NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO. 14
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

Feb. 26, 1963 R. H. DU HAMEL ET AL 3,079,602

LOGARITHMICALLY PERIODIC ROD ANTENNA

Filed March 14, 1958 9 Sheets-Sheet 1

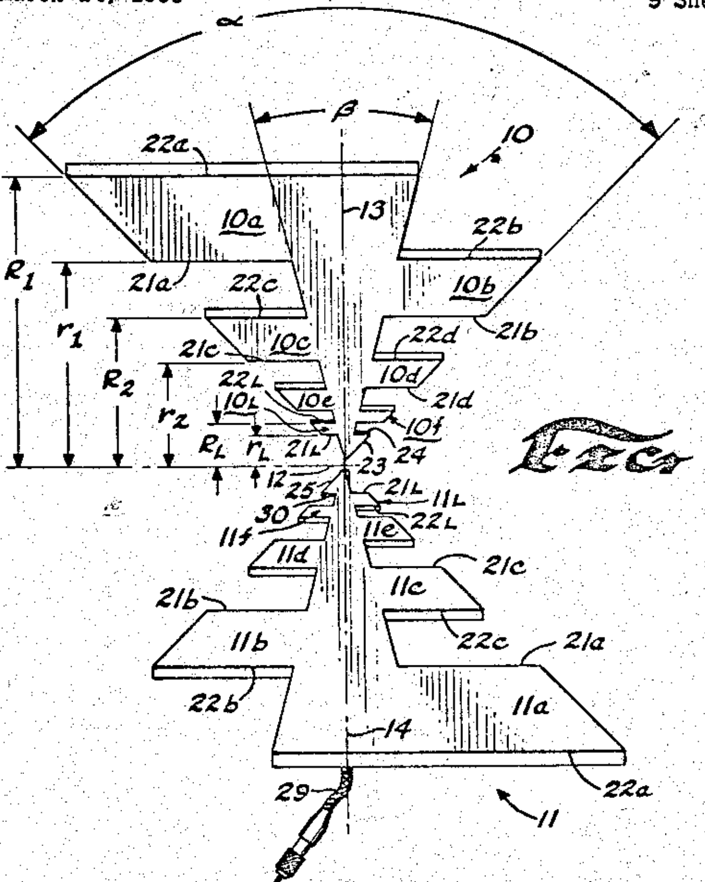

FIG. 1

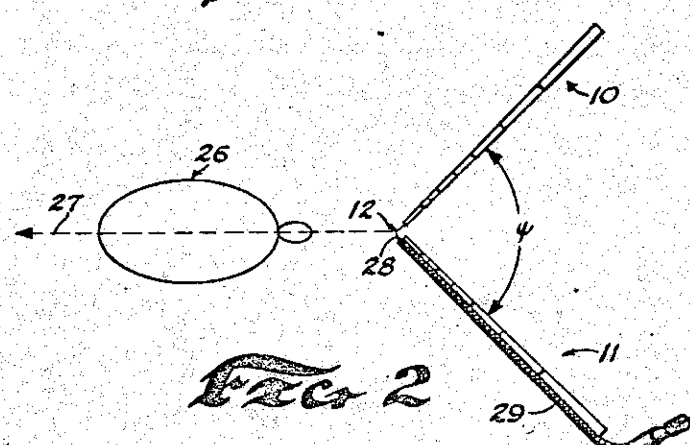

FIG. 2

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LOGARITHMICALLY PERIODIC ROD ANTENNA

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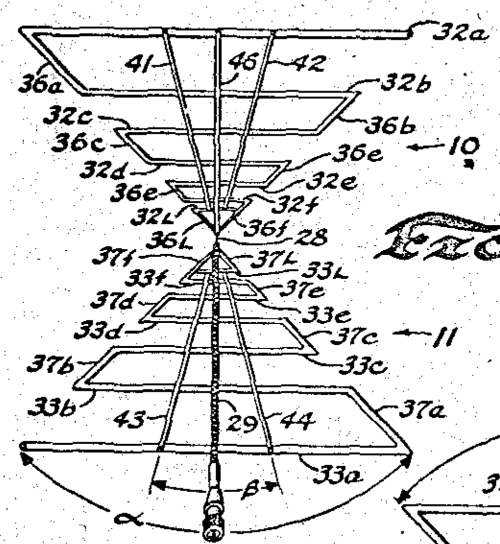

FIG. 3

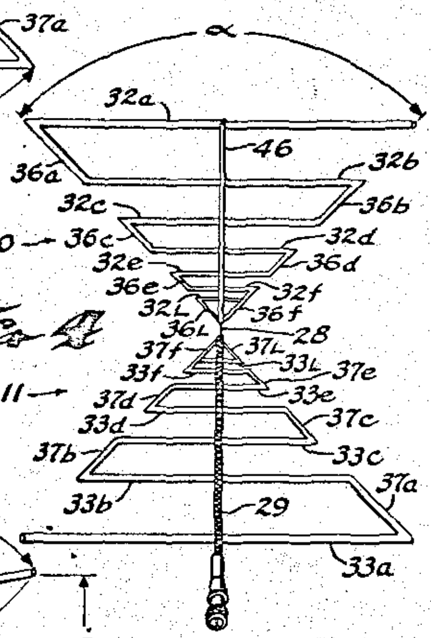

FIG. 4

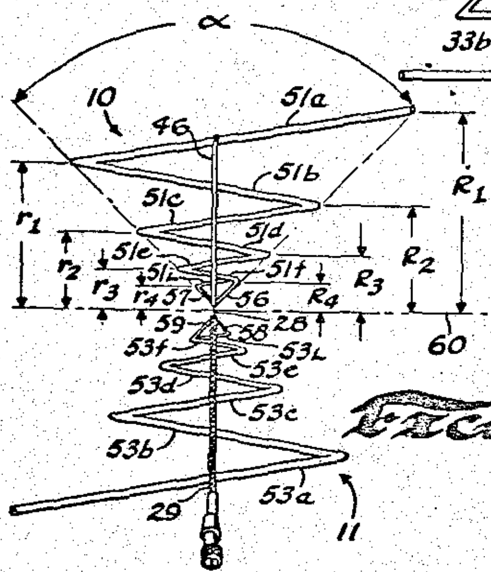

FIG. 5

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LOGARITHMICALLY PERIODIC ROD ANTENNA

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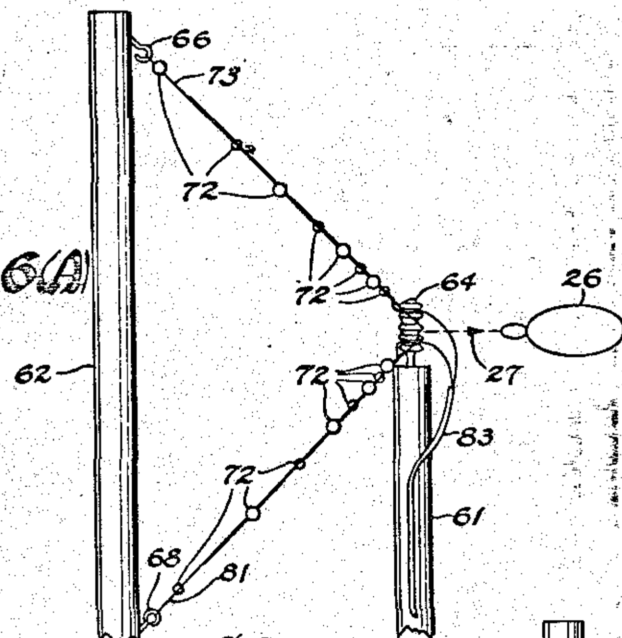

FIG. 6(A)

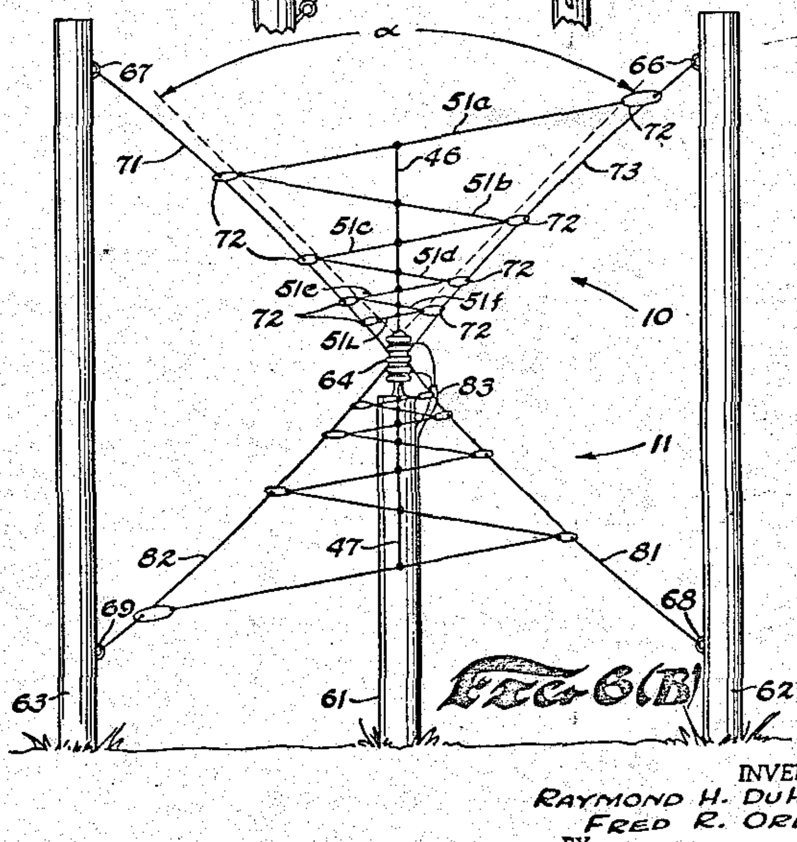

FIG. 6(B)

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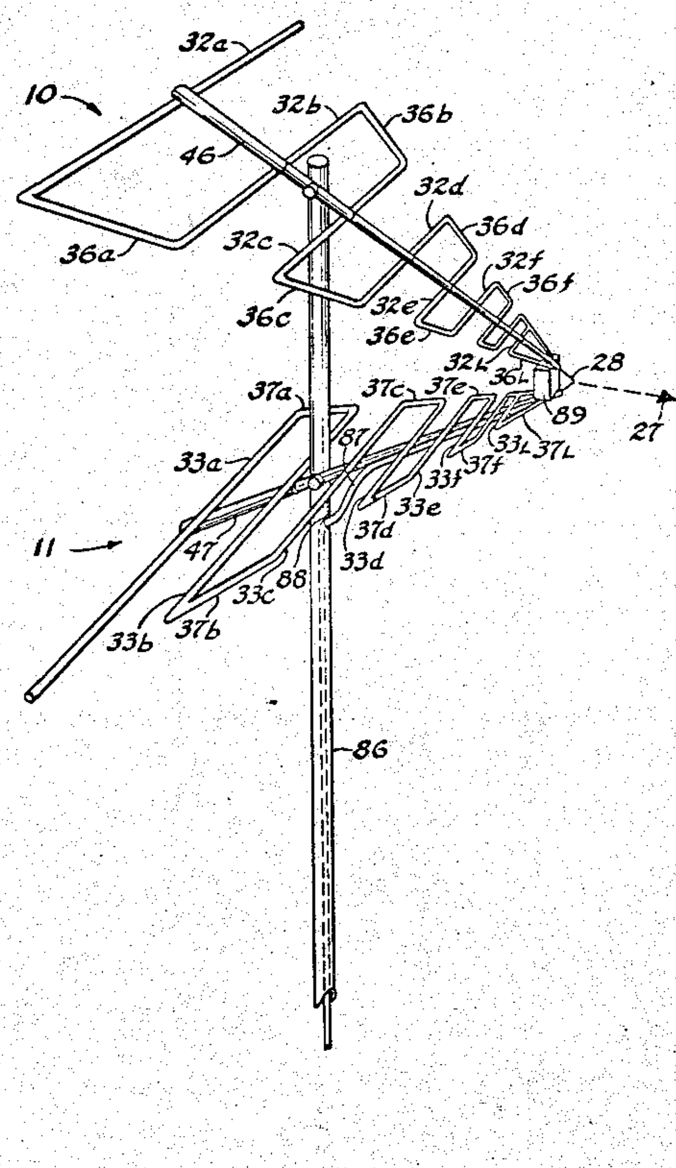
FIG. 7



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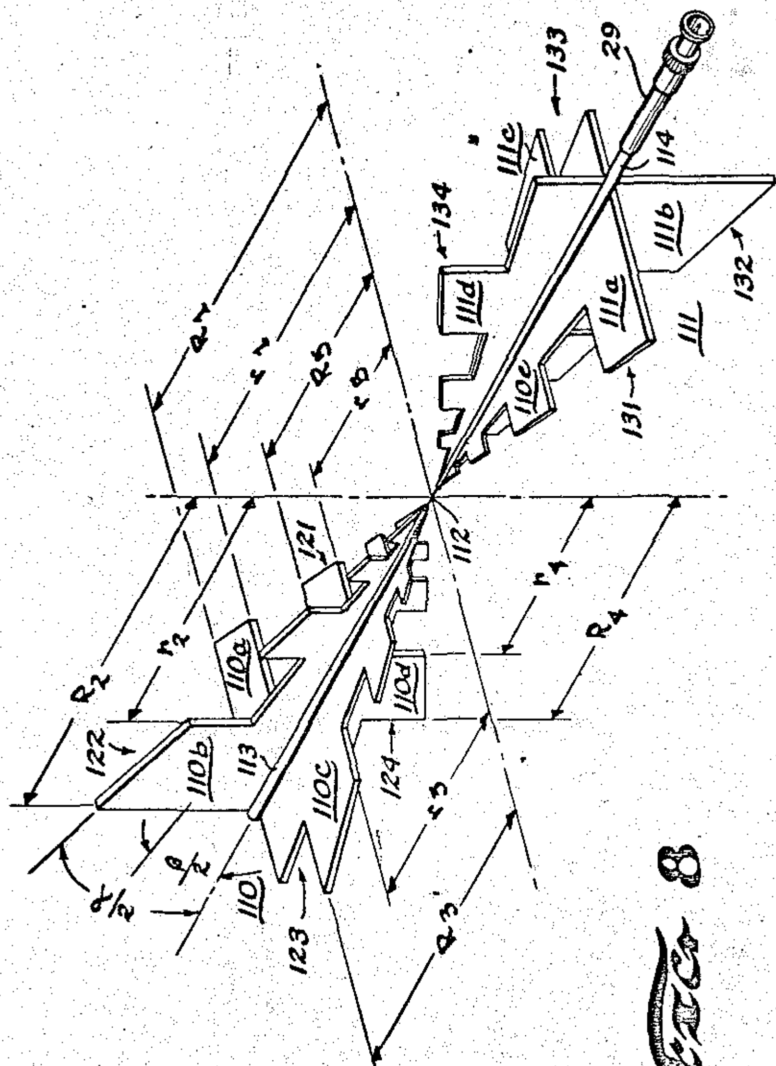

