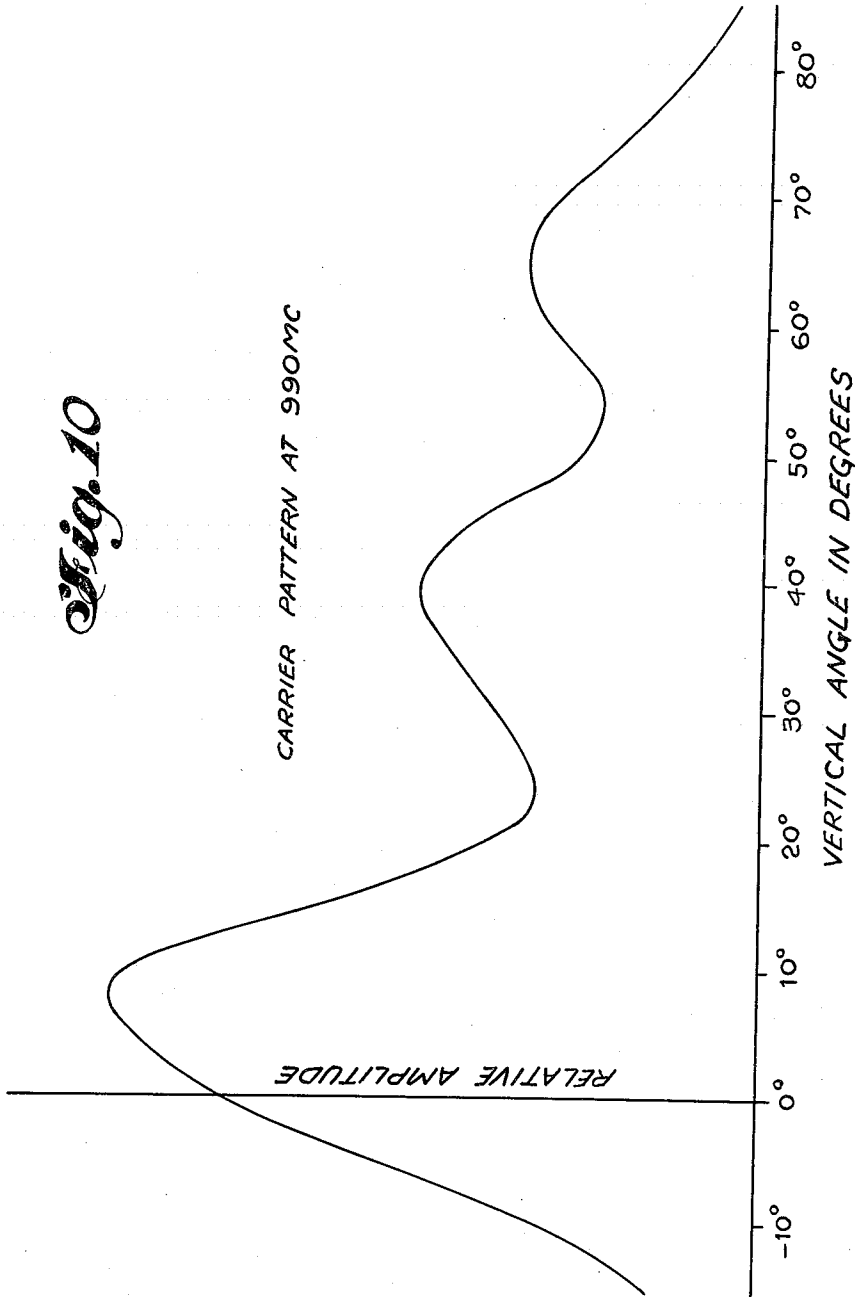
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