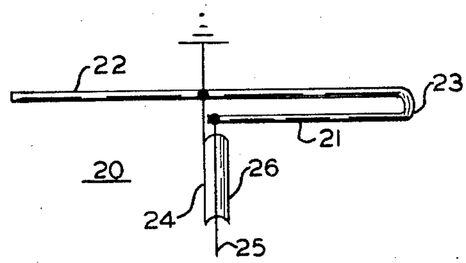
June 23, 1953 — N. W. ARAM — 2,643,334

TURNSTILE ANTENNA

Filed Oct. 23, 1948 — 4 Sheets-Sheet 1

FIG. 1



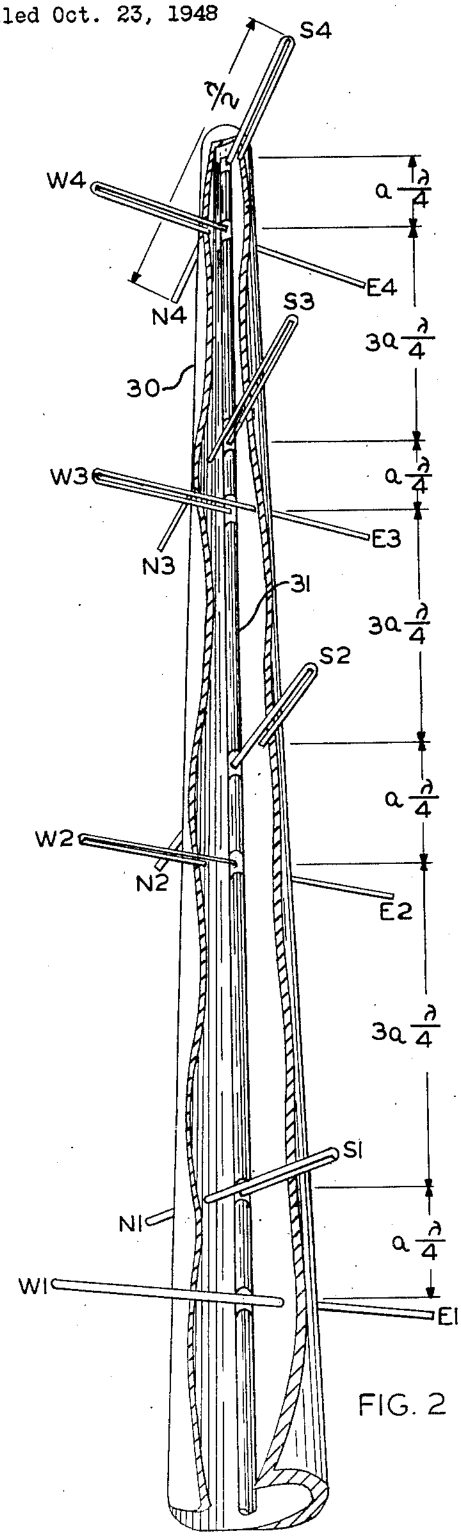


FIG. 2

FIG. 6

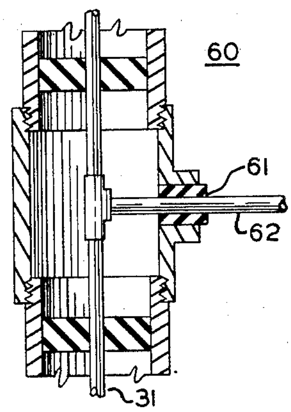


FIG. 7

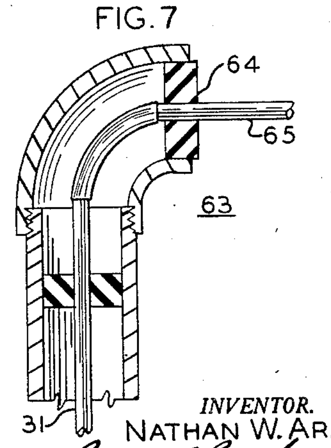


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FIG. 4

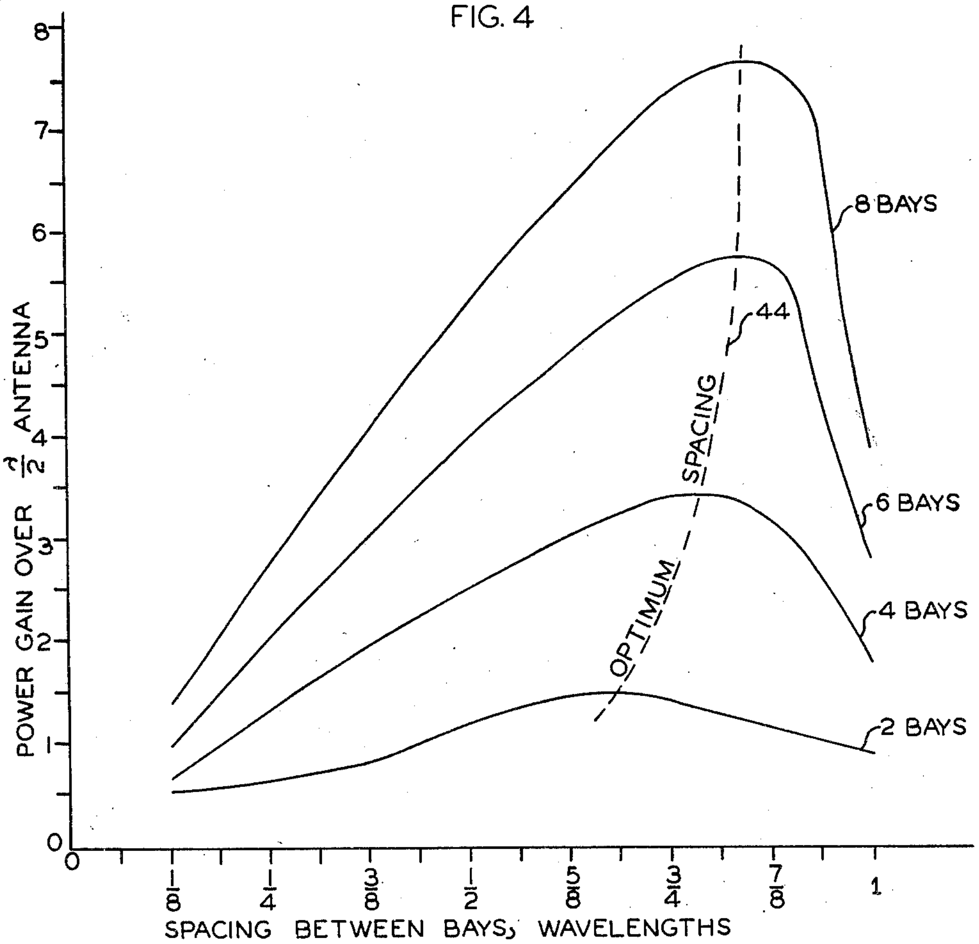

FIG.3

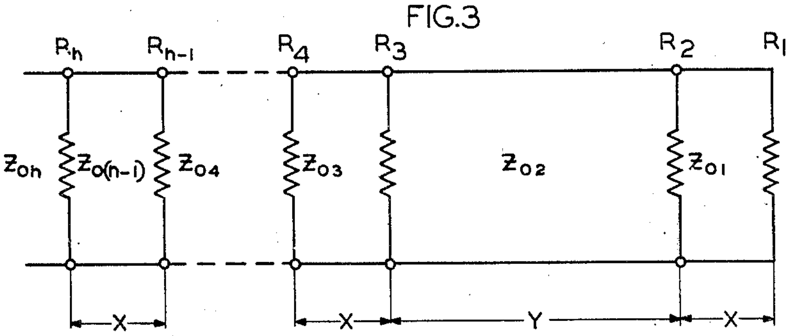

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FIG.5

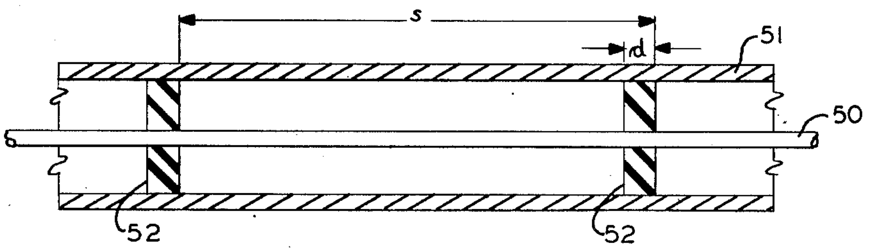

FIG.8a

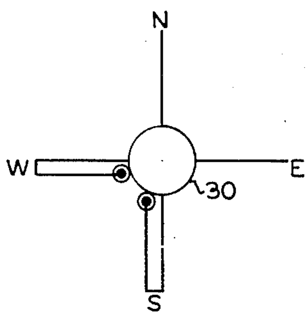

FIG.8b

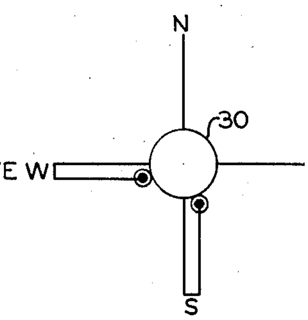

FIG.8c

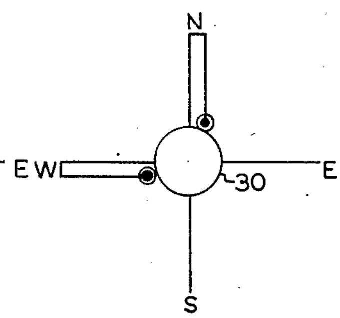