FIG. 8

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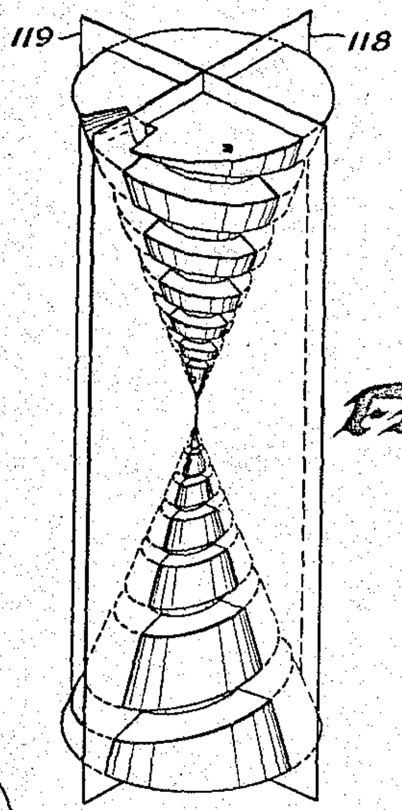

FIG. 9

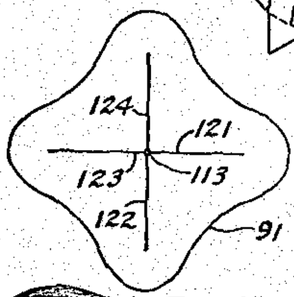

FIG. 10(A)

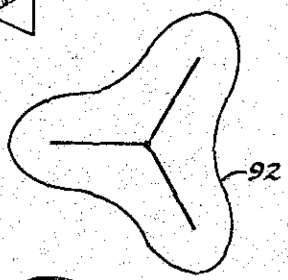

FIG. 10(B)

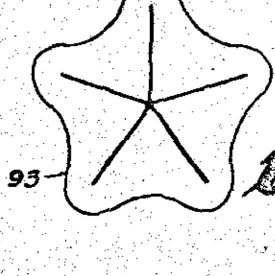

FIG. 10(C)

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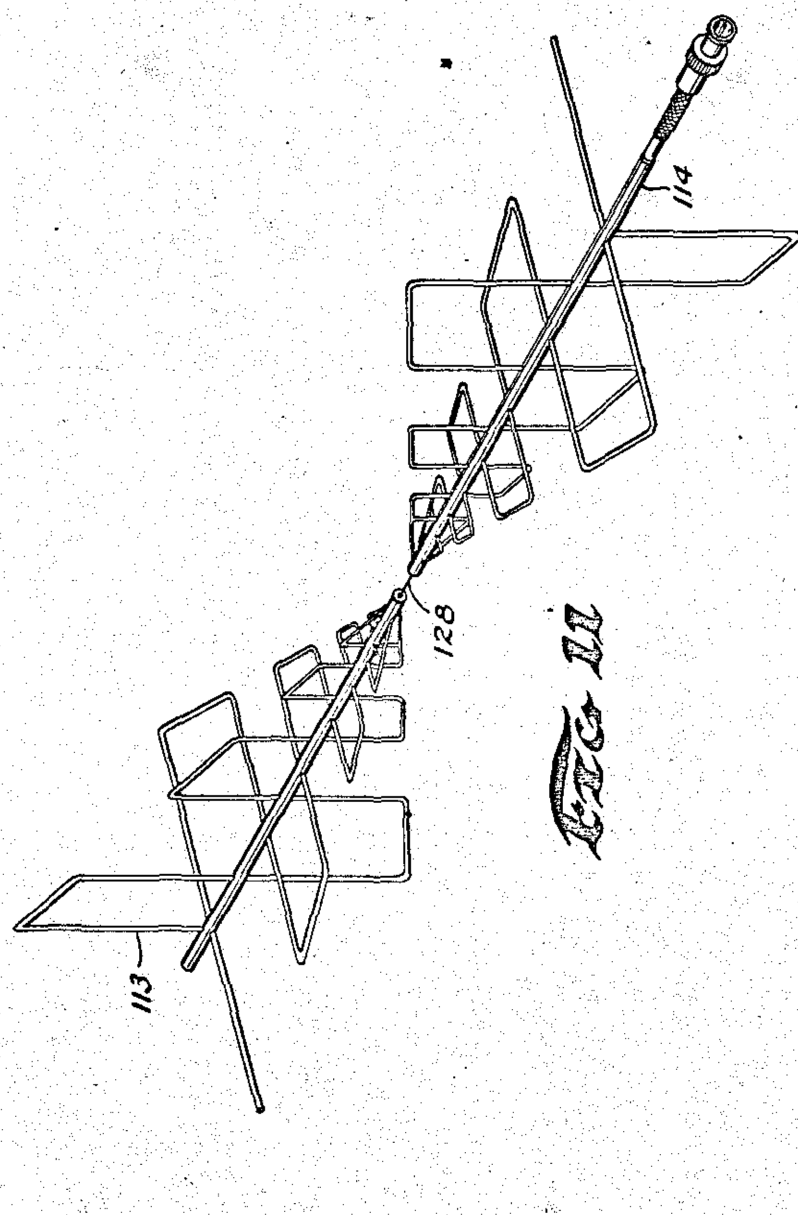

FIG. 11

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LOGARITHMICALLY PERIODIC ROD ANTENNA

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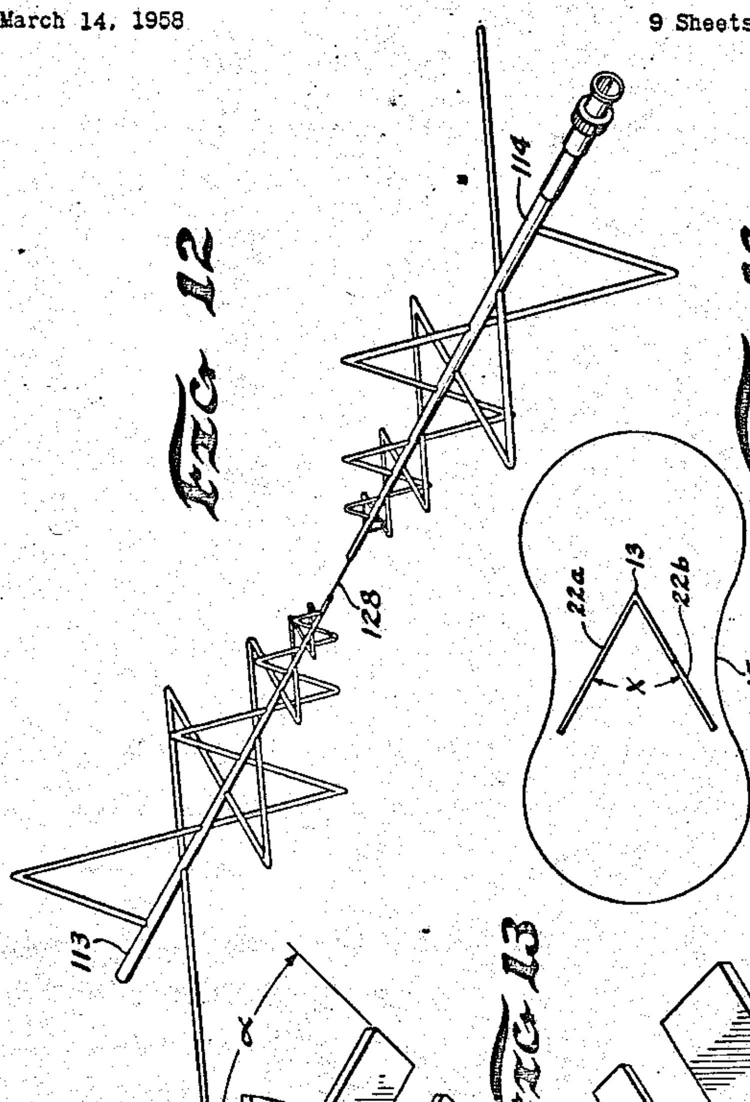

FIG. 12

FIG. 16

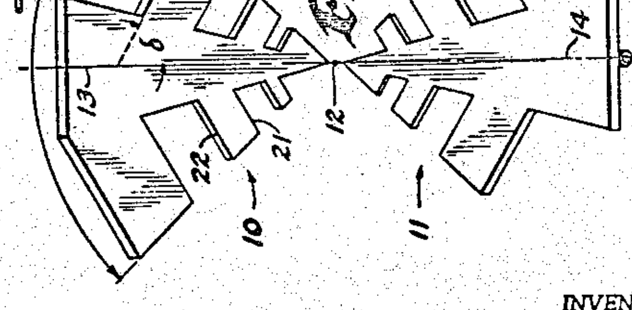

FIG. 13

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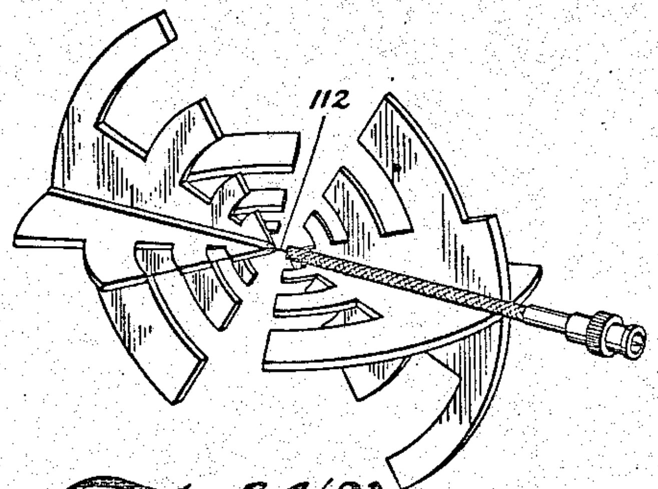

FIG. 14(A)

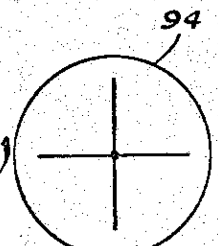

FIG. 14(B)

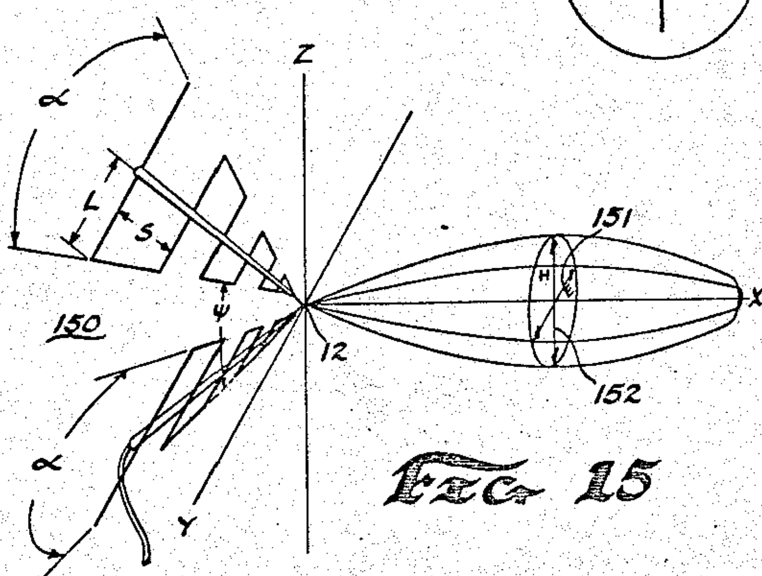

FIG. 15

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United States Patent Office

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Patented Feb. 26, 1963

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3,079,602

LOGARITHMICALLY PERIODIC ROD ANTENNA

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Filed Mar. 14, 1958, Ser. No. 721,408
14 Claims. (Cl. 343—908)

This invention relates to antennas of a type that can be described as logarithmically periodic, since their structure is repetitive in a logarithmic manner. Such antennas are particularly useful because they are capable of maintaining substantially-fixed radiation patterns and input impedances over a very broad frequency range, which may be greater than ten-to-one.

The general subject of such antennas is treated in a paper by R. H. DuHamel and D. E. Isbell, titled "Broadband Logarithmically Periodic Antenna Structures" and is found in the 1957 I.R.E. National Convention Record, Part I, of the group on Antennas and Propagation, Microwave Theory and Techniques. This article is only concerned with planar logarithmically periodic antennas which comply with the complementary principle when they are infinitely extended. The complementary principle requires that the same form be obtained when the antenna structure is interchanged with the planar space surrounding it. That is, the complementary principle requires that when an antenna and its complement are added together a complete infinite screen is obtained. In many situations, if an antenna has a complementary shape, it may be rotated by 90° about its center, and it will fill the area previously existing between its elements. If an antenna is identical to its principle it has a constant impedance of 60π ohms which is independent of frequency. This is explained in an article by V. H. Rumsey titled "Frequency Independent Antenna" found in the same I.R.E. records as the first-mentioned article. It was previously believed that the complementary principle must be adhered to in order to obtain a constant antenna input impedance independent of frequency.

The present invention deviates from the complementary principle in several ways and yet is able to maintain a radiation pattern and input impedance that are very nearly independent of frequency over a very broad range. For example, antenna structures made according to this invention need not lie in a single plane, which is a requirement of the complementary principle. Furthermore, when a form of the invention is made to lie in a single plane, it need not satisfy the complementary principle. The invention teaches how a logarithmically periodic antenna structure can be made entirely with a straight-lined configuration.

The invention provides a structure that is logarithmically periodic from a given vertex point. As a consequence, similar portions of the antenna repeat with a geometric-progression relationship as a function of their distance from the vertex. Transverse construction lines in the invention can be made linear to permit substantial structural simplifications, particularly for large sized antennas to extend their range to relatively low frequencies.

Some of the objects of this invention are the following:

To provide an antenna which maintains the same radiation pattern throughout an extremely large operating frequency range;

To provide an antenna which maintains a very-nearly constant input impedance over an extremely large frequency range;

To provide a logarithmically periodic antenna with a radiation pattern that can be made omnidirectional;

To provide a logarithmically periodic antenna with a radiation pattern that is controllably asymmetric;

To provide logarithmically periodic antennas having structural simplicity, while permitting frequency independence of radiation pattern and input frequency over extremely broad frequency ranges; and

To provide a logarithmically periodic antenna which can be entirely made of straight-lined structure, capable of easy fabrication from wire or rods.

Further objects, features and advantages of the invention will become apparent to a person skilled in the art upon further study of the specification and accompanying drawings, in which:

FIGURE 1 illustrates an elevational view of one form of the invention;

FIGURE 2 shows a side view and radiation pattern;

FIGURES 3, 4, 5, 6(A), 6(B) and 7 represent other forms of the invention;

FIGURE 8 is a perspective of a three-dimensional form of the invention;

FIGURE 9 illustrates a conical development of the three-dimensional form in FIGURE 8;

FIGURES 10(A), (B) and (C) show end views of various forms of the invention with their radiation patterns;

FIGURES 11 and 12 show perspectives of other three-dimensional forms of the invention;

FIGURE 13 provides a modification of the invention;

FIGURES 14(A) and (B) respectively illustrate a rounded-tooth three-dimensional form, and its end view and radiation pattern;

FIGURE 15 represents a radiation pattern; and

FIGURE 16 shows an end view of a center-line folded antenna.

Now referring to detailed forms of the invention, FIGURE 1 is first considered. It shows a back-elevational view of an antenna made from a pair of metal sheets having a thickness that tapers toward a terminal point 12. FIGURE 2 shows a side view of the same antenna and orients the position of point 12, which is a reference point for the system but has no structural existence. The antenna includes half-portions 10 and 11 which are generally triangular in shape and have respective vertexes adjacent to point 12. Each half-portion 10 or 11 encompasses an angle α which is bisected by a center line 13 or 14, respectively, passing down their center. However, it is to be noted that neither half-portion 10 nor 11 is symmetrical about its center line.