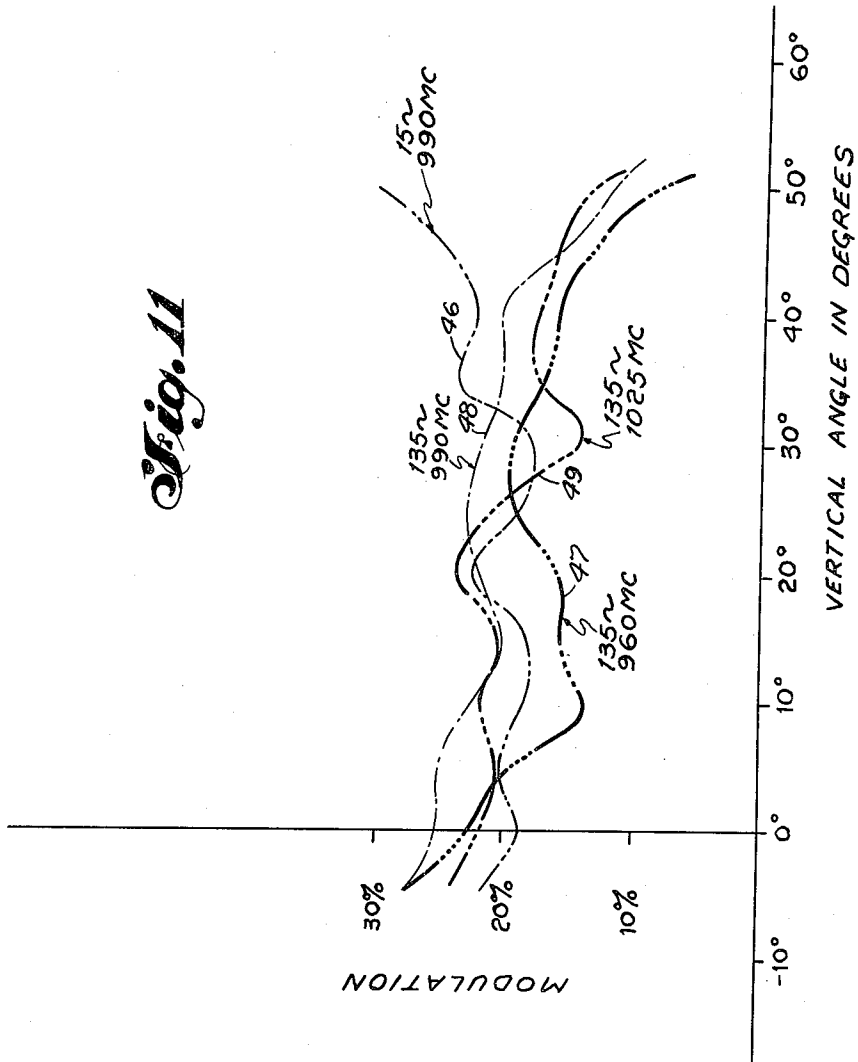
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Fig. 11