FIG.9a

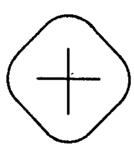

FIG.9b

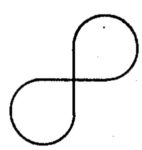

FIG.9c

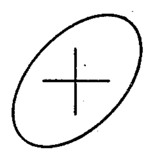

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FIG.10

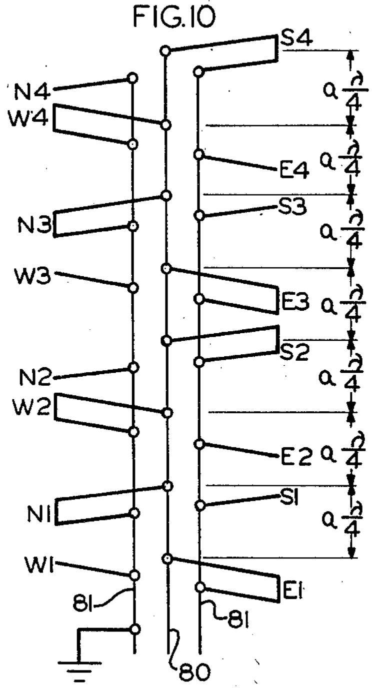


FIG.12

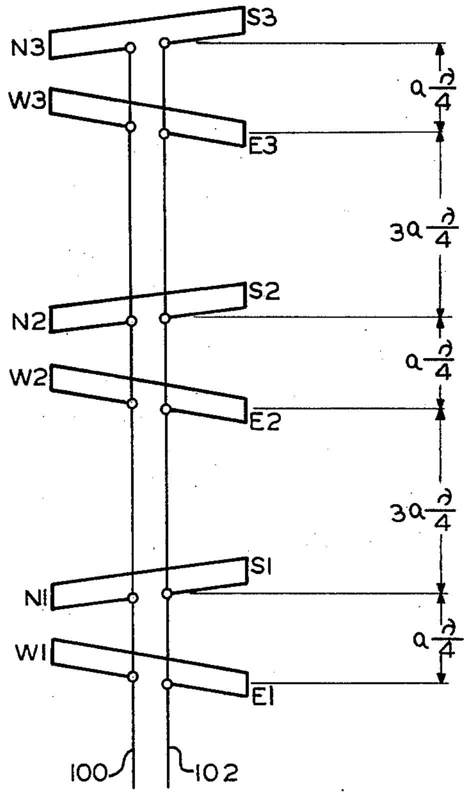
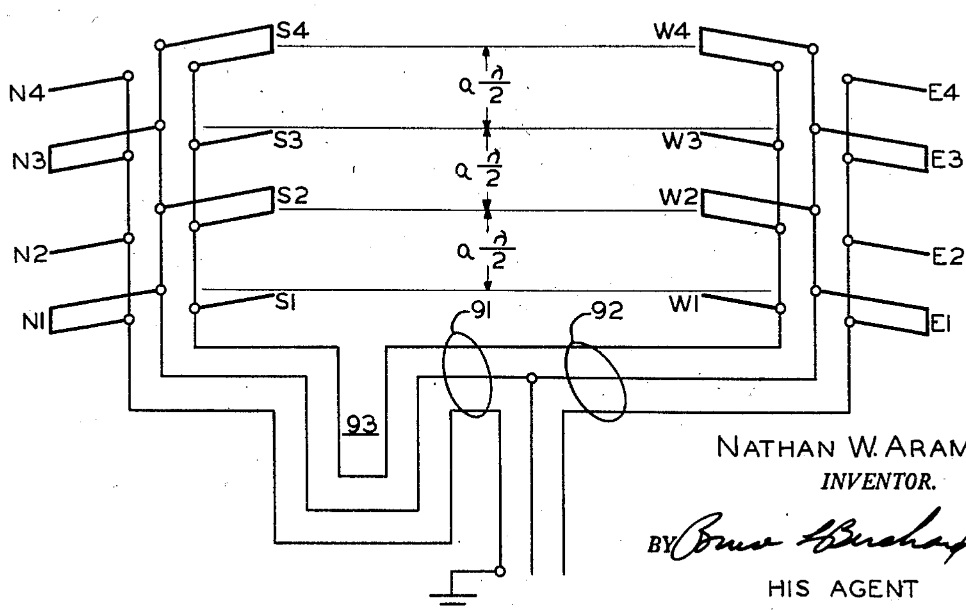


FIG.11



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Patented June 23, 1953

2,643,334

UNITED STATES PATENT OFFICE

2,643,334

TURNSTILE ANTENNA

Nathan W. Aram, Park Ridge, Ill., assignor to Zenith Radio Corporation, a corporation of Illinois

Application October 23, 1948, Serial No. 56,177

12 Claims. (Cl. 250—33.53)

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This invention relates to antennas and more particularly to antennas of the turnstile type. It is a primary object of the invention to provide a simplified and improved antenna of this type.

In the following description, it will be convenient to refer from time to time to specific groups of radiating elements. In general, in a turnstile antenna, the radiating elements are disposed in a pair of angularly displaced planes, the elements situated in each plane being referred to as a "panel" of radiating elements. Similarly, for convenience of reference, each pair of adjacent crossed elements will be termed a "bay."