Each half-portion 10 or 11 has transverse teeth extending on opposite sides of an inner triangular-shaped segment that is defined by an angle β. Angle β is symmetrically placed within angle α.

The two planes of half-portions 10 and 11 are oriented apart by an angle ψ, which can vary from 180° to 0°. increasing angle ψ beyond 180° causes it to repeat.

A plurality of teeth 10*a*, 10*b* through 10L are formed on half-portion 10; and a similar plurality of teeth 11*a*, 11*b* through 11L are formed on half-portion 11. In FIGURE 1, each of the teeth is trapezoidal in form when its transverse parallel sides are extended to meet center-line 13 or 14; and the parallel sides are perpendicular to their center-line. The teeth vary in size and spacing in a logarithmically periodic manner from terminal point 12. Thus, each tooth has parallel sides 21 and 22 with outer side 22 being the more distant of the two from point 12. Each tooth is bounded on its remaining two sides by lines defining angles α and β.

The location and size of the set of teeth of half-portion 10 on the left side of its center line 13 will first be defined. The location and size of the remaining teeth of the antenna can then be defined in terms of this set of teeth. The distances along center line 13 between point 12 and the outer sides 22 of alternate teeth 10*a*, 10*c* through 10L are represented by distances R_1, R_2 through R_L. Any two consecutive values of R are R_N and R_{N+1}, with the latter being the smaller distance. Similarly, r_1, r_2 through r_L represent distances of the inner sides of the same teeth from point 12; and of any consecutive pair of r are r_N and r_{N+1}, with the latter being the smaller distance. They are defined by the following expression:

$$\tau=\frac{R_{N+1}}{R_N}=\frac{r_{N+1}}{r_N} \quad (1)$$

where τ is a constant less than one, which is fixed for a given antenna design.

Expression 1 positions the teeth with respect to each other along the center-line but does not specify the width of the teeth. The width of any tooth of the set is the difference between R_n and r_n, which are related by the following expression:

$$\sigma=\frac{r_N}{R_N} \quad (2)$$

where σ is constant for a given antenna design.

Consequently, expression 2 completes the general definition of the set of teeth on the left side of center-line 13 in FIGURE 1.

The remaining teeth of antenna half-portion 10 can then be defined, because the teeth on the right-hand side of center-line 13 have their sides 22 and 21 aligned with the defined sides 21 and 22 respectively of the left-hand side, with the teeth on the right-hand side aligning with spaces between teeth on the left-hand side.

Furthermore, the teeth on the opposite antenna half-portion 11 are also thereby defined, because half-portions 10 and 11 are identically shaped. Thus, in FIGURE 1 the teeth on the right-hand side of portion 11 correspond to the teeth on the left-hand side of portion 10. Likewise, the teeth on the left-hand side of portion 11 correspond to the teeth on the right-hand side of portion 10.

Although the half-portions 10 and 11 are constructed in the same manner, they are positioned unsymmetrically with respect to each other in the sense that one is not the image of the other. This prevents the same antenna response from being obtained by positioning a single half-portion over a ground-plane that bisects angle ψ.

Expressions 1 and 2 determine a geometric-ratio sequence for tooth sizing and for tooth spacing. However, they permit different geometric-sequencies having the same geometric-ratio to define distances to inner and outer sides of a tooth, respectively. A particularly useful special case occurs when the teeth are similarly proportioned on opposite sides; and this is obtained when

$$\sigma=\sqrt{\tau} \quad (3)$$

When angle ψ is less than 180°, an asymmetrical radiation pattern 26 shown in FIGURE 2 is obtained, with the major lobe pointing in the direction of arrow 27. The primary polarization of the radiation is parallel to teeth sides 21 and 22. A secondary transverse polarization is also obtained, which is small and can be controlled. The radiation pattern is discussed below in more detail.

Theoretically, an infinite bandwidth from zero to infinite cycles-per-second can be obtained for the antenna by making each half-portion infinitely long, wherein the teeth become infinitely small as vertex 12 is approached and infinitely large in the opposite direction. In practice, finite dimensions are mandatory, and a finite number of teeth must be used. Thus, the bandwidth is then no longer infinite, but nevertheless, extremely large bandwidths can still be obtained. The number of teeth used in the given antenna is therefore somewhat arbitrary, although generally speaking more than two teeth must be used to obtain a structure which is logarithmically periodic. In each case, there is a practical limit to the size of the largest tooth, and the smallest tooth also has its limit. Thus, in antenna half-portion 10 in FIGURE 1, tooth 10L is the

smallest, and tooth 10a is the largest. Accordingly, the small triangular part 23 of half-portion 10 near vertex 12 has no teeth, due to the practical difficulties in making very small teeth. However, the outer side 24 of triangular portion 23 performs like the outer side 22 of a tooth, and it acts electrically like the smallest tooth of the antenna.

Half-portion 11 similarly has a small triangular portion 25 with an outer side 30 that corresponds to triangular part 23 and its outer side 24, respectively.

Structurally, the size of the largest and smallest teeth determine the lowest and highest frequency limits, respectively, of the range.

The high-frequency limit of the frequency independent range is reached when the length of smallest side 24 or 25 from the center-line to its α-boundary becomes about one-tenth of a wavelength of the radiated frequency.

On the other hand, the low frequency limit of the range is determined when the length of the largest side 22a, measured from center-line 13 to its α-boundary, is approximately one-quarter wavelength.

Although the frequency limits are determined by the sizes of the largest and smallest teeth in the structure, it is by no means to be implied that radiation occurs only from these teeth at the respective frequency limits. Rather, radiation at all times occurs from several of the teeth in varying degrees in a complex manner.

Ideally, the sheets of metal from which each of the antenna half-portions 10 and 11 is made have tapered thickness as explained above. In practice, however, it has been found that stepped thickness can be used to the same effect, and further that uniform thickness can be used without substantially inhibiting the operation of the antenna for very large bandwidths of the order of five-to-one.

The antenna of FIGURE 1 can be fed by means of either a balanced or an unbalanced line, but special precautions must be taken to prevent the line from interfering with the radiation pattern. An unbalanced line, coaxial cable 29, is used in FIGURES 1 and 2. In order to prevent it from interfering with the radiation pattern, it is brought along the solid triangular portion within angle β, with the outer conductor making contact therewith, and it terminates at the apex of half-portion 11. Its inner conductor 28 extends from the end of coaxial line 29 across the space between the apexes of the half-portions, and connects to the apex of half-portion 10. Outer conductor 29 is not at ground potential along half-portion 11 but varies in a manner that automatically transduces the unbalanced-line impedance to a balanced impedance connection for the antenna without unbalancing the antenna pattern. The near-zone electro-magnetic fields associated with the antenna decrease rapidly as extremity 22a is approached. Therefore, the presence of coaxial line 29 has little effect on the field and hence on the balance of the antenna structure. This effectively produces a very-wide-band balanced feed for the antenna.

Also, a balanced line can be connected to the antenna by being brought toward the antenna in FIGURE 2 along the direction of arrow 27, with opposite sides of the line being connected to the apexes of the respective half-portions. If the transmission line is brought from the side of the antenna that is perpendicular to the paper at point 27 in FIGURE 2, it interferes with the radiation pattern to some degree, which in many cases makes such type of connection undesirable.

Although each half-portion 10 and 11 is in a respective plane in FIGURES 1 and 2, each can also be folded about its center-line 13 and 14. FIGURE 16 shows an end view of such antenna where Ψ is 180° and x is the fold angle between the radical members of half-portion 10 having respective end teeth 22a and 22b. The figure-eight type radiation pattern 15 of this antenna is made more omnidirectional as angle x is made smaller. Optimum omnidirectionality is obtained with x between 120° and 130°. As angle x is made smaller the antenna becomes more frequency-sensitive and its bandwidth decreases.

We have also discovered structural modifications of the antenna given in FIGURES 1 and 2, which greatly facilitate the use of the invention. FIGURES 3 through 7 illustrate such modifications, and teach how the invention can be constructed from conducting rods or wire, while still maintaining the required operating characteristics of the invention. With regard to FIGURE 3, rods are used to provide an outline of the configuration given in FIGURE 1. Although the antenna of FIGURE 1 does not have an identical complementary structure, it still provides a clear distinction between the teeth and spaces between the teeth. The structure of FIGURE 3 is hence even farther from the complementary principle, since the internal portion of any tooth defined by rods or wire is also a space. Nevertheless, we have experimentally determined that the structure of FIGURE 3 operates in substantially the same manner as the structure of FIGURE 1.

FIGURE 3 also includes two half-portions 10 and 11. Half-portion 10 includes a plurality of transverse rods 32*a*, 32*b* through 32L. Similarly, half-portion 11 comprises transverse rods 33*a*, 33*b* through 33L. The rods of half-portion 10 are positioned with respect to the center of the antenna in the same manner as tooth sides 21 and 22 were located in FIGURE 1, that is, by means of expressions 1 and 2 above. Rod sections 36*a*, 36*b* through 36L are placed on the boundary of the teeth of portion 10, as defined by angle α. Similarly, the teeth in portion 11 have lateral bounds provided by rod sections 37*a*, 37*b* through 37L, which likewise are aligned along angle α. A pair of rods 41 and 42 are fixed to portion 10 along the sides of angle β; and rods 43 and 44 are similarly positioned in portion 11. A centrally positioned rod 46 is also provided along half-portion 10, while coaxial cable 29 is brought centrally along half-portion 11 with its outer conductor connected to respective transverse rods 33. Its inner conductor 28 exits from the coaxial line at the apex of portion 11 and connects to the apex of portion 10.

The antenna system of FIGURE 4 is similar to that shown in FIGURE 3 and like portions carry like reference numbers. However, in effect, angle β is made zero in FIGURE 4 by not providing rods 41, 42, 43 and 44.

FIGURE 5 shows a modification of the antenna of FIGURE 4, wherein the trapezoidal teeth elements of FIGURE 4 are modified into triangular shapes. Thus, in FIGURE 5 the two antenna portions 10 and 11 are again confined within an angle α; and like FIGURE 4, there is also provided a center rod 46 in portion 10 of FIGURE 5 and coaxial cable 29 along portion 11. In effect, items 46 and 29 are bisectors of angle α.

Thus, in FIGURE 5, portion 10 is composed of transverse rods 51*a*, 51*b* through 51L. Similarly, portion 11 comprises transverse rods 53*a*, 53*b* through 53L. The rods connected at their ends to form transverse triangular teeth. The outer apex of each triangular tooth lies on a defining line of angle α.

If the antenna of FIGURE 5 were superimposedl on a corresponding antenna of the type in FIGURE 1, the apexes of the triangular teeth of FIGURE 5 would be located on the lateral sides of corresponding trapezoidal teeth.

The positioning of the transverse rods in FIGURE 5 is preferably determined by means of expressions 1 and 2 given above. However, the terms of the expressions are preferably defined in FIGURE 5 with respect to the apex points of the transverse teeth. This is done with respect to antenna half-portion 10 by designating its apexes on the right-hand side in FIGURE 5 by means of R and by designating its apexes on the left-hand side by *r*. The dimensions R and *r* are measured from a transverse line 60 that passes through terminal point 12 and is transverse to center-line members 46 and 29. The end of each rod 51*a* and 53*a* farthest from point 12 is considered an apex, and each has a distance R_1 from line 60.

With this definition of the positions of the elements in FIGURE 5, it will be found that their points of intersection with center-line members 46 and 29 also satisfy expressions 1 and 2 above, with expression 3 being a specific case. Also, it will be noted that alternate elements in FIGURE 5 are parallel to each other; for example, elements 51*a* and 51*c* are parallel, 51*b* and 51*d* are parallel, and so forth.

In FIGURE 5, the apex part of portion 10 is defined by rods 56, 57 and 51L. Likewise, in portion 11 the apex triangle is defined by rods 58, 59 and 53L.

FIGURE 2 may also represent a side view of any FIGURES 3, 4 and 5, wherein their two half-portions are separated by an angle Ψ which may vary from 0° to 180°.

The basic triangular-toothed configuration of FIGURE 5 leads to the greatest structural simplification in some cases over other forms of the invention, while maintaining the desired operating conditions. Thus, the configuration of FIGURE 5, as also do FIGURES 3 and 4, permits wire structures for very large antennas capable of having extreme broadbandedness which extends into the lower frequencies. In order to lower the low frequency limit of the antenna range, it is necessary to increase the size of the larger elements of the antenna. Since the width of the largest transverse element approximates one-half wavelength of the lowest frequency, it can be realized that at very low frequencies the transverse elements can become rather large.

FIGURES 6(A) and (B) illustrate how the antenna configuration given in FIGURE 5 can be constructed of wire. It is constructed using three poles 61, 62 and 63 firmly supported uprightly from the ground. Again the antenna comprises the two half-portions 10 and 11. A plural waisted insulator 64 is provided at the top of a pole 61 and is situated at the apex of the antenna. The poles are preferably wood so as not to interfere with the radiation. A pair of hooks 66 and 67 are respectively fastened in horizontal alignment to poles 62 and 63 near their top. Similarly, a second pair of hooks 68 and 69 are fastened with horizontal alignment to the lower portions of poles 62 and 63. A taunt line 71 is connected between hook 67 and the upper-middle waist of insulator 64. Line 71 consists of metal wire segments mechanically coupled but electrically separated by insulators 72. Similarly, another line segment 73 is connected between the upper-middle waist of insulator 64 and hook 66. Line 73 is likewise comprised of wire segments similarly coupled by insulators 72. Lines 71 and 73 are structural only and are interrupted electrically by the insulator to prevent them from having an antenna function. A dielectric type of structural line could preferably be used for lines 71 and 72 without insulators; however, no dielectric material is known which is properly stable under tension. The insulators 72 along lines 71 and 73 are positioned to support the apexes of the triangular teeth.

Transverse wires 51*a* through 51L are positioned between the supporting lines 71 and 73 with an angle α in the manner defined for FIGURE 5. Insulators 72 connect to the apex of each transverse tooth along lines defining α.

In a like manner, the lower half-portion 11 of the antenna is strung between a pair of structural lines 81 and 82, which correspond respectively to lines 71 and 73. Thus, lines 81 and 82 are strung between the lower-middle waist of insulator 64 and hooks 68 and 69, respectively. A central wire 46 connects the elements of section 10 along the bisector of angle α. Similarly, a central wire 47 connects the transverse elements of antenna portion 11 to bisect its angle α. Central lines 46 and 47 connect to the upper and lower waists of insulator 64.

A balanced transmission line 83 is brought along pole 61. It fans away from the antenna and then is brought directly toward its apex, where the opposite sides of the line respectively connect to the ends of leads 46 and 47. The directivity of the antenna system of FIGURES 6(A) and (B) is the direction of arrow 27 in FIGURE 6(A) and provides pattern 26 in that figure.

Where it is desired to make the antenna of FIGURE 6 have a symmetrical figure-eight pattern, angle ψ should be 180°, and the entire antenna may be supported between two parallel upright poles in a manner which is obvious in view of the description of the antenna in FIGURE 6. A coaxial feed line is then preferably used, as given in the prior figures.