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OMNIDIRECTIONAL BEACON ANTENNA

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6 Claims. (Cl. 343-761)

This invention relates to omnidirectional beacon antennas and more particularly to omnidirectional beacon antennas for use in producing a rotating multilobed radiation pattern having a fundamental modulation frequency and one or more additional harmonics of the fundamental frequency for use in radio navigation systems such as that commonly known as TACAN.

Omnidirectional beacon systems such as in TACAN have a high order of directional accuracy which is dependent upon the use of a directive antenna pattern rotated at a fundamental frequency and modulated by a harmonic of this fundamental frequency so as to produce a generally multilobed rotating directive radiation pattern. The antennas usually consist of a central omnidirectional radiator surrounded by radiation pattern modifying elements adapted to revolve around the central radiator. Due to the rotation of the multiple-modulation antenna pattern, a receiver located remotely from the transmitter receives energy which appears as an amplitude-modulated wave having a fundamental modulation component and a modulation component at a harmonic frequency of the fundamental. Both fundamental and harmonic frequency reference signals are transmitted for comparison with the received components of the rotating pattern so that the receiver may determine its azimuth relative to the beacon's antenna system.

Antennas of this type are usually designed to achieve their greatest gains at low angles in the vertical plane. Sufficient modulation is easily obtained at these low angles, but at high angles, especially for the harmonic modulation, a satisfactory level is difficult to obtain. If at high angles the carrier strength can be reduced while maintaining the modulation strength, the relative modulation is increased. Such a carrier pattern may be obtained by the vertical stacking of elements to form an array for the central radiator. With this type of central radiator, it has been the practice to use long resistive wires as parasitic modulating elements. These wires are vertically disposed on a rotating dielectric cylinder, and extend substantially the length of the central array. However, these long parasitic elements have some disadvantages in obtaining optimum modulation characteristics over the desired frequency band, and at high vertical angles. For example, the spacing from the center for proper excitation does not coincide with the best spacing for the vertical pattern. Also the standing wave of current set up near the ends of the long wire parasite is not insignificant, effecting a considerable change in current distribution along the length of the parasite. Therefore, the R.F. phase and radiation pattern from the parasites changes rapidly with frequency, producing a large change in modulation level.

The principal object of this invention is to provide an improved antenna for a beacon system, of the type with a vertically stacked array as a central radiator, having good modulation levels over a broad band of frequencies and in vertical coverage.

According to the principal aspect of the invention, an

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antenna having a vertically stacked central array is provided with a plurality of parasitic modulating elements, at least some of which are limited to approximately a half wavelength long to permit adjustment of the parasites to obtain greatly improved characteristics.

Further, the exact length of some of the parasites may differ from a half wavelength by a substantial portion of a quarter wavelength, that is, the total length of each individual element may be between one and three quarter wavelengths, thereby affecting its current phase and permitting the radiation phase of the total modulation component to be adjusted as desired. Using short elements also permits the elements to be located vertically to place the radiation centers at the best points. With short elements the radiation center does not shift appreciably for changes in frequency, as it does with long elements.

In addition to length and vertical location, the radius from center, resistance and number of the elements may be adjusted as in previous designs.

The foregoing and other objects and features of this invention and the manner of attaining them will become more apparent and the invention itself will be best understood by reference to the following description of embodiments of the invention taken in conjunction with the accompanying drawings comprising Figs. 1 to 11, wherein:

Fig. 1 is a fragmentary perspective view, partly diagrammatic, of a beacon antenna system embodying the principles of this invention;

Fig. 2 is a cross-section view, partly diagrammatic taken along lines 2-2 of Fig. 1;

Figs. 3 and 4 are views of the harmonic and fundamental parasite arrangements, respectively, of the antenna system of Figs. 1 and 2;

Fig. 5 is a view of a harmonic parasite arrangement for an alternative antenna system;

Figs. 6 and 7 are diagrams in horizontal and vertical planes, respectively, useful in explaining the formation of the radiation pattern;

Fig. 8 is a vector diagram of the radiation components;

Fig. 9 is a graph of two Bessel coefficients of the radiation components; and

Figs. 10 and 11 are graphs showing radiation patterns obtained with the antenna system of Figs. 1 to 4.

A description of TACAN may be found in "Electrical Communications" published by International Telephone and Telegraph Corporation, New York, New York, volume 33, No. 1, March 1956, with the principles of antenna design on pages 35-59.

Referring to Figs. 1 and 2, a beacon antenna system is shown comprising a stationary central array 1 enclosed in a dielectric cylinder 2, and surrounded by a rotating structure which includes a group of fundamental parasitic modulating elements 3 on a dielectric cylinder 4 and nine groups of harmonic parasitic modulating elements 5 on a dielectric cylinder 6.

The central array 1 comprises four vertically disposed and vertically aligned center-fed half wavelength radiating elements 7 to 10, each consisting of two tubular quarter wavelength sections. The feed system is generally similar to that described on pages 42 and 43 of the "Electrical Communications" publication. A coaxial line having an inner conductor 11 and an outer conductor 12 is coupled at its lower end to a source of R.F. energy not shown. The upper end 13 of inner conductor 11, reduced in cross-section, is inserted into and connected to an upper rod conductor 14. The rod 14 and tubular conductor 12 are equal in outside diameter and separated to form a main feed point 15. Rod 14 and the outside surface of conductor 12 then form the inner conductors of coaxial transmission lines, the outer conductors being formed by tubular sections 15, 16 and 17. The respective ends of tubular sections 15, 16 and 17 are connected