In Patent No. 2,338,564 issued on January 4, 1944, to Nathan W. Aram for Turnstile Antenna, and assigned to the same assignee as the present application, there is disclosed and claimed as a preferred embodiment a turnstile antenna employing folded dipoles as radiating elements, each of such elements being arranged for connection to individual straight feeder lines disposed about the outer surface of a supporting mast.

It is a particular object of this invention to provide a simplified turnstile antenna requiring a minimum number of component parts.

It is an important object of this invention to provide a turnstile antenna having novel radiating elements arranged to reduce the number of requisite feeder lines.

It is a more specific object of the invention to provide a simplified turnstile antenna employing radiating elements adapted to unbalanced feeding, thereby to reduce the number of requisite feeder lines.

It is a further object of the invention to provide a simplified turnstile antenna having improved power gain characteristics.

Yet another object of the invention is to provide an improved turnstile antenna having improved power gain characteristics by virtue of optimum spacing between adjacent bays of radiating elements.

For a vertical panel of horizontal radiators to have maximum gain in the horizontal direction, the radiators are preferably excited by in-phase currents. If, as in conventional turnstile antennas, the radiating elements are vertically separated by a half-wavelength and are fed by transmission lines having a propagation velocity approximately equal to that of a free-space electromagnetic wave, transposition, as for example by means of half-wave phasing loops, is required

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to insure in-phase excitation of the radiating elements.

Still another object of the invention, therefore, is to provide a simplified turnstile antenna including an array of vertically spaced radiating elements exhibiting maximum gain in a horizontal direction without requiring the transposition of feeder lines.

It is a more specific object of the invention to eliminate the requirement for transposition of feeder lines to a turnstile antenna by utilizing loaded transmission lines to feed the successive radiating elements, the propagation velocity of such transmission lines bearing substantially the same ratio to the free-space propagation velocity as does the physical spacing between such radiators to a free-space wavelength.

In order to obtain an omnidirectional horizontal radiation pattern from a turnstile antenna comprising a plurality of radiating elements arranged in a pair of angularly displaced panels, it is necessary to provide quadrature phasing between the exciting currents of the two panels of radiating elements. Such quadrature phasing is normally obtained by the use of quarter wave phasing loops.

It is an important object of this invention to provide a further simplified turnstile antenna by eliminating the necessity for such quarter wave phasing loops.

Still another object of the invention is to provide an improved and simplified turnstile antenna in which quadrature phasing between panels is obtained by vertical separation of the radiating elements of each bay.

The features of this invention which are believed to be novel are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may best be understood, however, by reference to the following description taken in connection with the accompanying drawings, in which like reference numerals indicate like elements, and in which:

Figure 1 is a schematic representation of a novel radiating element embodying the present invention.

Figure 2 is a perspective view of an improved turnstile antenna embodying the novel element shown in Figure 1.

Figure 3 is a schematic representation of an approximate equivalent circuit for the antenna of Figure 2.

Figure 4 is a graphical representation of the power gain characteristic of an antenna such as that shown in Figure 2.

Figure 5 is a cross-sectional view of a feeder line which is suitable for use with the antenna of Figure 2.

Figure 6 is a sectional detail showing the manner in which the coaxial feeder line is connected to radiating elements other than the uppermost one.

Figure 7 is a sectional detail showing the manner in which the coaxial feeder line is connected to the uppermost radiating element.

Figures 8*a*, 8*b*, and 8*c* are schematic representations showing alternative embodiments.

Figures 9*a*, 9*b*, and 9*c* are graphical representations of the radiation patterns of the antenna of Figure 2.

Figure 10 is a schematic representation of a further embodiment of this invention.

Figure 11 is a schematic representation of still another embodiment of the invention.

Figure 12 is a schematic representation of still a further embodiment of the invention.

With reference to Figure 1, there is shown a novel radiating element **20** constructed in accordance with the present invention, such element comprising a pair of conductive members **21** and **22** interconnected by a U-shaped conductive member **23**, the length of member **22** being substantially twice that of **21** and being substantially a half wavelength or an odd integral multiple of a half wavelength at the frequency to be transmitted. The second conductive member **22** may be grounded at substantially its midpoint, thereby to adapt element **20** for direct unbalanced feeding. Radiating element **20** may be fed by a coaxial feeder line **24**, the inner conductor **25** of which is connected to the free end of first member **21** and the shield **26** of which is connected to the midpoint of member **22**.

Viewed in another way, the novel radiating element **20** comprises a quarter-wave folded dipole arm consisting of members **21** and **23** and half of member **22**, and a quarter-wave simple dipole arm collinear with and electrically connected to one leg of the folded dipole arm, such simple dipole arm comprising the other half of member **22**. Element **20** as shown may also be viewed as an unbalanced folded dipole from which the return bend of the short-circuited loop has been removed. It is contemplated that members **21**, **22**, and **23** may be either solid or tubular in construction.