FIGURE 7 illustrates a rotatable single-mast mounting of the form of the invention shown in FIGURE 4, and like reference numbers are used for like components. The antenna system of FIGURE 7, for example, can be a radio-ham antenna which is preferably extremely broadband to receive many of the ham bands. Unlike other ham antennas, the one in FIGURE 7 does not require any tuning for the various bands, and furthermore it maintains a directivity which is constant for all bands within its range. Thus, if the antenna is designed for a fifteen-to-one range, it can provide a horizontally polarized transmission at various points in the spectrum between two and thirty megacycles. In FIGURE 7, the opposite halves of the antenna, 10 and 11, are supported on rotatable mast 86. The central members 46 and 47 of antenna portions 10 and 11 are step-tapered in cross-section, in order to enhance broadbandedness. The taper is largest at elements 32*a* and 33*a* and narrows to a point adjacent to the antenna apex. Also, in order to enhance broadbandedness the largest diameter rods are 32*a* and 33*a*, with the diameters of the rods decreasing as their positions approach the antenna apex.

Mast 86 can be made of conducting material, and when it is made of conducting material it should be connected to supports 46 and 47 at points midway between any two adjacent rods 32 or 33, respectively. It has been found experimentally that a metal mast does not interfere with the radiation pattern when it is connected to such midpoints, because it appears that voltage-null points exist along rods 46 and 47 at the points midway between adjacent transverse rods.

A coaxial transmission line 87 passes upwardly through mast 86, which is hollow, and passes outwardly through a hole 88 in the mast and has its outer conductor connected along central member 47 until it terminates at the apex of the antenna as taught with FIGURE 4. Thus, its center conductor 28 extends outwardly and connects to the end of central member 46. A dielectric block 89 connects the apex ends of half-portions 10 and 11 to provide mechanical rigidity only.

It has been found that the center-line conducting member 46 and 29 in FIGURES 4 and 5, and 46 and 47 in FIGURE 6 can be removed with some deterioration of broadbandedness but with substantial broadbandedness remaining. Then, balanced transmission lines are preferable, although a coaxial cable connected along the periphery of the teeth of one side to the apex could also be used to feed the antenna.

FIGURE 8 illustrates an omnidirectional form of the invention. With an oversimplification of statement which will be realized shortly, FIGURE 8 comprises two antennas of the type shown in FIGURE 1 positioned in space quadrature. The oversimplification referred to is that such two antennas do not have corresponding teeth. That is, the quadrature plane antennas have their teeth differently placed. A picturesque manner of describing the positioning of the teeth of each antenna half-portion 110 and 111 in FIGURE 8 is to say that the teeth of each provide a spiral staircase leading to the antenna terminal 112. The spiral effect is shown in FIGURE 9, which shows a logarithmic or equiangular spiral developed on a cone. Thus, one would have an antenna of the type in FIGURE 8 by passing two transverse planes 118 and 119 along the axis of the cones in FIGURE 9.

While theoretically the spiralling can extend to infinity, in practice, it must be finitely terminated. Thus in FIGURES 8 and 9, termination is defined by planes transversely intersecting the center-line of the half-portions 110 and 111 at points equally distant from terminal point 112.

FIGURE 10(A) shows an end view of the antenna of FIGURE 8, which provides an omnidirectional-type radiation pattern 91.

Half-portion 110 includes four radial members 121, 122, 123 and 124 shown in FIGURE 10(A), which are fastened together along the center-line of 113—114 that passes through both half-portions. In the same sense, there are two radial members on the opposite sides of center line 13 in FIGURE 1 to define half-portion 10. The same situation is found in each half-portion in each of FIGURES 1–9. A radial member thus is confined within an angle

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from the center line of a half-portion. Similarly, half-portion 111 includes four radial members 131, 132, 133 and 134. Each radial member is included within an angle

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from the antenna center line, as shown in FIGURE 8. In obtaining the spiral-staircase effect, the outer edge of any two adjacent spiral-related teeth, not being cut off by the bounding planes, such as 110*c* and 110*d*, have their respective outer sides defined by the expression:

$$\tau^{1/4}=\frac{R_{N+1}}{R_N}=\frac{r_{N+1}}{r_N} \tag{4}$$

Hence, distances R_N and R_{N+1} in expression 4 from a transverse plane passing through a point 112 are given by R_3 and R_4 for teeth 110*c* and 110*d*. Similarly, r_N and r_{N+1} are taken from the inner sides of consecutive spiral teeth to satisfy expression 4. Also, the center-line distance r_N and R_N of the inner and outer sides of any tooth from point 112 will also have the fixed ratio given in expression 2 above, and the special case of expression 3 can like wise be satisfied.

Antenna portion 111 is formed in the same manner as portion 110 except that the spiralling goes in reversed directions for the respective half-portions 110 and 111 looking from terminal point 112. Nevertheless, portion 111 is twisted 180° with respect to portion 110 about their center-line. Thus, tooth 110*b* corresponds to 111*b*, tooth 110*c* corresponds to tooth 111*c*, etc., with corresponding teeth being on opposite sides of the common center-line.

Due to the 180° reversal about the center-line of antenna half-portions 110 and 111 with respect to each other, the two half-portions are not antenna images of one another. Accordingly, one half-portion cannot be provided over a transverse ground-plane through point 112 to obtain the same omnidirectional-type response which is obtained with the two half-portions disposed as shown.

Although there are four radial members used in each half-portion of FIGURE 8, actually any number greater than two can be used, and the same rules apply for proportioning adjacent teeth in the spiral-staircase manner. The dimensions of an antenna having m number of radial members per half-portion can be found as follows:

$$\tau^{\frac{1}{m}}=\frac{R_{N+1}}{R_N}=\frac{r_{N+1}}{r_N} \tag{5}$$

Where three radial members are used in each half-portion, an end view is shown in FIGURE 10(B). Extending the rationale to five radial members per half-portion, an end view is given by FIGURE 10(C). This can be extended to any number m of radial members with the ultimate limit being the spiral-grooved cones of FIGURE 9 as the number m approaches infinity.

The omnidirectional-type patterns such as patterns 91, 92 and 93 in FIGURES 10(A), (B) and (C) are slightly distorted according to the number of radial members used per antenna portion. However, this deviation from a perfect omnidirectionality is generally small and not objectionable in practice, while at times has definite advantages.

FIGURE 11 is basically the same as FIGURE 8 except that it is made of wire network which simplifies construction in many cases. Thus, the individual radial sections of FIGURE 11 are outlined by wire to form the toothed-configuration of FIGURE 8. The transverse rods in FIGURE 11 do not intersect the coaxial cable 114, but merely fasten to its outer conductor. In practice, the rods are continuous and coaxial line 114 and center-rod 113 lie in a corner of their cross-over planes. The center-conductor 128 connects to the apex end of rod 113, which can be a solid conducting rod.

The antenna network of FIGURE 12 is a triangular-toothed version of the form in FIGURE 11 and has similarities to FIGURE 5. Accordingly, the variation from 11 and 12 is similar to the variations from FIGURES 4 to 5.

In regard to the three-dimensional structures given in FIGURES 8 through 12, it was stated above that opposite half-portions are not images. However, when the entire antenna assembly having both halves is erected over a ground plane, the image of the entire antenna is view in the ground plane and this does not interfere with the radiation pattern.

FIGURE 14(A) illustrates a rounded-tooth version of the form of the invention given in FIGURE 8. FIGURE 14(A) differs from FIGURE 8 in that in FIGURE 14(A) the edge of each tooth is a segment of a circle about terminal point 112. Thus, dimensions R_N and r_N in FIGURE 14(A) are taken from point 112 of the antenna to any point along a respective tooth edge. An improvement in the omnidirectionality of the radiation pattern was found in the rounded-toothed version of FIGURE 14(A) over the previously straight-toothed version of FIGURES 8, 11 and 12. Thus, the circular radiation pattern 94 shown in FIGURE 14(B) is obtained about an end view of the antenna given in FIGURE 13(A).

FIGURE 13 illustrates a modified version of FIGURE 1. Unlike FIGURE 1, where all the teeth have their inner and outer edges perpendicular to center-lines 13 and 14, the teeth in FIGURE 14 have their outer and inner sides 22 and 21 intersect center-lines 14 and 13 at an angle δ. The points of intersection of the tooth edges with the center line are determined in the same manner as was given for FIGURE 1. That is, the points of intersection are determined by expressions 1 and 2 above. Otherwise the antenna in FIGURE 14 is the same as that shown in FIGURE 1, and a corresponding radiation pattern is obtained. The angle δ may be proportioned as desired, but better performance is taken if the teeth drop toward terminal point 12.

FIGURE 15 illustrates the forward radiation lobe of the antenna. There will also be a backward lobe, not shown here. The backward lobe is equal to the forward lobe only when angle ψ is 180°. As ψ decreases, the backward lobe decreases, and accordingly the front-to-back intensity ratio increases. Thus, by making ψ small, the back lobe is made minor in comparison to the forward lobe, and can be made to have an intensity of twenty or thirty decibels below that of the forward lobe.

Antenna 150 in FIGURE 15 is illustrated with respect to x, y and z coordinate axes. These axes intersect at the *apex terminal point* 12 of antenna 150. Thus, axis x aligns centrally with the entire antenna structure to bisect angle ψ. Axis y is parallel to the transverse rods of the antenna, which is of the type shown in FIGURE 4. The radiation E-vector is parallel to the y axis. Accordingly the xy plane will be called the E-plane. Furthermore, the radiation H-vector is parallel to the z axis, and the xz plane is called the H-plane.

When angle ψ is decreased from 180° toward zero with all other parameters remaining constant, the beam-width 151 of the E-plane pattern remains substantially fixed. However, the beam-width 152 of the H-plane pattern increases in beam-width. Furthermore, the front-to-back ratio increases. The H-plane variation is a first order effect with variataion of ψ.

When angle α is decreased with all other parameters remaining constant including angle ψ, there is a small second-order decrease in E-plane beam-width 151. However, there is a first-order decrease in H-plane beam-width 152. Nevertheless, there is a practical limit to decreasing angle α without increasing τ. The limit can be specified approximately by referring to a parameter ϵ which relates tooth width S to tooth length L, shown in FIGURE 15, according to the following expression:

$$\epsilon = \frac{S}{L} \tag{6}$$

It has been found desirable to maintain ϵ equal to or less than 0.6.

If the tooth-spacing ratio τ of expression 1 above is increased while all other parameters remain fixed, the number of teeth, of course, increases for a given sized antenna. As a consequence, both beam-widths 151 and 152 in the E and H-planes, respectively, decrease in a small corresponding amount, which is a second-order effect.

Although this invention has been described with respect to particular embodiments thereof, it is not to be so limited as changes and modifications may be made therein which are within the full intended scope of the invention as defined by the appended claims.

We claim:

1. A straight-toothed logarithmically periodic antenna comprising two half-portions, each comprising two opposite radial members connected along the central part of their half-portion, the two half-portions bounding a solid angle ψ and being generally triangular in shape and having adjacent apexes, each of said radial members being bounded by an apex angle

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from a line along the central part of either half-portion, first and second center-conducting members respectively extending from the apexes to the ends of the respective half-portions along their central parts, each half-portion having a plurality of rods cross-connected to its center-conducting member and terminated by the bounds of its angle

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connecting means provided at the ends of said transverse rods along the outer boundaries of each angle

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of each radial member, respective teeth closed by said connecting means, the connecting means on opposite radial members of each half-portion being staggered with respect to each other, the distances along a radial from the apex of said transverse rods of each radial member being a geometric sequence, and a transmission line having opposite sides connected to the respective apexes of said two half-portions.

2. An antenna as defined in claim 1 in which the diameters of said rods are proportioned to their distance from their apex.

3. An antenna as defined in claim 1 in which alternate rods of each half-portion are parallel.

4. An antenna as defined in claim 1 in which both

antenna half-portions and their radial members lie in the same plane.

5. An antenna as defined in claim 1 in which a plurality of rod portions comprise said connecting means, with said rod portions of each radial member being aligned.

6. A triangular-toothed logarithmically periodic antenna comprising opposite antenna half-portions, each half-portion being in a respective plane and having a generally-triangular shape, said half-portions having adjacent apexes and being bounded by a respective apex plane-angle α, the respective planes being oriented by a solid-angle ψ, a respective conducting center-member provided with each half-portion and positioned along the bisector of its angle α, a plurality of rods connected across said center-member of each half-portion, adjacent rods connected at their ends along the boundaries of angle α and there terminated, alternate rods being parallel, the distances from the apex of each half-portion to the opposite ends of each of its rods having a geometric-sequence ratio σ.

7. A three-dimensional straight-toothed logarithmically periodic antenna comprising two opposite half-portions which are aligned along the same center-line, each half-portion triangularly tapering to an apex, with the apexes of both half-portions being closely adjacent, a transmission-line having opposite sides connected to the respective apexes, each half-portion having more than two radial-toothed members symmetrically connected along said center-line, the teeth of each member extending outwardly from the center-line of its half-portion, each radial member having an apex angle

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with respect to its center-line, the teeth of said radial members of each half-section aligned along a conical logarithmic spiral beginning at the respective apex of each half section.

8. A three-dimensional periodic antenna as defined in claim 7 in which the thickness of the radial sections increases linearly from the apex of each antenna half-portion.

9. A three-dimensional periodic antenna as defined in claim 7 in which said teeth are formed of rods located along the periphery of said teeth, a respective center rod positioned along the center-line of each of said half-portions and connected to transverse ones of the rods forming said teeth.

10. A three-dimensional logarithmically periodic antenna comprising a pair of half-portions aligned along a common center-line, each half-portion formed in the same manner as the other but one rotated 180° about the center-line with respect to the other, each half-portion having an apex, with the apexes being closely adjacent, a respective center member of each half-portion passing along its center-line, more than two radial members provided in each half-portion and being symmetrically disposed around their center-line, each radial member having a triangular shape and a common apex, each radial member bounded by an apex angle of

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measured from the center-line, a transmission-line having opposite sides connected respectively to the apexes of said antenna half-portions, each radial member comprising a plurality of triangular teeth positioned transversely from said center-line, each of said teeth having its outer side bounded by angle

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the teeth of the radial members of any one half-portion arranged along a conical logarithmic spiral from the apex of the half-portion.

11. A triangular-toothed three-dimensional antenna as defined in claim 10 in which each of said antenna half-portions is formed from wire aligned with the periphery of said teeth, a central wire being provided along the center-line of each of said half-portions and connecting to the wires forming its teeth that cross said center-line.

12. An antenna as defined in claim 11 in which four radial members are provided for each antenna half-portion.

13. A three-dimensional rounded-toothed logarithmically periodic antenna comprising two half-portions symmetrically aligned about a center-line passing through said antenna, with each half-portion having an apex, and said apexes being closely adjacent although separated from one another, a transmission line having opposite sides connected to the respective apexes, a plurality of more than two radial members comprising each half-section, each radial member being generally triangular in shape and having an apex at the apex of its antenna half-portion, with each radial member having an apex angle of

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a plurality of teeth formed in each radial member, with each tooth having inner and outer sides which are circular about its apex as a center, the teeth of each half-portion arranged to form a conical logarithmic spiral from its apex, the distances of adjacent sides of adjacent spiral teeth having a fixed ratio τ, the opposite antenna half-portions being formed in the same manner but being rotated 180° with respect to each other about the center-line.

14. A curved-tooth three-dimensional antenna as defined in claim 13 in which each half-portion includes four symmetrically placed radial members.