by flange portions 18 to respective sections of the radiating elements as shown. The upper section of radiating element 7 has a flange portion 19 connecting it to conductor 14, and the lower section of element 10 has a flange portion 20 connecting it to conductor 12. A conductive sleeve 21 surrounding conductor 14 and a conductive sleeve 22 surrounding conductor 12 serve as impedance transformers in the transmission lines. The R.F. power flows in transmission line 11—12 to feed point 15 and divides between transmission lines 14—16 and 12—16. At the center feed point of element 8 the energy divides between radiating element 8 and by transformer 21 to transmission line 14—15 and thence to radiating element 7. At the center feed point of element 9 the energy divides between radiating element 9 and by transformer 22 to transmission line 12—17 and thence to radiating element 10. The energy to the radiating elements 7 to 10, respectively, divides approximately in the proportion 1, 2, 2, 1 and phase relation —45, —30, +30, —45, respectively.

The rotating dielectric cylinders 4 and 6 have an upper dielectric cap 23 and are supported on a conductive counterpoise surface 24. The rotating assembly is mounted on a supporting structure 25, is supported on the inner stationary structure by bearings not shown, and is driven at 900 r.p.m. by an arrangement shown as a motor 26 and a gear arrangement 27. The entire antenna unit is covered by a stationary dielectric radome 28 on a support 29, and is mounted on a base, not shown.

The inner parasitic elements 3 produce 15 c.p.s. modulation, and the outer parasitic elements 5 produce the ninth harmonic modulation at 135 c.p.s. Fig. 3 shows one of the nine groups of 135-cycle parasites 5 on a portion of the dielectric cylinder 6, and Fig. 4 shows the 15-cycle parasites 3 on a portion of dielectric cylinder 4.

In an embodiment of the antenna system for operation in the frequency band of 960 mc. to 1025 mc., the outer cylinder 7 may have an outer diameter of 40 $\frac{3}{4}$ inches. Each group of the parasites 5 (Fig. 3) includes elements 30 to 32 with their bottom edges 17 $\frac{1}{4}$ inches from the bottom of the cylinder, with element 30, 7 inches long and elements 31 and 32, each 5 inches long and spaced $\frac{1}{2}$ inch from element 30. An element 33 in vertical alignment with element 30 is 4 $\frac{1}{4}$ inches long with its center spaced 38 $\frac{3}{4}$ inches from the bottom of the cylinder. An element 34 is spaced 20 degrees from elements 30 and 33, is 7 inches long and is spaced with its bottom edge 4 $\frac{1}{2}$ inches below the center of element 33. Elements 30 and 33 are of #30 A.W.G. copper wire, element 34 is of #24 A.W.G. copper wire and elements 31 and 32 are of Nichrome wire having a resistance of 450 ohms per foot.

The inner rotating cylinder 4 has an outside diameter of 5 inches. The fundamental parasite group 3 (Fig. 4) includes elements 35 and 36 in vertical alignment spaced 2 $\frac{1}{4}$ inches apart, each 6 $\frac{1}{2}$ inches long with the point midway between them 21 $\frac{1}{16}$ inches above the counterpoise surface. V-shaped elements 37 and 38 have legs 3 $\frac{3}{4}$ inches long forming an angle of 60 degrees, with the center points each $\frac{3}{8}$ inch from the point midway between elements 35 and 36. Elements 37 and 38 serve to increase the coupling between elements 35 and 36. Element 39 in vertical alignment with elements 35 and 36 is 4 $\frac{3}{4}$ inches long with its bottom end 35 $\frac{3}{8}$ inches above the counterpoise surface. All of the elements 35 to 39 are of #36 A.W.G. copper wire.

The approximate distance between the centers of the half wave elements 7 and 8, is 11 inches or about one wavelength; between elements 8 and 9, 7 inches or about 0.6 wavelength; and between elements 9 and 10, 11 inches. The bottom of element 10 is 21 $\frac{1}{16}$ inches above the counterpoise surface, and 5 $\frac{1}{16}$ inches above the bottom edge of the outer rotating cylinder 6.