It has been found that a radiating element of this type provides substantially the same radiation pattern as a simple half-wave radiator or folded dipole of conventional construction. It is thought that this desirable result is accomplished because of parasitic excitation of the simple dipole arm. In other words, provision of a perpendicular imaging plane or collinear imaging conductor apparently gives rise to series resonant radiating current components which, together with the anti-resonant radiating components from the loop comprising member **21**, member **23**, and half of member **22**, suffice to set up substantially the same field as that set up by a conventional folded dipole of the same overall length.

Element **20** of Figure 1 is particularly advantageous in that it is inherently unbalanced. Since a coaxial line is also essentially unbalanced, element **20** may be designed to preclude the possibility of any substantial balance-to-unbalance mismatch without the use of a balance-to-unbalance impedance transformer. For this reason, the number of required coaxial feeder lines and fittings may be substantially reduced from the number required when using a conventional balanced radiating element.

There is shown in Figure 2 an improved and simplified turnstile antenna embodying a plurality of radiating elements of the type shown and described in connection with Figure 1 and comprising a conductive mast **30** which is preferably grounded. Since the field strength existing at any given receiving point is proportional to the height of the transmitting antenna, the mast **30** is preferably located at the highest available position, as for example at the top of a skyscraper.

A turnstile antenna may comprise a plurality of bays of half-wave radiating elements supported on mast **30**, each bay comprising a pair of elements disposed at right angles to each other. All of the elements in each panel, that is, those having one direction (for example, north and south in one case, and east and west in the other case), are excited by in-phase currents. Moreover, the elements of one direction (north and south for example), are excited in phase quadrature with respect to the elements of the other direction (east and west for example). With this quadrature excitation, the radiation pattern is substantially omnidirectional. Radiation is concentrated toward the horizontal direction as a function of the number of bays of radiating elements.

While the antenna of Figure 2 has been shown comprising four bays of radiating elements, it is apparent that any number of bays may be employed. Furthermore, while the antenna arrangements described have been shown to be oriented in a vertical direction, it is to be noted that for certain purposes the mast and the antenna as a whole may be tilted from the vertical.

For convenience of reference, the various radiating elements are referred to in the drawings and in this specification as N2—S2, E3—W3, etc., the letter combination of each indicium designating the direction of the radiating element and the numeral denoting its position in the series of radiators, in its particular panel, referred to the bottom of the mast **30**. Similarly, it is convenient to refer to the individual portions of the radiating elements as **N2**, **E3**, **S4**, etc. It is noted, however, that this nomenclature is for ease of reference only; since the radiation pattern is substantially omnidirectional, the points of the compass to which the elements are directed are immaterial, and it is observed that the entire unit may be considered to be rotated by any desired amount without any substantial effect on the radiation pattern.

Thus it is noted that, in the embodiment of Figure 2, elements **N4—S4** and **E4**—W4, for example, constitute a bay, and elements N1—S1, N2—S2, N3—S3, and **N4—S4**, for example, constitute a panel.

In the Figure 2 embodiment of the invention, a single feeder line **31**, the construction of which is to be hereinafter described in detail, is employed to feed the radiating elements, the usual requirement for half-wave and quarter-wave phasing loops being eliminated. To this end, the radiating elements constituting each bay (N3—S3 and E3—W3, for example) are vertically separated by an amount

$$\frac{a\lambda}{4}$$

where a is the ratio at the operating frequency of the propagation velocity of feeder line 31 to the propaagtion velocity of free-space and λ is the free-space wavelength. Furthermore, adjacent elements in each of the mutually perpendicular panels are separated by an amount equal to $a\lambda$. In this manner, in-phase excitation of all elements in each panel is assured.

It is apparent that, while the vetrical separation between adjacent elements in each panel has been set forth as substantially $a\lambda$, any integral multiple of this value may be used. Similarly, the vertical separation between corresponding elements of the respective panels may be any odd integral multiple of

$$\frac{a\lambda}{4}$$

It may be desirable to choose such values of terminal impedances of the radiating elements and such characteristic impedance values for the various sections of the feeder line as to effect substantially equal power distribution between the radiating elements. There is shown in Figure 3, in schematic form, an approximate equivalent circuit for an antenna comprising a series of n radiating elements $R_1, R_2 \ldots R_n$ mutually displaced along a transmission line by distances x and y, where x and y are each equal to a quarter wavelength of the transmission line or any odd integral multiple thereof. For example, x may represent an electrical quarter wavelength of the transmission line

$$\left(\frac{a\lambda}{4}\right)$$

and y may represent an electrical three-quarters wavelength of the line

$$\left(3\frac{a\lambda}{4}\right)$$

in which case R_1 represents the terminal impedance of element N4—S4, R_2 represents the terminal impedance of element E4—W4, etc. (Figure 2).

For equal power distribution between the n radiating elements, the following condition has been found to obtain:

$$Z_0{}^2{}_{(m-1)}=\frac{1}{(m-1)^2}R_{(m-1)}R_{(m)} \qquad (1)$$

where R_m represents the resistive terminal impedance of any one of the elements, $Z_{0(M-1)}$ represents the characteristic impedance of the section of transmission line feeding the same element, and m is any integer from 2 to n.