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ANTENNA

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Fig. 1a

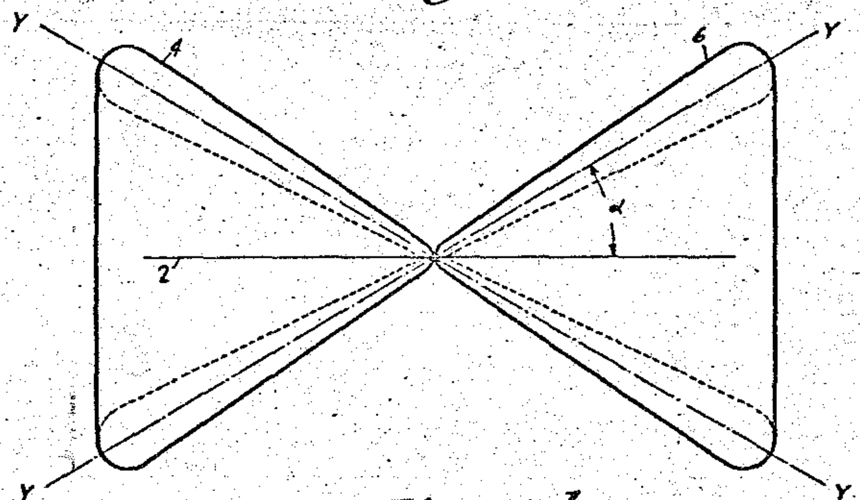

Fig. 1b

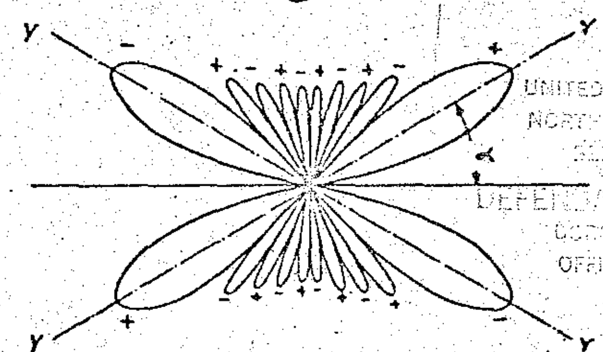

Fig. 2b

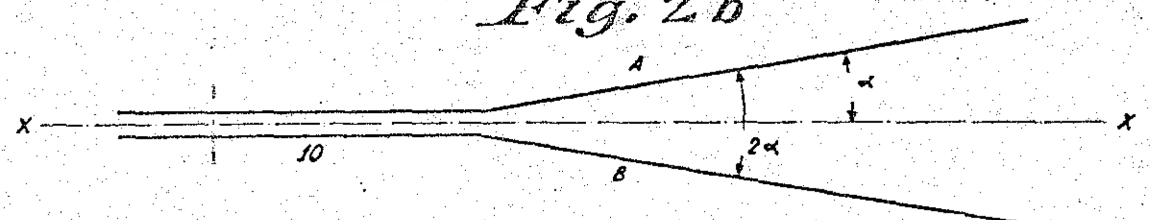

Fig. 2a

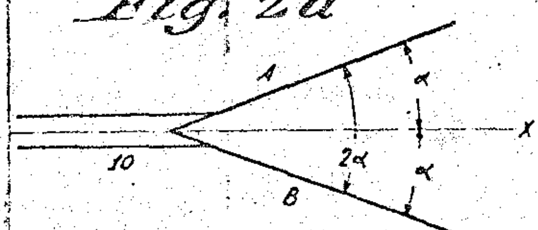

Fig. 2c

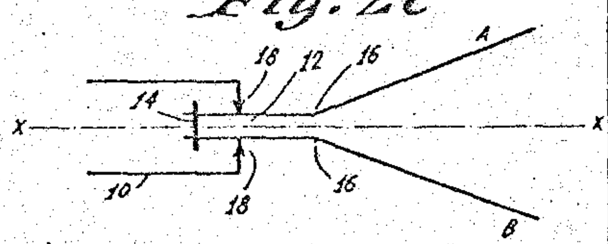

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Fig. 3

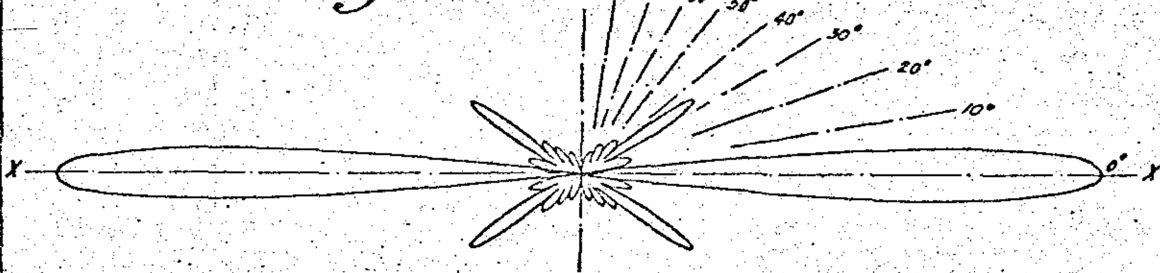

Fig. 4

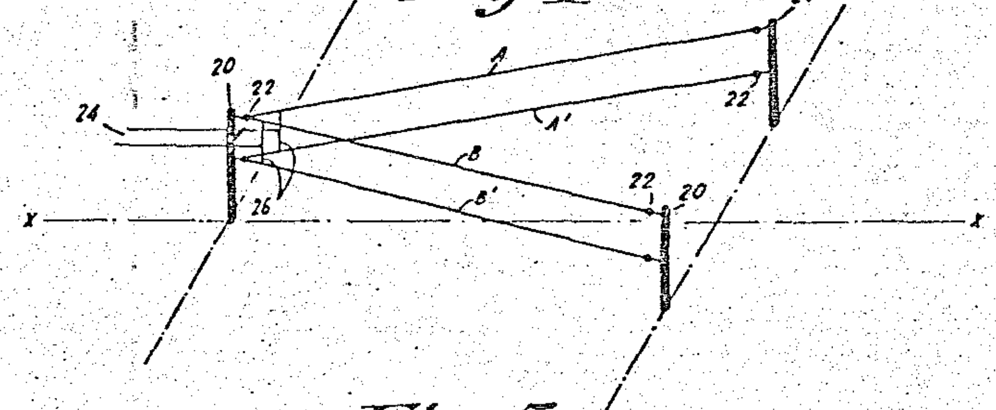

Fig. 5

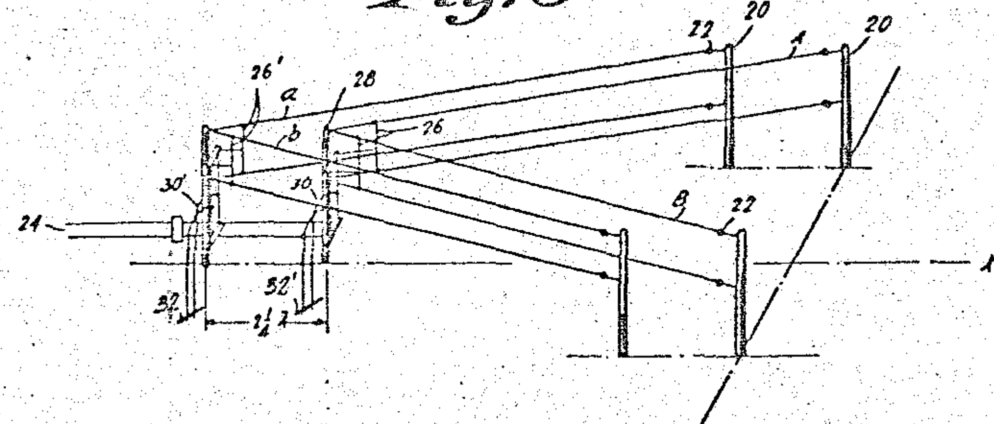

Fig. 6

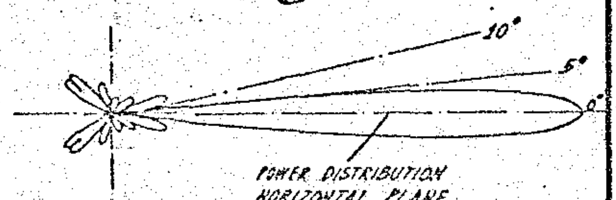

Fig. 7

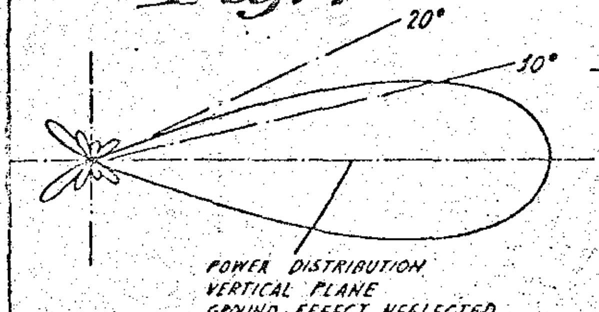

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Fig. 8

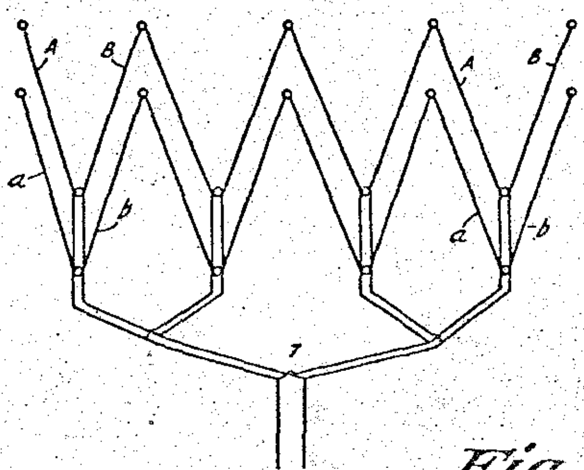

Fig. 10

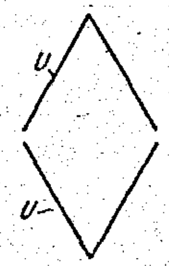

Fig. 10a

Fig. 9

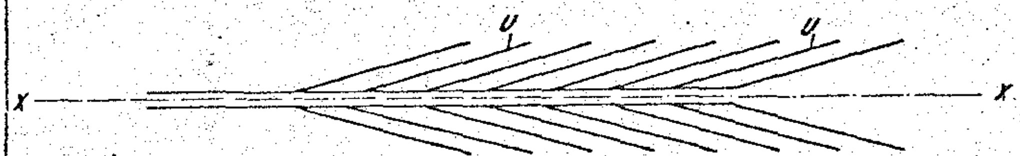

Fig. 11

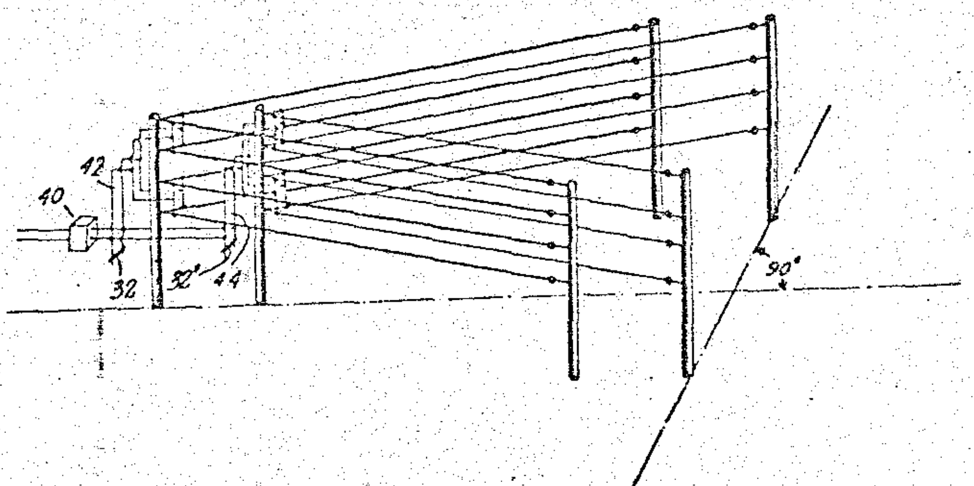

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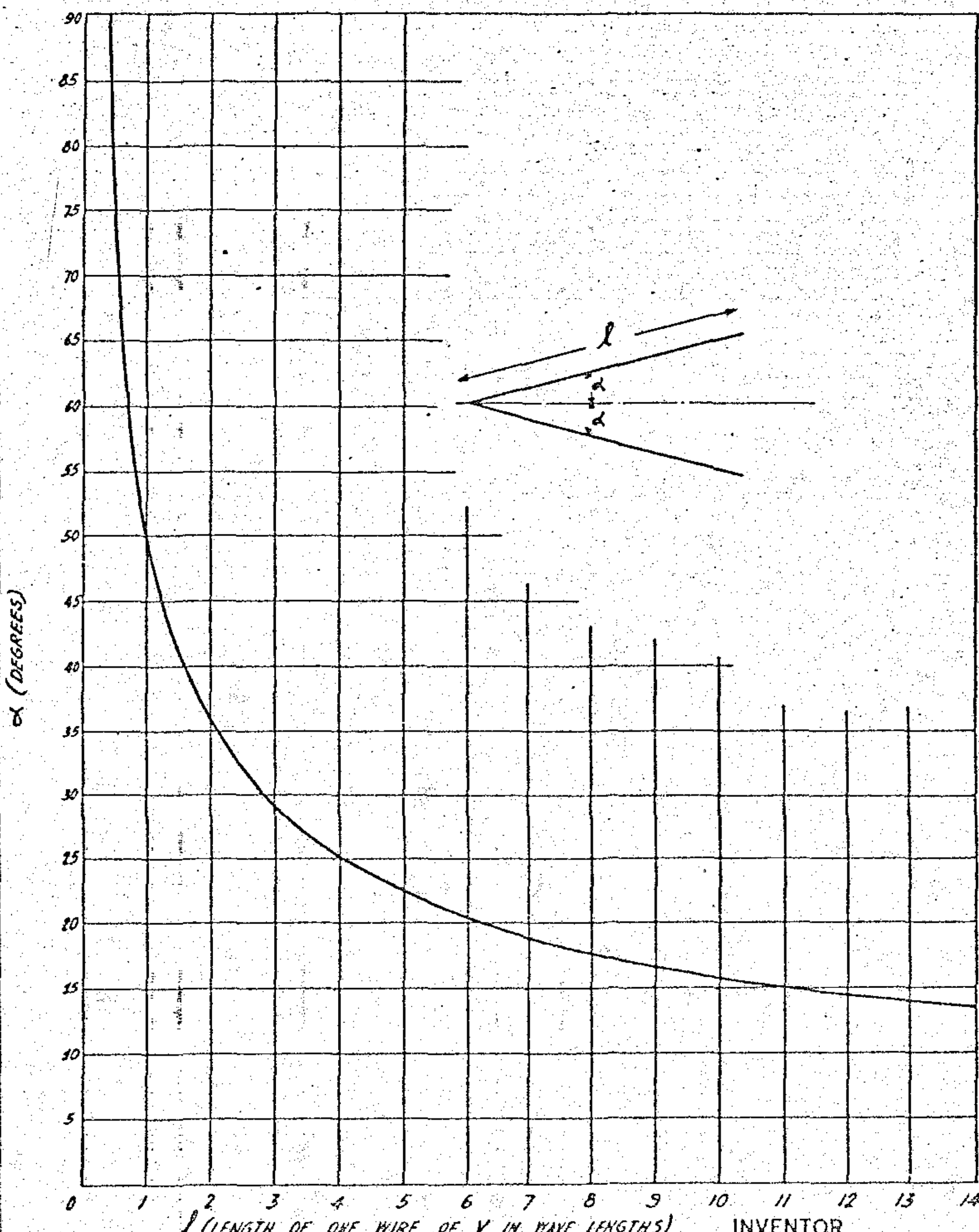
Fig. 12



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Patented Sept. 18, 1934

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UNITED STATES PATENT OFFICE

1,974,387

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Application June 11, 1930, Serial No. 460,467

41 Claims. (Cl. 250—33)

This invention relates to directive antenna systems, and has for its primary object to provide a simplified and highly efficient antenna system utilizing standing wave phenomena.