The principles of this invention may also be employed

with a beacon antenna in the form having a central array of seven vertically aligned biconical elements as disclosed in the "Electrical Communications" publication. The structure will be similar in all respects as disclosed there except for the arrangement of the parasites on the rotating cylinders. The upper counterpoise below the top radiating element is also removed. Fig. 5 shows an arrangement for one of the nine groups of 135 c.p.s. parasites mounted on the outer rotating cylinder. Three elements having their bottom ends 3 $\frac{1}{2}$ inches above the bottom edge of the cylinder include a long 34 $\frac{1}{2}$ -inch center element 40 and two 4 $\frac{1}{2}$ -inch elements 41 and 42, $\frac{1}{2}$ inch either side of element 40. Seven elements having their bottom ends 43 $\frac{1}{2}$ inches above the bottom edge of the cylinder include a 7-inch center element 43 in vertical alignment with element 40, and six 4 $\frac{1}{4}$ -inch elements including two elements 44 spaced $\frac{1}{2}$ inch from element 43 and four elements 45 each spaced $\frac{3}{4}$ inch from the adjacent elements. All of the elements are of Nichrome wire, element 43 having resistance of 450 ohms per foot, and the remaining elements having a resistance of 700 ohms per foot.

The mathematical analysis of the derivation of the antenna pattern for TACAN may be found on pages 55–59 of the "Electrical Communications" publication. The theory of operation and the results obtained with the antenna of this invention may be explained by reference to Figs. 6 to 11.

Fig. 6 is a diagram of the projection in a horizontal plane of one central radiating element and one rotating parasitic element at a horizontal distance ρ from the center. A distant receiver is at an angle ϕ from a point due south of the antenna. The parasite has an angular displacement θ from a line drawn to the receiver from the central radiator. The received signal includes a component C from the central element and a component P from the parasite.

Fig. 7 is a diagram in the vertical plane of the two elements of Fig. 6, with θ equal to zero. Considering the centers of the elements, the parasite is displaced a vertical distance h above the central element. The receiver is at a vertical angle B from the horizontal plane of the antenna. The direct distance d between the elements is equal to $\sqrt{h^2 + \rho^2}$.

Fig. 8 is a simple vector diagram of the radiated signals. The center element radiates a carrier signal K_C . The rotating element will produce a signal having two components K_P and M_P which are always in quadrature. There is a relative current phase α between the parasites and the central element which depends upon factors including the relative excitation phase and the phase angle of self-impedance of the elements. If the radiation centers of the center and parasitic elements are in a single plane, the relative radiation phase ψ of K_P with respect to K_C is equal to the relative current phase α . However, by displacing the parasites a vertical distance h , the radiation phase of the parasites becomes

$$\psi = \alpha + h \sin B$$

Analysis using the Bessel function expansion shows that the component K_P includes a carrier component and all even harmonic modulation components of θ , and the component M_P contains all the odd harmonic terms. With a carrier radio frequency equal to $w_k/2\pi$, the resulting field pattern at the distance point may be given by the following equation:

$$E = (M_P \sin \psi + K_P \cos \psi + K_C) \cos w_k t + (M_P \cos \psi + K_P \sin \psi) \sin w_k t$$

The radiation pattern for each element is assumed to be circular in the horizontal plane, and in the vertical plane to be functions $F(B)$ and $f(B)$ of the angle B for the center element and parasite respectively. Assuming one center element and nine parasites equally spaced around a cylinder at a radius ρ and angle B, the analysis

shows that the odd harmonic terms other than the ninth and the even harmonic terms other than the carrier term are negligible for the values of radius ρ to be considered, and therefore the coefficients in the equation given above may be expressed as follows:

$$M_P = 18af(B)J_9(\rho \cos B) \cos 9\theta$$

$$K_P = 9af(B)J_0(\rho \cos B)$$

K_C is a function $F(B)$ of the vertical angle

The term $J_0(\rho \cos B)$ is the Bessel term of order zero and argument $(\rho \cos B)$, and the term $J_9(\rho \cos B)$ is the Bessel term of order nine and argument $(\rho \cos B)$. The constant "a" depends on the relative signal strength from the rotating and center elements. If the angular rate of rotation about the central element is ω_N , then θ is equal to $(\omega_N t - \phi)$.