There is shown in Figure 4 a graphical representation of power gain-vertical separation characteristics of typical turnstile antennas of differing number of bays. From the curves 40—43, it is apparent that increased power gain is obtainable by increasing the number of bays employed; furthermore, for any given number of bays, there is an optimum separation between bays for which spacing maximum power gain is obtained. The increased power gain at spacings greater than one-half wavelength is due to the effect of the mutual impedances whereby the resistive component of terminal impedance of the individual radiating element is reduced, permitting larger current per unit power. As an incident advantage, it is found that the reactive components of the mutual impedances, which must be compensated for by adjustment of the terminal impedances of the radiating elements, are substantially less at optimum spacing than at the conventional halfwave spacing. Thus, an optimum spacing curve 44, connecting the maxima of the power gain characteristics 40—43, may be drawn. It is then apparent that an optimum power gain of about 3.4 is obtainable with a four-bay turnstile antenna having a spacing between adjacent elements in each panel of about 0.78λ. Optimum spacing varies from about 0.68λ for a two-bay antenna to about 0.84λ for an eight-bay antenna.

Referring again to the antenna of Figure 2, and recalling that optimum spacing for a four-bay antenna is 0.78λ, adjacent elements in each panel (N3—S3 and N4—S4, for example) are vertically separated by about 0.78λ, and the coaxial feeder line 31 is designed, in a manner to be hereinafter more fully described, to have a propagation velocity equal to 0.78 of that of free space. In this manner, optimum power gain is obtained while minimizing the required number of line fittings and eliminating the necessity for phasing loops.

Figure 5 shows a cross-sectional view of a coaxial line suitable for use as a feeder 31 in an antenna such as that shown and described in connection with Figure 2. The feeder line comprises an inner conductor 50 coaxially supported within an outer conductor 51 by means of a number of dielectric beads or spacers 52. Such a beaded coaxial line may be designed for any propagation velocity ratio within a wide range as follows:

For bead spacing s substantially less than a quarter-wavelength, the propagation velocity is inversely proportional to the square root of the average dielectric constant. It has been determined that cylindrical beads determine the propagation velocity of an air-dielectric coaxial line in accordance with the following equation:

$$a=\frac{1}{\sqrt{1+(k-1)\,d/s}} \qquad (2)$$

where a is the ratio of line to free-space propagation velocities, k is the bead dielectric constant, d is the bead thickness, and s is the bead spacing. The ratio d/s is the fraction of the dielectric volume occupied by the beads, which fraction may be used in an approximate solution for a when beads of non-cylindrical form are used.

Thus, if a velocity ratio a of 0.75 is required, the ratio of bead thickness to spacing is $d/s=0.156$ for a ceramic bead having a dielectric constant k of 6.

The transmission line surge impedance is reduced by the beads in the same ratio as the propagation velocity. That is,

$$\frac{Z_0'}{Z_0}=a \qquad (3)$$

where Z_0 is the surge impedance of a line constructed without beads and Z_0' is the surge impedance of the beaded line. A larger conductor-diameter ratio must be used to obtain a given surge impedance in the presence of insulating beads, the required ratio being:

$$\frac{d_1}{d_2}=\text{antilog}_{10}\frac{Z_0'}{138a} \qquad (4)$$

where d_1 is the inner diameter of the outer conductor and d_2 is the outer diameter of the inner conductor.

There is shown in Figure 6 a fitting 60 suitable for electrically connecting the individual radiating elements to the feeder line 31. Fitting

60 comprises a dielectric bushing 61 through which the radiating element 62 is connected to the feeder line. Element 62 corresponds to leg 21 of element 20 of Figure 1. For the uppermost radiating element (N4—S4 of Figure 2, for example) a fitting 63 such as that shown in Figure 7, which also comprises a dielectric bushing 64 through which the radiating element 65 is connected to the feeder line 31, may be employed.

While the antenna of Figure 2 has been shown comprising a single feeder line, it is apparent that in some applications it may be desirable to employ a pair of feeder lines rising from a common junction. In such an embodiment, the feeder lines may be disposed about the outer surface of the supporting mast 30, as shown in Figure 8, and the radiating elements constituting each bay may be oriented in any of three ways as shown in Figures 8*a*, 8*b*, and 8*c*. If optimum spacing is employed between bays and the necessity for transposition is eliminated by the use of a properly loaded line, all bays would employ the same orientation, i. e. any one of the orientations illustrated in Figures 8*a*, 8*b*, and 8*c*, depending on which is most convenient.

There are shown in Figure 9 in simplified schematic form several diagrams representing the horizontal radiation patterns for an antenna such as that shown in Figure 2 for different angles of elevation from the horizontal. In the horizontal plane including the center of the antennna array, the respective elements constituting a bay (N3—S4 and E3—W3 of Figure 2, for example) are equally distant from a remote receiving point (not shown). Therefore, the signal components from these elements have the same quadrature relationship which they would possess if elements N3—S3 and E3—W3 were coplanar and phased by means of a looped quarter-wave line. Such a radiation pattern (for the horizontal direction, zero angle of elevation) is shown schematically in Figure 9*a*, and is substantially omnidirectional.