It is known that when a wire having a length greater than the operating wave length is excited in such manner that standing waves are produced thereon, radiation will occur principally in the direction of symmetrical cones having their apices at the center of the wire. Such is the case with a wire having a length equal to a plurality of one-half wave lengths at the operating frequency. The radiation pattern produced in such instance appears, in cross section, in the form of symmetrical cones about the wire. The present invention, which makes use of these phenomena, in its most simple aspect employs a pair of open-ended wires energized in phase opposition to have standing waves throughout the length of the wires, the wires having such angular relation with respect to each other as to obtain a highly directional, efficient and simple antenna system. It is proposed to place these wires at an angle with respect to each other so that principal radiation takes place along the bisector of the angle. This angle, in general, corresponds to the angle of the principal cone of radiation of one of the conductors.

Another object of the invention is to disclose the angle for the best directional propagation for open-ended wires of any finite length, preferably longer than the operating wave length, having standing waves thereon and arranged in the manner proposed.

Since a pair of wires of the type above described having standing waves of opposite and instantaneous polarity thereon which are angularly disposed with respect to each other, radiate equally well in two directions, i. e., towards the diverging ends of the wires and towards the converging ends of the wires, such an arrangement is bidirectional.

A further object of the present invention therefore is to provide a unidirectional arrangement. This may preferably be accomplished by placing a similar parallel pair of wires an odd number of quarter wave lengths away from the wires forming the antenna proper in a direction taken along the bisector of the angle formed by the wires. The second pair of wires may be left unenergized or floating, or they may be energized in proper phase such that for one direction radiation cancellation occurs, whereas in the other direction there is a strengthening of propagated electromagnetic waves.

A still further object is to concentrate the beam in planes transverse to the plane of the wires. These transverse planes usually include the vertical plane, since the wires are ordinarily disposed in horizontal planes. This may be effected by placing similar arrangements of wires above or below a given arrangement of wires. To increase horizontal directivity, the arrangements of wires may be duplicated side by side.

Other objects and features will appear in the subsequent detailed description referring to the various embodiments of the invention disclosed in the accompanying drawings.

Figure 1a illustrates, generally, the principal conical radiational characteristic of a long conductor upon which standing waves are produced,

Figure 1b illustrates in cross section, the radiation characteristic of a wire five wave lengths long,

Figures 2a, 2b and 2c indicate various forms of the fundamental unit of the present invention wherein long linear conductors having standing waves thereon are disposed at an angle such that principal radiation occurs along the direction of the bisector of the angle,

Figure 3 indicates the bidirectional characteristic of one of the units shown in any of the Figures 2a, 2b, or 2c,

Figure 4 illustrates an antenna system for concentrating the directional beam radiated from one of the units shown in Figures 2a, 2b, and 2c,

Figure 5 illustrates the arrangement of a plurality of units such as shown in Figure 2 for obtaining unidirectional propagation,

Figures 6 and 7 illustrate, respectively, the power distribution in the horizontal and vertical planes from one antenna system of particular dimensions of the type shown in Figure 5,

Figure 8 illustrates a broadside arrangement of unidirectional units for further increasing the directivity of a propagated beam of electromagnetic waves,

Figure 9 indicates schematically in plan view, an end-on or in line arrangement of units for increasing the directivity of a beam of waves,

Figures 10 and 10a indicate diamond shaped arrangements of units for obtaining unidirectional propagation,

Figure 11 illustrates a preferred form of the invention for concentrating a unidirectional beam of energy horizontally and vertically, when the length of wires is of the order of 6 to 12 wave lengths, and,

Figure 12 is a graph showing the relationship between the length of one of a pair of conductors and half the angle between them for obtaining *maximum radiation along* the bisector of said angle. As indicated by the sketch of the antenna system in the upper right hand corner of this figure, this relationship holds most strictly when the wires are of equal length.

In general, as shown in Figure 1*a*, there are two principal hollow cones 4, 6 of radiation about a wire such as indicated by the reference character 2, which is long relative to the working wave length. The cones are symmetrical about the wire 2, and the axis of the cones coincides with that of the radiator 2. For a given length of wire measured in wavelengths, the angle α between the axes Y—Y, of each lobe or ear of the cone which appears as such in cross section, and the wire 2 is constant.

More specifically, a cross section of the solid polar diagram of the radiation from a wire, which wire is a number of wave lengths long and has standing waves thereon, contains as many ears per quadrant as there are wave lengths in the wire. Thus, as shown in Figure 1*b*, there are five ears in each quadrant for a wire five wave lengths long, the principal ears or lobes of radiation occurring along the axes Y—Y. As indicated, the instantaneous directions of the field represented by adjacent ears are reversed.

Now, if it is desired to radiate energy principally in the direction of axis X—X of Figures 2*a*, 2*b*, and 2*c*, the conductors, shown in Figure 1, should be turned an angle α relative to the direction X—X; and, in order to increase still further the directional characteristic along the axis X—X, according to the present invention, two wires are used each of which makes an angle α with the axis X—X on opposite sides of the axis in a fashion such that the axis and the pair of wires lie in a single plane. In directions other than along the axis X—X, addition of radiation from the two wires is imperfect, and at certain angles radiation cancellation will occur: Consequently, a pair of wires disposed at the angle α with respect to the X—X axis will have a radiation characteristic in the plane of the pair of wires of the general type shown in Figure 3.

By considering a long wire the equivalent of a very large number of very short, (Hertz) oscillators and by adding up the field components at any point P having a direction angle θ relative to the axis of the wire, where the point P is a great distance from the wire as compared to the length of the wire such that all lines from point P to any point on the wire are essentially parallel, it can be shown that the field strength H is given by the following proportionality for a conductor an odd number of half wave lengths long:

$$H \propto \frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

The letter "n" indicates the number of half wave lengths contained in the wire.

For a wire an even number of half wave lengths long, in similar fashion, the field strength "H" is given by the following proportionality:

$$H \propto \frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

Where n as above indicates the number of half wave lengths on the wire.

The value for which the angle θ in either of the above equations makes the expression a maximum value gives the value for the angle α at which each wire of the V should be disposed relative to the direction X—X of desired wave propagation. Obviously the critical value of θ for either of the above equations may readily be determined; its value for wires up to fourteen wave lengths long is given graphically in Figure 12. For practical purposes the empirical formula

$$\alpha = 50.9\left(\frac{l}{\lambda}\right)^{-0.513} \text{degrees}$$

is sufficiently accurate where l equals the length of the wire and λ the wave length, both in the same units of measurement. Where a pair of wires of substantially equal length are used to form the V antenna of the present invention, they should be spaced apart at an angle substantially equal to twice the angle α as determined in any of the ways described above.

In order to obtain a bidirectional unit having a characteristic such as shown in Figure 3, as already indicated, any of the arrangements shown in Figures 2*a*, 2*b*, or 2*c* may be utilized. The fundamental unit is shown in Figure 2*a* where a transmission line 10 supplies high frequency energy to a pair of wires A, B forming the angle 2α with each other. The angle α is the angle made by one of the conductors with the X—X axis along which it is desired that the radiators A, B, propagate energy. The conductors A, B, are joined together at their apex which falls in the axis X—X as shown. The wires may be fed intermediate their ends in a fashion similar to that in which a half wave length oscillator is fed intermediate its ends. If desired, as shown in Figure 2*b*, the radiating wires may be terminated on a transmission line 10 instead of being connected together at the apex as shown in Figure 2*a*.

The arrangement shown in Figure 2*c* is preferred since it facilitates tuning of the antenna unit comprising the pair of wires A, B. The transmission line 10 feeds energy to a U-shaped loop 12, the legs of which are short circuited by an adjustable short circuiting strap 14, representing a voltage nodal point. The ends 16 of the loop 12 supply energy obtained from line 10 to the conductors A, B whereby the conductors are excited in phase opposition. Adjustment of impedance is accomplished along the legs of the loop by suitable adjustable tapping points 18 in order that reflection along transmission line 10 may be reduced.

Use of the loop allows of completion of the tuning of the antenna wires by making the total effective tuning length of each wire of the V or radiating unit substantially equal to an odd number of quarter wave lengths. The effective radiating length is the length of wire included in the V only, since the loop itself is substantially non-radiating and can be made to be any length.

When tuning of the V is properly accomplished by the U-loop, the system presents a pure resistive load to the transmission line. By tapping the transmission line to the legs of the U at a suitable distance from the short circuiting strip, the effective resistance of the antenna system can be made equal to the surge impedance of the line, which is a necessary condition for maximum transmission efficiency.

It should be noted that energy should be fed so as to energize the radiators A, B in phase opposition, otherwise at a distant point P along the axis X—X there would be radiation cancellation instead of addition. It is also to be distinctly understood that the unit, so far described, is not only useful for radiation purposes in a transmitting arrangement but may be utilized equally as well for reception. That is, the antenna system according to the present invention is equally well suited for any type of radiant action whether it be collection of radiation energy or the transmission thereof.

It is to be further understood that the wires of each unit can be of any desired length provided they are placed at the correct angle for their particular length. For best tuning, the total overall length of both of the wires and the U loop terminating them should be effectively an integral number of half wave lengths, although the portion forming the radiation element can be of any length. The law giving the correct angle for lengths between odd and even number of half wave lengths is not given herein due to its complexity but the empirical formula and the curve of Figure 12 will be found accurate for all practical purposes, whether or not the length of wire dealt with corresponds to an integral number of half wave lengths.

In order to prevent undesired high angle radiation, and in order to concentrate the desired beam in elevation, the scheme shown in Figure 4 may be utilized. In Figure 4, pairs of wires A, B and A', B' are placed in parallel horizontal planes and supported by masts 20 and suitably insulated therefrom by suitable insulators 22. Both pairs of wires or units are fed cophasally from a transmission line 24 through conductors 26, the wires of each pair or unit being fed in opposite phase. In order to increase the elevational concentration of radiated energy, the pair A, B and the pair of wires A', B' are placed apart in horizontal planes by a substantial spacing of preferably not less than one-half wave length. The lower pair should be at least one-half wave length above ground. Bidirectional propagation ensues along the axis X—X but in a much more concentrated form relative to the use of a single unit.

The vertical spacing of the units one above the other need not be made an integral number of half wave lengths. For wires whose lengths approach the order of magnitude from 6 to 10 wave lengths, a spacing greater than one-half wave length is preferred.

In practice, where the height of the antenna is limited by economic considerations and wherein it is desired to make ground absorption as low as possible, a good compromise is a half wave length spacing. For transmission of energy having a wave length of 17 or 18 meters, a good practical antenna may be had wherein the lower wires are about three-quarters of a wave length above ground, and the spacing between wires is one-half wave length. Eighty foot poles or masts may be used to support the wires.

In order to obtain a unidirectional radiation characteristic, pairs of parallel units such as shown in Figures 2a, 2b, and 2c may be spaced apart a distance along the axis X—X, which in effect is the bisector of the angle formed by each pair of wires in each unit. This distance may, in the preferred arrangement, be equal to an odd number of quarter wave lengths.

Such a system combined with means for concentrating the beam in a direction traversing the plane of the wires of each unit is shown in Figure 5. That is, Figure 5 illustrates a system such as shown in Figure 4 duplicated in a direction along the X—X axis whereby, in a horizontal plane, a directional characteristic is obtained such as that shown in Figure 6 and, in a vertical plane a power distribution characteristic such as shown in Figure 7.

The system of Figure 5, comprising the pair of wires A, B paralleled by similar pairs *a, b* spaced apart along the direction X—X an odd number of quarter wave lengths and, as shown nine-quarters of a wave length behind the apex 28 of wires A, B, is excited so that the wires *a, b*, have standing current waves thereon 90 degrees ahead in phase of the standing current waves on wires A, B. Consequently, energy will be propagated principally along the axis X—X towards the diverging ends of the radiators. In order to concentrate the beam of energy so radiated, similar pairs of radiators are placed below the pairs A, B and *a, b* in planes suitably spaced from the first mentioned pairs of radiators to obtain the desired vertical or elevational concentration. The lower pairs of radiators are excited cophasally with respect to the upper pairs through conductors 26, 26' fed by transmission line 24. In order to tune the various units, there are provided U-shaped loops 30, 30' which are short circuited by straps at 32, 32', similar to 14 at Figure 2c and as shown in Figure 11.

By exciting wires *a, b* 90 degrees lagging relative to radiators A, B, unidirectional propagation may be obtained in an opposite direction, or, towards the converging ends or apices of the units.

If greater concentration of the radiated energy is desired, several systems such as shown in Figure 5, for example, comprising an effective radiating unit A, B and an effective reflecting unit *a, b* may be placed in broadside with other units, and the several units excited cophasally. Thus, in Figure 8 each of the radiating units A, B shown in plan view is provided with a reflecting unit *a, b*. By means of branched transmission lines, as shown diagrammatically at T, each system is fed cophasally as a result of which an extremely concentrated beam of energy in the plane of the units is transmitted in a direction from the reflecting units towards the radiating units or the reverse, depending upon the relative phase of the standing waves on the units.

The units may be arranged in end-on fashion or coaxially as shown in Figure 9 where each of the units U is spaced apart in the direction of desired propagation. By making the phase difference between each of the units equal to

$$2\pi\frac{S}{\lambda}$$

where S is a spacing of each unit measured along the axis, concentrated unidirectional propagation may be obtained in either direction along the X—X axis depending upon whether or not the standing waves on the succeeding units lag or lead each other by the phase difference given according to the foregoing expression.

Other combinations will readily suggest themselves to those skilled in the art, for example, the units U may be placed diamond shaped fashion such as shown in Figure 10, or, they may be superimposed as shown in Figure 10a, the wires of each unit traversing each other.

In order to obtain greater concentration of the radiated beam of energy in a direction traversing the plane of each unit, the systems may be extended in the fashion shown in Figure 11. Here, the system of Figure 5 has been duplicated in a vertical direction, giving increased concentration of the beam in elevation. Energy is fed to the system through an impedance matching device 40 and thence cophasally to the reflecting units through a suitable connection 42. Energy is similarly fed to the radiating units through a suitable connection 44. By suitable tuning and by suitable spacing of the radiating pairs of wires and reflecting pairs of wires, unidirectional propagation may be obtained in either direction along the bisector of the angle formed by the wires of each pair.

The spacing of the antenna and reflector, of the system shown in Figure 11 where the wires are 6 to 12 wave lengths long, is made preferably nine-quarters of a wave length. For wires longer than ten waves lengths, the preferred form should have a greater spacing between the antenna and reflector such as two and three-quarters or three and one-quarter wave lengths. For wires on the order of three or four wave lengths long, the reflector spacing from the antenna may be one and one-quarter wave lengths or less. In general, as the lengths of wires in terms of wave lengths increase, the reflector and antenna spacing should be increased.

In each of the systems for reception, the transmission line would simply be coupled to a suitable receiver, the antenna being directed upon a transmitting station.

The wires, though preferably placed in horizontal planes may be placed at any desired angle without departing from the scope of this invention, and, during transmission it may often be found desirable to have the plane of the wires tilted away from the earth and towards the direction in which the beam of energy is to be propagated.