From Fig. 8 it may be seen that the carrier components K_C and K_P will combine to produce a resultant K_R . For most effective amplitude modulation, the modulation component M_P should be at 0° or 180° to K_R . This occurs when the relative radiation phase ψ is centered around an odd integral number of 90° , that is, $n\pi/2$ with n an odd integer, with a slight adjustment because of the effect of K_P . The radiation phase of an element depends on its current phase, the determining factors of which include the excitation phase and the self-impedance of the element. The excitation phase with parasitic rotating elements is the spacing d in electrical distance. If the self-impedance phase is set equal to zero, the proper radiation phase for maximum modulation occurs at the odd numbers of quarter wavelength for the spacing d .

A graph of the J_0 and J_9 Bessel coefficient terms, according to wavelength, is given in Fig. 9. A maximum in the J_9 curve and a point of proper excitation phase occurs near seven quarter wavelengths. However, the effective value of spacing for radiated modulation signals decreases in proportion to the cosine of the elevation angle B . With h equal to zero and equal to $1/4$ wavelengths, the J_9 term drops rapidly as the vertical angle is increased. The graph shows the determination of the value for an angle of 35° at point X on the J_9 curve. For good high angle coverage, it is desirable to use a spacing which is well past the maximum on the J_9 curve. In the prior art antennas with long parasites, a compromise spacing was chosen so that the point of operation at 0° was between the two optimum values. The result was that for 0° elevation the excitation is late, causing reduction in modulation at the high frequency end of the band and increased modulation at the low end. Further, due to the shift along the Bessel curve, there is a more rapid decrease in modulation with elevation angle than would ideally occur.

However, by using short parasites with their radiation centers displaced vertically by a distance h , the radiation phase ψ becomes a function of the vertical angle B , as explained above. This factor may be designed to compensate for the drop in the Bessel function with vertical angle, and thereby greatly improve the vertical coverage.

Also, with long resistive parasites, the standing wave of current set up near the ends of the parasites is not insignificant. Although the use of high resistance wire for parasites tends to minimize this effect, it is now apparent that the standing wave is sufficient to effect considerable change in the current distribution along the length of the parasite. The result is that the R.F. phase and the pattern of the radiation from the parasites changes rapidly with frequency. Due to the large slope of the sideband and carrier lobes around zero, this slight shift in pattern produces a large change in modulation level.

At higher angles, the effect of radio frequency (R.F.) phase shift is more important. A relative shift of 90° for the R.F. phase of radiation from the parasites will result in complete obliteration of the ninth harmonic modulation. This means that the equiphasic surfaces for

the radiation from the central array and from the parasites must conform within an inch or two for all points in space where modulation is to be received. For large vertical apertures, this becomes difficult to achieve at high angles, due to the vertical shifts in the effective center of radiation produced by the changing current distribution in the parasites.

According to the invention short parasites approximately a half wavelength long are used to permit adjustment to obtain the optimum spacing and radiation phase for good vertical coverage and broadband modulation characteristics. The short parasites have definite centers of radiation which do not shift appreciably as the frequency is changed.

The current I_P in a parasite having an impedance Z_P and excited by a voltage E_P is given by $I_P = E_P/Z_P$. The strength and phase of E_P depend on the distance d and the current in the central radiator. The factors determining Z_P include the resistance and length of the parasite.

It is to be noted that in an antenna system as disclosed in this application, each of the parasites is in the radiation field of each of the central array elements.

The radiation pattern for the antenna system is the resultant of all of the central and parasitic radiating elements. The diagram of Fig. 8 may be used to represent the total radiation components from the central array and the parasites for one modulation frequency. The total central array component is the K_C , and the total parasite components are K_P and M_P . It is desirable that M_P be nearly at 0° or 180° with respect to K_R , and that the depth of amplitude modulation, determined by the ratio of the properly phased component of M_P to K_R , be between 12 and 30 percent, at all frequencies within the band and up to high vertical angles.