For a 90° angle of elevation (i. e., in the vertical direction) the horizontal radiation pattern for a turnstile antenna such as that shown in Figure 2 is approximately of the form of figure-eight with its axis rotated 45° from the axis of either radiating element. Such a radiation pattern is shown schematically in Figure 9*b*.

At angles of elevation intermediate 0° and 90°, the horizontal pattern is intermediate the pattern shown in Figures 9*a* and 9*b*; for example, there is shown in Figure 9*c* a schematic representation of the horizontal radiation pattern for an angle of elevation of 45°.

In practice, the deviation of the radiation pattern from its substantially omnidirectional form as the angle of elevation is increased is of little or no consequence, since normal radiation and normal gain are obtained in the horizontal direction.

In certain applications, it may be desirable to employ additional radiating elements; such additional radiating elements may be added to the antenna represented in Figure 2 in the manner illustrated schematically in Figure 10. In such an embodiment, the vertical separation between adjacent elements is always

$$\frac{a\lambda}{4}$$

and each element is advanced 90° in azimuth from the preceding element. A single coaxial feeder line has its inner conductor 80 connected to each of the radiating elements. The outer conductor 81 is connected to each simple dipole arm and to one end of each folded dipole arm and is grounded.

In lieu of mutually displacing the radiating elements constituting each bay, they may be oriented in the same horizontal plane and fed by individual feeders which are excited in phase quadrature. Such an embodiment is shown schematically in Figure 11, in which four bays of radiating elements are shown. Adjacent elements in each panel (N4—S4 and N3—S3, for example) are displaced 180° in azimuth to provide the required transposition. A pair of feeder lines 91 and 92 are employed; all elements in each panel are connected to the same feeder line, and the respective elements constituting each bay are connected to different feeder lines. Feeder lines 91 and 92 may be paralleled at the base of the antenna. A quarter-wave phasing loop 93 is connected in series with one of the lines (here shown in series with line 91) in order to provide quadrature excitation of the respective elements constituting each bay.

The use of a coaxial line having a propagation velocity which is related to the free-space propagation velocity in the same ratio as is the physical spacing between radiating elements to a free-space wave-length may be also employed in antennas utilizing conventional radiating elements, such as those of the folded dipole type. There is shown in schematic form in Figure 12 such an antenna, which is substantially identical with the embodiment of Figure 2 with the exception that folded dipole radiating elements are used, and balanced feeding is required. As shown, the respective ends of each folded dipole are connected to one of a pair of coaxial feeder lines 100 and 101. Adjacent elements (N3—S3 and N2—S2 for example) in each panel are separated by an amount substantially equal to the ratio of the propagation velocity of the feeder line to that of free-space multiplied by a free-space wavelength.

While the invention has been described in connection with an antenna embodying a plurality of radiating elements, it is contemplated that, in view of the well-known reciprocal relations existing between transmitting and receiving antenna elements, the radiating elements disclosed and claimed herein may be utilized either for the transmission or reception of high frequency energy. Furthermore, although the invention has been particularly described in connection with turnstile antennas, it is contemplated that the invention may also be applied to broadside arrays incorporating only one panel of radiating elements.

While the invention has been shown and described in connection with certain preferred embodiments, it is to be understood that numerous modifications and variations may be made, and it is contemplated in the appended claims to cover all such modifications and variations as fall within the true spirit and scope of the invention.

I claim:

1. An antenna including, in combination: a grounded conductive mast; a coaxial transmission line feeder disposed within said mast; an unbalanced dipole radiating element comprising a folded dipole arm and a simple dipole arm collinear with and electrically connected to one leg of said folded dipole arm; a connection from the inner conductor of said feeder to the unconnected leg of said folded dipole arm; and a

connection from the junction of said folded dipole arm and said simple dipole arm to said grounded mast and to the outer conductor of said feeder.

2. An antenna comprising, in combination: a plurality of vertically separated radiating elements each of which comprises a folded dipole arm and a simple dipole arm collinear with and electrically connected to one leg of said folded dipole arm; and a loaded transmission line feeder interconnecting said elements and having a propagation velocity materially less than that of free space; the ratio of the physical separation between adjacent elements to a free-space wavelength being substantially equal to an integral multiple of the ratio of the propagation velocity of said feeder line to the propagation velocity of free space.

3. An antenna for radiating high frequency energy into space, and including, in combination: a grounded conductive mast; a plurality of unbalanced radiating elements supported on said mast in a pair of mutually perpendicular panels; a coaxial feeder line disposed within said mast and interconnecting said elements; the separation in each panel between adjacent elements being substantially an integral multiple of the ratio of the propagation velocity of said feeder line to the propagation velocity of free space multiplied by a free-space wavelength, and corresponding elements of said panels being displaced with respect to each other by substantially an odd integral multiple of said propagation velocity ratio multiplied by a free-space quarter-wavelength.