By the term "plurality of wave lengths", or "plurality of half wave lengths", or "several half wave lengths", it is not intended that the wires so described shall necessarily be an exact or approximate integral number of such lengths, unless so specified, but rather that each of the wires so described shall be sufficiently long to include the lengths specified.

Having thus described my invention, what I claim is:

1. A directional antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and another pair of conductors parallel and similar to said first mentioned pair of conductors and spaced therefrom an odd number of quarter wave lengths measured in a direction along the bisector of the angle of the conductors.

2. A directional transmitting antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths and being open-ended; means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators; and, another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors, an odd number of quarter wave lengths.

3. A directional antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other in a horizontal plane, each of a length including substantially a plurality of half wave lengths, means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and, another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of quarter wave lengths.

4. A directional transmitting antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths and being open-ended and disposed in a horizontal plane; means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators; and, another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of quarter wave lengths.

5. A directional antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths, means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and, another pair of conductors similar to said first mentioned pair of conductors spaced apart from said first mentioned pair in a direction traversing the planes of each pair.

6. A directional antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths, means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors; and, another pair of conductors similar to said first mentioned pair of conductors spaced apart from said first mentioned pair, in a direction perpendicular to the plane of the pair of conductors a number of half wave lengths.

7. An antenna comprising parallel pairs of angularly disposed conductors, said conductors being angularly disposed with respect to each other, spaced apart along the direction of the bisector of the angle formed by the conductors an odd number of quarter wave lengths, and, similar pairs of conductors in planes parallel to and spaced apart vertically from the planes of the first mentioned pairs of conductors.

8. A transmitting antenna system comprising parallel pairs of angularly disposed conductors, said conductors being angularly disposed with respect to each other, arranged in a horizontal plane having their apices spaced apart along the direction of the bisector of the angle formed by the conductors an odd number of quarter wave lengths, and similar pairs of conductors disposed in a parallel horizontal plane a vertical distance away from said first mentioned plane, equal to one or more half wave lengths.

9. An antenna system comprising a pair of linear conductors, said conductors being angularly disposed with respect to each other, each substantially an odd number of half wave lengths long and angularly disposed with respect to each other at an angle substantially equal to the angle for which the field strength at a distant point lying in the direction of the bisector is a maximum, said field strength being proportional to

$$\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

where n is the number of half wave lengths contained in each conductor and θ is the half angle between the wires, and means in circuit with said antenna for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors throughout their length.

10. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed with respect to each other at an angle substantially equal to the angle for which the field strength at a distant point lying in the direction of the bisector is a maximum, said field strength being proportional to

$$\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

where n is the number of half wave lengths contained in said conductor and θ is the half angle between the wires, and means in circuit with said antenna for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors throughout their length.

11. An antenna comprising a pair of linear conductors, each substantially an odd number of half wave lengths long and angularly disposed with respect to each other at an angle equal to twice the angle for which the expression

$$\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

is a maximum, n being the number of half wave lengths contained in each conductor, and, a similar pair of conductors spaced from said first pair by an odd number of quarter wave lengths in a direction along the bisector of the angle of the conductors.

12. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed with respect to each other at an angle substantially equal to twice the angle for which the expression

$$\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

is a maximum, n being the number of half wave lengths contained in each conductor, and a similar pair of conductors spaced from said first pair by an odd number of quarter wave lengths in a direction along the bisector of the angle of the conductors.

13. An antenna comprising a pair of linear conductors, each substantially an odd number of half wave lengths long and angularly disposed with respect to each other at an angle equal to twice the angle for which the expression

$$\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

is a maximum, n being the number of half wave lengths contained in each conductor, and a similar parallel pair of conductors away from the first mentioned pair in a direction perpendicular to the planes of the pairs.

14. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed with respect to each other at an angle substantially equal to twice the angle for which the expression

$$\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

is a maximum, n being the number of half wave lengths contained in each conductor, and a similar pair of conductors away from the first mentioned pair in a direction perpendicular to the planes of the pairs.

15. An antenna comprising a pair of relatively long conductors disposed with respect to each other at an angle substantially equal to twice

$$50.9\left(\frac{l}{\lambda}\right)^{-0.513}$$

degrees, l being the length of the wire and λ the operating wave length in like units, and means in circuit with said antenna for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors throughout their length.

16. An antenna comprising a pair of relatively long conductors disposed with respect to each other at an angle substantially equal to twice

$$50.9\left(\frac{l}{\lambda}\right)^{-0.513}$$

degrees, and, a similar parallel pair of conductors spaced an odd number of quarter wave lengths away from said first mentioned pair along the bisector of the angle of the conductors, l being the length of each wire and λ being the operating wave length in like units.

17. An antenna comprising pairs of long conductors, the conductors of each pair disposed with respect to each other at an angle substantially equal to twice

$$50.9\left(\frac{l}{\lambda}\right)^{-0.513}$$

degrees, and the pairs being placed in parallel planes substantially an odd number of half wave lengths apart, l being the length of each wire and λ being the operating wave length in like units.

18. An antenna comprising pairs of relatively long conductors the conductors of each pair being disposed with respect to each other at an angle substantially equal to twice

$$50.9\left(\frac{l}{\lambda}\right)^{-0.513}$$

degrees the apices of each pair being separated along the direction of the bisector of the angle formed by the conductors by an odd number of quarter wave lengths; and, similar pairs of conductors in a substantially parallel plane spaced apart from said first pairs, l being the length of each wire and λ being the operating wave length in like units.

19. An antenna arrangement comprising a pair of diverging linear conductors angularly disposed with respect to each other, another pair of angularly disposed diverging conductors similar to said first mentioned pair and spaced apart from said first pair in a direction along the bisector of the angle of the conductors, both said pairs of angularly disposed conductors being arranged to form opposite angles of a four sided plane figure, the conductors of each pair being excited in phase opposition whereby radiant action occurs principally in the plane of said conductors and along the direction of said bisector.

20. A diamond-shaped antenna arrangement comprising a pair of V-shaped antennæ arranged to form a parallelogram, and means for connecting the apex of each V antenna to high frequency apparatus whereby the legs of each V which lie alongside each other are excited in phase opposition so that radiant action occurs principally in the plane of the V-shaped antennæ and principally in a direction along a line joining the apices of said V-shaped antennæ.

21. An antenna system comprising a pair of linear conductors angularly disposed with respect to each other, each of a length including substantially a plurality of one-half wave lengths and being open-ended, another similar pair of angularly disposed linear conductors also of a length including a plurality of one-half wave lengths and being open-ended, both of said pairs being so arranged that the open ends of one pair point in a substantially opposite direction with respect to the open ends of the other pair and the acute angles formed by said pairs face one another, and means for exciting the radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators.

22. A directional transmitting antenna arrangement comprising a pair of V-shaped antennæ arranged to form a parallelogram, and means for exciting the radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators whereby radiant action occurs principally in the plane of said radiators and principally along a line joining the apices of said V-shaped antennæ.

23. A directional antenna arrangement comprising a pair of open-ended V-shaped antennæ arranged in a horizontal plane such that the open ends of each pair point in opposite directions with respect to the other pair, and means for connecting the apex of each V antenna to high frequency apparatus whereby radiant action occurs principally in the plane of the V-shaped antennæ and principally in a direction corresponding to the line joining the apices of said V-shaped antennæ.

24. A directional antenna arrangement comprising a pair of open-ended V-shaped antennæ arranged such that the acute angle formed by the individual conductors of each pair of antennæ face each other and the open ends of each pair point in different directions, and means for connecting the apex of each V antenna to high frequency apparatus whereby radiant action occurs principally in the plane of the V-shaped antennæ and principally in a direction corresponding to a line joining the apices of said V-shaped antennæ.

25. A directional antenna arrangement comprising a pair of V-shaped antennæ arranged in such manner that the acute angle formed by the individual conductors of each pair face each other, and means for connecting the apex of each V antenna to high frequency apparatus whereby radiant action occurs principally in the plane of the radiators and principally in a direction corresponding to a line joining the apices of said V-shaped antennæ.

26. A directional antenna comprising a pair of linear conductors angularly disposed with respect to each other and placed in a plane at an angle to the horizontal, said plane extending in the desired direction of transmission, each conductor being of a length including substantially a plurality of one-half wave lengths, means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of one-quarter wave lengths.

27. A directional transmitting antenna comprising a pair of linear conductors angularly disposed with respect to each other, each of a length including substantially a plurality of one-half wave lengths and being open-ended, and disposed in a plane at an angle from the horizontal, said plane extending in the desired direction of transmission, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators, and another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of one-quarter wave lengths.

28. A directional transmitting antenna comprising a plurality of pairs of linear conductors, the conductors of each pair being angularly disposed with respect to each other, each conductor being of a length including substantially a plurality of one-half wave lengths and being open-ended, said plurality of pairs being disposed in a horizontal plane along the bisector of the angle of the conductors, means for exciting the two radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators of each pair, and means for feeding the successive pairs of radiators so that the currents in the successive radiators of each pair differ in phase by an angle $2\pi S/\lambda$ where S is the spacing along the bisector and λ the wave length.

29. A directional transmitting antenna comprising a plurality of pairs of linear conductors, the conductors of each pair being angularly disposed with respect to each other, each conductor being of a length including substantially a plurality of one-half wave lengths and being open-ended, said plurality of pairs being disposed in a plane at an angle from the horizontal, said plane extending in the desired direction of transmission, means for exciting the two radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators of each pair, and means for feeding the successive pairs of radiators so that the currents in the successive radiators of each pair differ in phase by an angle $2\pi S/\lambda$ where S is the spacing and λ the wave length.

30. A broadside directional antenna comprising a pair of linear conductors angularly disposed with respect to each other, another pair of angu-

larly disposed linear conductors arranged adjacent and in the same plane with said first pair so that said two pairs are side by side and have their acute angles opening in the same direction, and means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisectors of the angles formed by the conductors of each pair for effecting beam concentration.

31. A broadside directional antenna comprising a pair of linear conductors angularly disposed with respect to each other in a horizontal plane, another pair of angularly disposed linear conductors arranged adjacent and in the same plane with said pair so that said two pairs are side by side and have their acute angles opening in the same direction, said pairs being arranged to be excited in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon.

32. A directional transmitting antenna comprising a pair of linear conductors angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths and being open-ended, a transmission line, a pair of vertical connections extending from said pair of conductors to said transmission line, and means in circuit with said transmission line for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors, another pair of conductors substantially similar and parallel to said first mentioned pair and spaced therefrom in a direction along the bisector of the angle of the conductors, and a pair of vertical connections in circuit with said last pair of conductors, and joining said last pair with said transmission line.

33. A directional transmitting antenna comprising a pair of linear conductors angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths and being open-ended, a transmission line, a pair of vertical connections extending from said pair of conductors to said transmission line, and means in circuit with said transmission line for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors, another pair of conductors substantially similar and parallel to said first mentioned pair and spaced therefrom in a direction along the bisector of the angle of the conductors, and a pair of vertical connections in circuit with said last pair of conductors, said two pairs of vertical connections being joined together by a pair of horizontal conductors.

34. An antenna arrangement comprising a pair of conductors each of a length including several half wave lengths at the operating frequency, said conductors being angularly disposed at an acute angle with respect to each other, each conductor making the same angle with, but lying on opposite sides of a line representing the desired direction of radiant action, and a U-shaped metallic circuit having legs substantially parallel to each other connected between substantially opposite points on said angularly disposed conductors, which points are relatively close together.

35. An antenna arrangement comprising a pair of conductors each of a length including several half wave lengths at the operating frequency, said conductors being angularly disposed with respect to each other, each conductor making the same angle with, but lying on opposite sides of a line representing the desired direction of radiant action, and a circuit having conductors substantially parallel to each other connected between substantially opposite points on said angularly disposed conductors, which points are relatively close together, and means for effectively connecting together for high frequency currents, similarly located points on each of said parallel conductors.

36. An antenna arrangement comprising a pair of conductors each of a length including several half wave lengths at the operating frequency, said conductors being angularly disposed with respect to each other, each conductor making the same angle with, but lying on opposite sides of, a line representing the desired direction of radiant action, a U-shaped circuit having legs substantially parallel to each other connected between substantially opposite points on said angularly disposed conductors, which points are relatively close together, and a transmission line connected to the legs of said U-shaped circuit and to said angularly disposed conductors for energizing said conductors in phase opposition.

37. A directional antenna comprising a pair of angularly disposed substantially straight conductors, said conductors being angularly disposed with respect to each other, each conductor being of a length including a plurality of half wave lengths at a desired operating frequency, means for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon whereby radiant action of the system formed by said angularly disposed linear conductors is predominantly along the direction of the bisector of the angle formed by the conductors, another pair of conductors parallel and similar to said first mentioned pair of conductors, and a substantially radiationless transmission line, not less than a quarter wave length long at the desired operating frequency, joining substantially opposite points on said pairs of conductors, the points on each pair being relatively close together.

38. A directional antenna comprising a pair of straight conductors angularly disposed with respect to each other, each conductor being of a length including a plurality of wave lengths at the operating frequency and being electrically open-ended at their most widely separated ends, means for exciting said conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon, and another pair of open-ended conductors similar and parallel to said first mentioned pair of conductors and being spaced therefrom in a direction along the bisector of the angle of the conductors such that radiant action of said pairs of conductors is substantially unidirectional.

39. A directional antenna comprising a pair of straight conductors angularly disposed with respect to each other, each conductor being of a length including a plurality of half wave lengths at the operating frequency, said conductors being electrically open-ended at their most widely separated ends, another pair of open-ended conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors, and a substantially radiationless transmission line connected between points on said pairs of conductors, the points chosen on each pair being relatively close together, said transmission line being not less than a quarter

wave length long at the desired operating frequency.

40. A directional antenna comprising two pairs of conductors, the conductors of each pair being substantially straight and being arranged so as to form substantially a V, each conductor of each of said pairs of conductors being of a length including a plurality of wave lengths at the desired operating frequency, the most remote ends of the conductors of each pair being electrically open-ended, both pairs of conductors lying in the same plane and symmetrically about a line representing a desired direction of radiant action.

41. A directional antenna comprising two pairs of conductors, the conductors of each pair being substantially straight and being arranged so as to form substantially a V, each conductor of each of said pairs of conductors being of a length including a plurality of wave lengths at the desired operating frequency, the most remote ends of the conductors of each pair being electrically open-ended, both pairs of conductors lying in the same plane and symmetrically about a line representing a desired direction of radiant action, and a substantially radiationless transmission line not less than a quarter wave length long connected between similar points on said pairs of conductors, the points taken on each pair of conductors being close together relative to the electrical open ends of said conductors.

PHILIP STAATS CARTER.

June 8, 1937. P. F. GODLEY ET AL 2,083,260

RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

Filed April 10, 1934 6 Sheets-Sheet 1

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO. 16
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

Fig. 1.

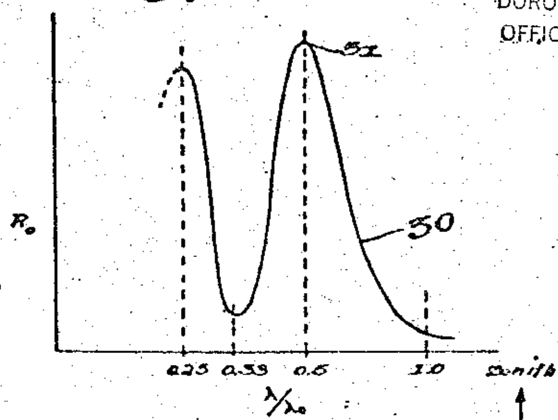


Fig. 5.