The factors which determine the value and phase of M_P include the number, resistance, and length of the wires used for the parasites, their spacing from the center, and their vertical location on the cylinder. It is usually desirable to keep K_P to a minimum. The J_0 curve shows the effect of the spacing on this quadrature carrier term. The value of K_C varies with vertical angles, and is determined by factors such as the spacing of the central array elements, the feed system, and the driving power.

The antenna system of Figs. 1 to 4 has a carrier radiation pattern which varies with vertical angle as shown by the curve of Fig. 10. The percentage of modulation is shown in Fig. 11 with the 15-cycle modulation at 990 mc. shown by curve 46, and the 135-cycle modulation at 960, 990, and 1025 mc. shown by curves 47, 48, and 49, respectively.

While we have described above the principles of this 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 our invention as set forth in the objects thereof and in the accompanying claims.

We claim:

1. An antenna system comprising the combination of a central array having a plurality of radiating elements disposed in vertical alignment coupled to a source of input energy feeding a greater amount of energy at different phases to the middle ones of said radiating elements than is coupled to the upper and lower ones of said radiating elements, the vertical height of said array being substantially greater than a wavelength and a plurality of parasitic elements disposed around said array at a given radial distance therefrom, each parasitic element being located within the radiation field of each radiation element, the majority of said parasitic elements being located radially of said middle radiating elements with at least some of said parasitic elements being approximately a half wavelength long, said parasitic elements being distributed in vertically disposed arrangements along the length of said central array, the distance

between any two adjacent parasitic elements in each of said arrangements not exceeding one wavelength.

2. A system as in claim 1, in which said radiating elements are vertically disposed half wavelength elements.

3. A system as in claim 1, in which said parasitic elements are disposed for rotation about said central array to produce a space modulated radiation pattern and in which at least some of said parasitic elements are between one quarter and three quarter wavelengths long.

4. A system as in claim 3, further including a second plurality of parasitic elements at a second radial distance from said array and disposed for rotation thereabout, said second group of parasitic elements being distributed in vertically disposed arrangements along the length of said central array, the distance between any two adjacent parasitic elements in each of said arrangements not exceeding one wavelength, the majority of said second group of parasitic elements being located radially of said middle radiating elements and at least some of said second group of parasitic elements being between one quarter and three quarter wavelengths long.

5. A system as in claim 3, further including a second plurality of parasitic elements at a second radial distance from said array and disposed for rotation thereabout, said second group of parasitic elements being distributed in vertically disposed arrangements along the length of said central array, the distance between any two adjacent parasitic elements in each of said arrangements not exceeding one wavelength, the majority of said second group of parasitic elements being located radially of the upper radiating elements of said central array, the greater number of said majority being less than a half wavelength long and the remaining elements of said second group including some elements approximately three wavelengths long.

6. A beacon antenna system producing a multilobed rotating pattern of radiation having a fundamental lobe and harmonic lobes comprising the combination of a central array having a plurality of half wavelength elements vertically disposed with relation to each other, coupled to a source of carrier frequency energy feeding

a greater amount of said energy at different phases to the middle ones of said radiating elements than is coupled to the upper and lower ones of said radiating elements, a first plurality of parasitic elements at a given radial distance from said central array disposed for rotation around said array to produce said fundamental lobe, said first plurality of elements consisting of vertically disposed members and V-shaped members, said V-shaped members and the majority of said vertically disposed members of said first group being located radially of said middle radiating elements, a second group of parasitic elements at a second radial distance from said array disposed for rotation around said array to produce said harmonic lobes, said second group consisting of closely spaced vertically disposed elements located radially of said middle radiating elements and widely spaced vertically disposed elements located radially of the upper radiating elements, at least some of the elements of said first and second groups being between one quarter and three quarter wavelengths long, and means for rotating said first and second groups about said central array to produce said rotating multilobed pattern, each of said first and second groups of parasitic elements being distributed in vertically disposed arrangements along the length of said central array, the distance between any two adjacent parasitic elements in each of said arrangements not exceeding one wavelength.

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