4. A turnstile antenna comprising, in combination: a plurality of spaced radiating elements disposed in each of a pair of vertical panels and each comprising a folded dipole arm and a simple dipole arm collinear with and electrically connected to one leg of said folded dipole arm; and a feeder line interconnecting said elements, the ratio of the physical separation between adjacent elements in each of said panels to a free-space wavelength being substantially equal to an integral multiple of the ratio of the propagation velocity of said feeder line to the propagation velocity of free-space, and corresponding elements of said panels being displaced with respect to each other by a distance substantially equal to an odd integral multiplied by a free-space quarter-wavelength.

5. A turnstile antenna comprising, in combination: a plurality of spaced radiating elements disposed in each of a pair of mutually perpendicular vertical panels and each element comprising a folded dipole arm and a single dipole arm collinear with and electrically connected with one leg of said folded dipole arm; and a feeder line interconnecting said elements, the ratio of the physical separation between adjacent elements in each of said panels to a free-space wavelength being substantially equal to an integral multiple of the ratio of the propagation velocity of said feeder line to the propagation velocity of free space, and corresponding elements of said panels being displaced with respect to each other by a distance substantially equal to an odd integral multiple of said propagation velocity ratio multiplied by a free-space quarter-wavelength.

6. A turnstile antenna comprising, in combination: a plurality of spaced radiating elements supported on a conductive mast in each of a pair of vertical panels and each comprising a folded dipole arm and a simple dipole arm collinear with and electrically connected to one leg of said folded dipole arm; and a coaxial feeder line interconnecting said elements, the separation between adjacent elements in each panel being substantially

$$c a \lambda$$

and the separation between corresponding elements of said panels being substantially

$$(2n+1)\frac{a\lambda}{4}$$

where c and n are integers, a is the ratio of the propagation velocity of said feeder line to the propagation velocity of free-space, and λ is a free-space wavelength.

7. A turnstile antenna comprising, in combination: a plurality of spaced radiating elements supported on a conductive mast in each of a pair of vertical panels and each comprising a folded dipole arm and a simple dipole arm collinear with and electrically connected to one leg of said folded dipole arm; and a coaxial feeder line interconnecting said elements, the separation between adjacent elements in each panel being substantially

$$c a \lambda$$

and the separation between corresponding elements of said panels being substantially

$$(2n+1)\frac{a\lambda}{4}$$

where c and n are integers, a is the ratio of the propagation velocity of said feeder line to the propagation velocity of free-space, and λ is a free-space wavelength; and the terminal impedances of said elements and the characteristic impedances of the feeder line portions between adjacent elements being chosen substantially in accordance with the formula

$$Z_{0\,(m-1)}^2 = \frac{1}{(m-1)^2} R_{(m-1)} R_m$$

where R_m is the resistive terminal impedance of any one of said elements, $Z_{0(m-1)}$ is the characteristic impedance of the section of said feeder line feeding the same element, and m is any integer from 2 to n.

8. A turnstile antenna comprising, in combination: a pair of crossed panels of radiating elements each of which comprises a directly excited folded dipole arm and a parasitically excited simple dipole arm collinear with and electrically connected to one leg of said folded dipole arm; a first feeder line interconnecting all of the elements of one of said panels; a second feeder line interconnecting all of the elements of the other of said panels; and means for exciting said feeder lines in phase quadrature.

9. A turnstile antenna comprising, in combination: a pair of crossed panels of radiating elements each of which comprises a folded dipole arm and a simple dipole arm collinear with and electrically connected to one leg of said folded dipole arm; a first loaded transmission line feeder interconnecting all of the elements of one of said panels and having a propagation velocity materially less than that of free space; a second loaded transmission line feeder interconnecting all of the elements of the other of said panels and having a propagation velocity substantially equal to that of said first feeder; and means for exciting said feeder lines in phase quadrature, the ratio of physical separation between adjacent elements in each of said panels to a free-space

wavelength being substantially equal to an integral multiple of the ratio of the propagation velocity of said feeder lines to the propagation velocity of free space.

10. An unbalanced dipole radiating element comprising: a folded dipole arm; a simple dipole arm substantially collinear with and electrically connected to one leg of said folded dipole arm; and means, including a transmission line feeder connected to the other leg of said folded dipole arm, for directly exciting said folded dipole arm only.

11. An unbalanced dipole radiating element comprising: a folded dipole arm; a simple dipole arm substantially collinear with and electrically connected to one leg of said folded dipole arm; said simple dipole arm being of substantially the same length as said folded dipole arm; and means, including a transmission line feeder connected to the other leg of said folded dipole arm, for directly exciting said folded dipole arm only.

12. A half-wave unbalanced dipole radiating element comprising: a quarter-wavelength folded

dipole arm; a quarter-wavelength simple dipole arm substantially collinear with and electrically connected to one leg of said folded dipole arm; and means, including a transmission line feeder connected to the other leg of said folded dipole arm, for directly exciting said folded dipole arm only.

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