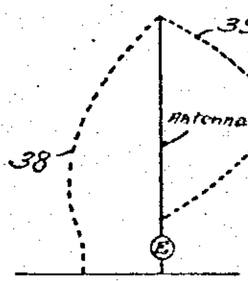


Fig. 6.

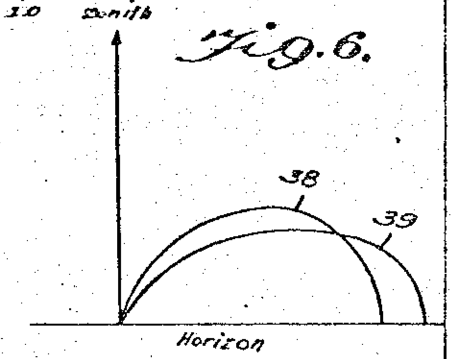


Fig. 2.

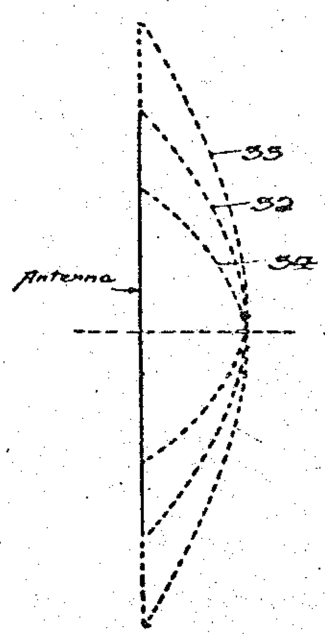


Fig. 3.

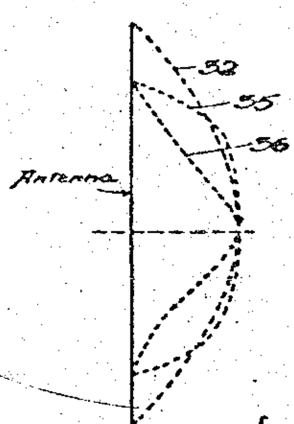


Fig. 4.

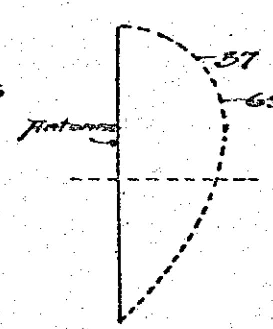
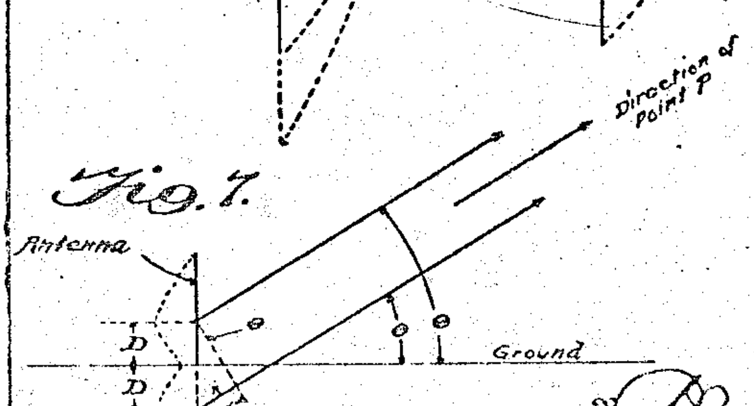


Fig. 7.



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June 8, 1937. P. F. GODLEY ET AL 2,083,260

RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

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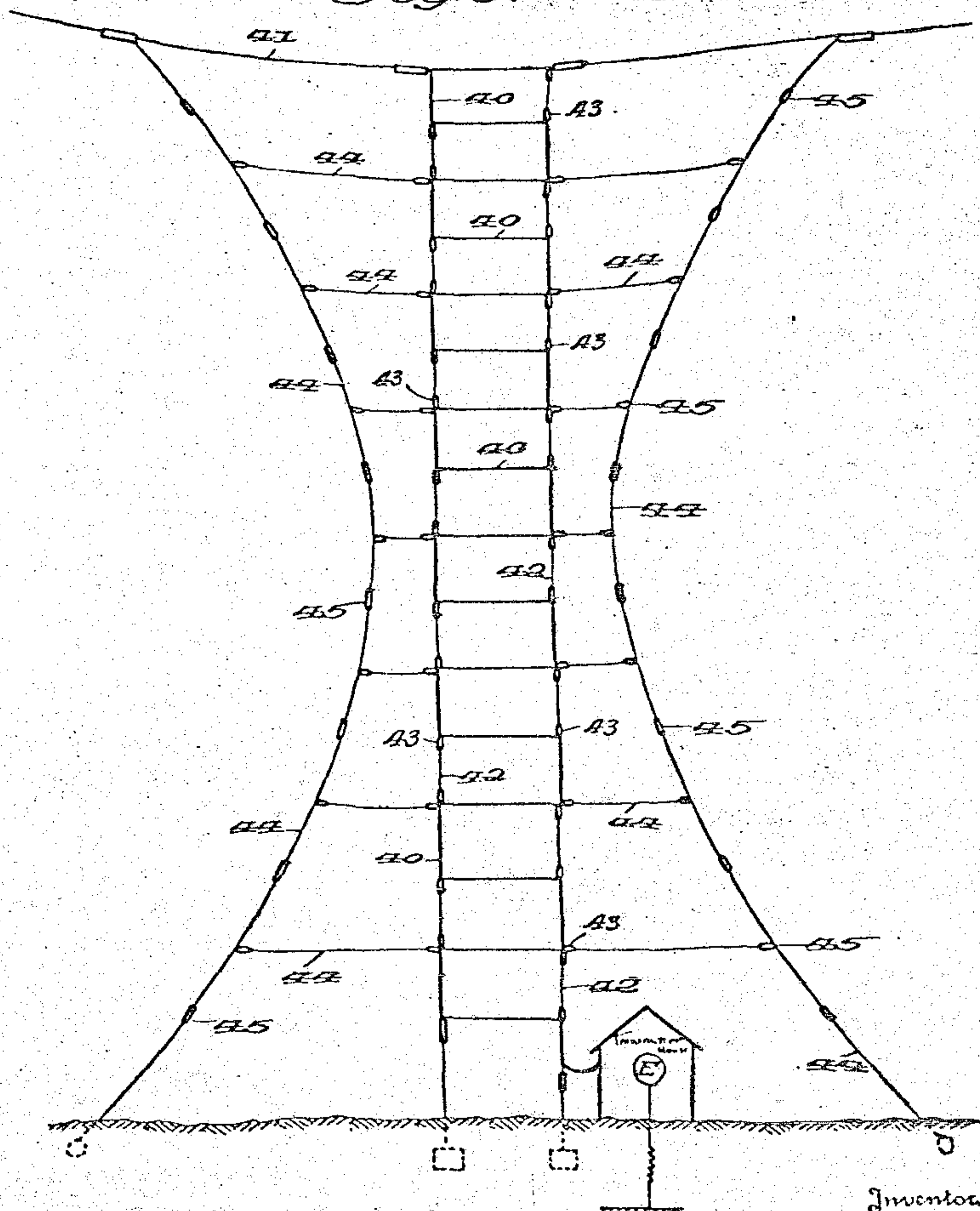
Fig. 8.



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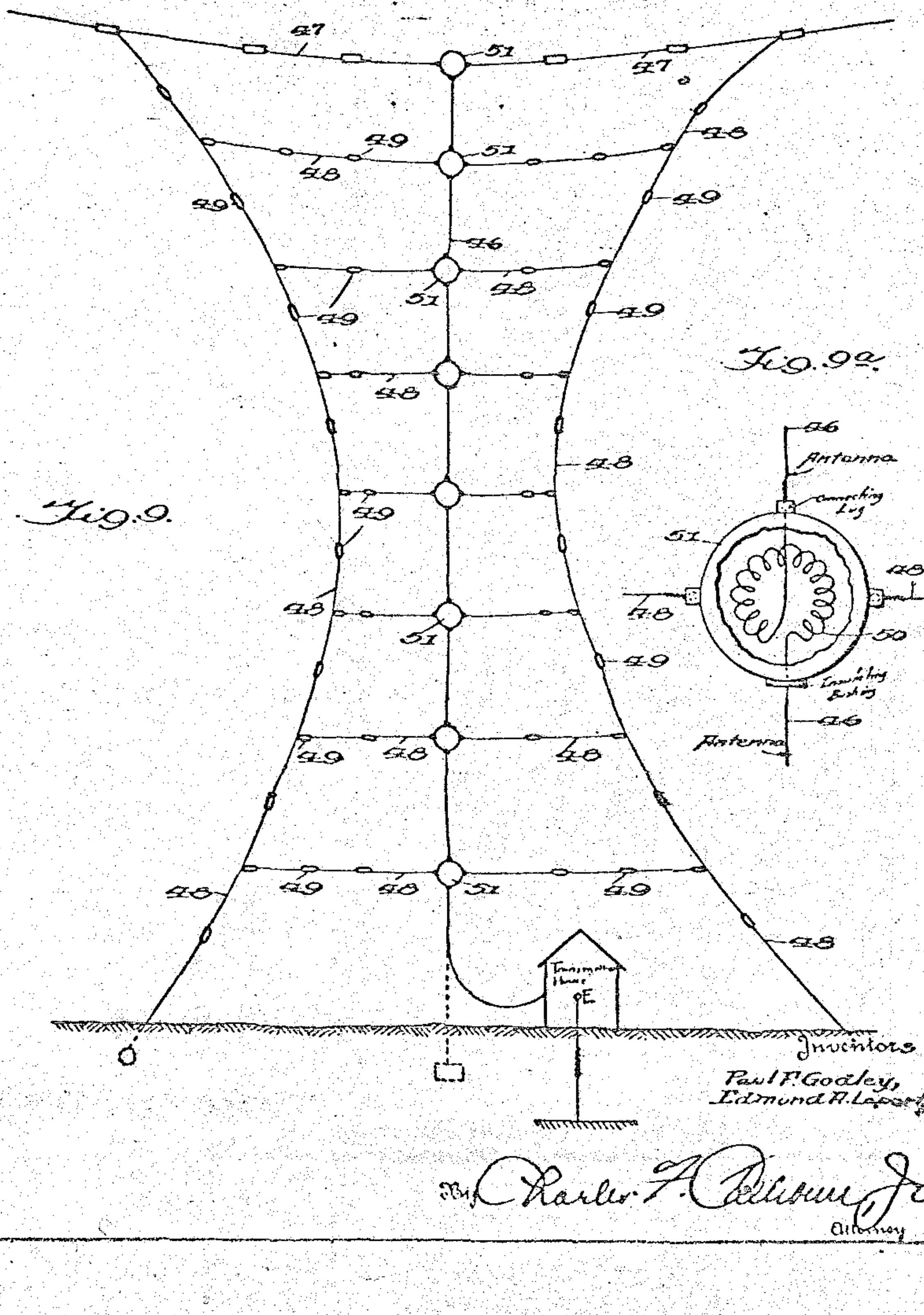
RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

Filed April 10, 1934 6 Sheets-Sheet 3



June 8, 1937. P. F. GODLEY ET AL 2,083,260

RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

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Fig. 10.

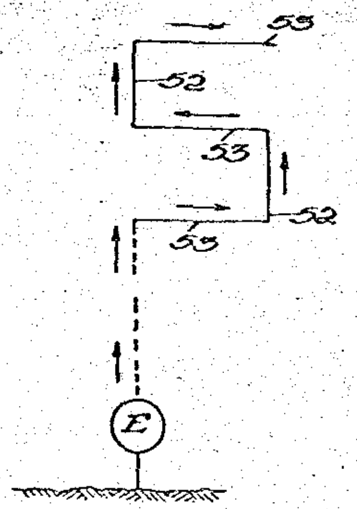


Fig. 11.

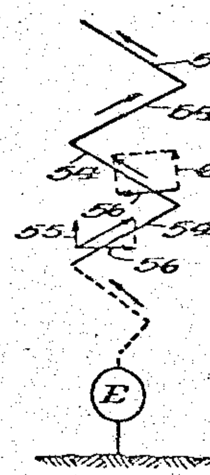


Fig. 12.

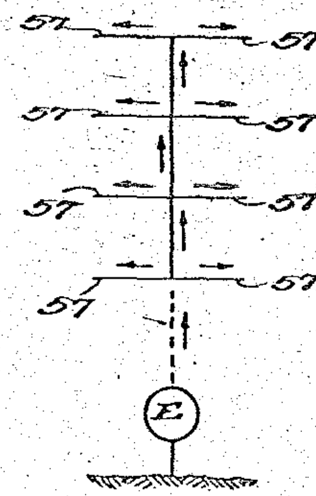


Fig. 13.

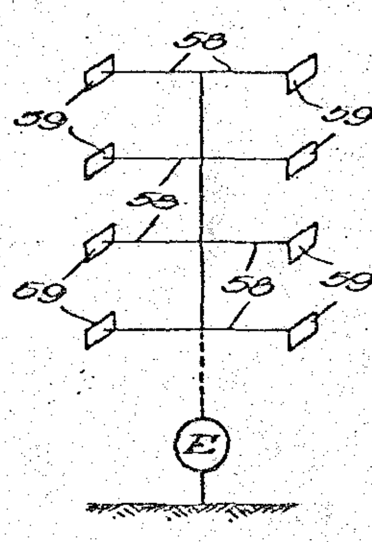
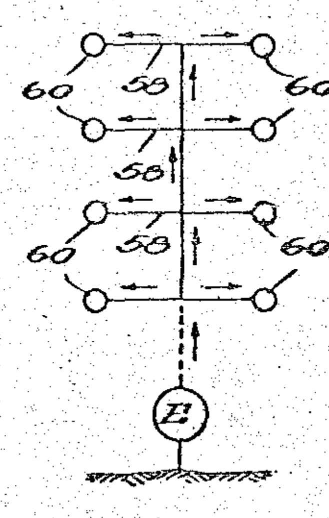


Fig. 14.



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RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

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Fig. 15

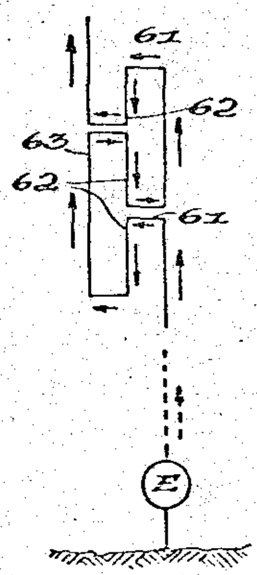


Fig. 16.

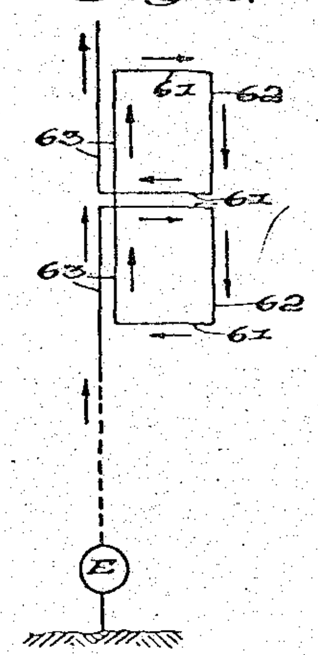


Fig. 17.

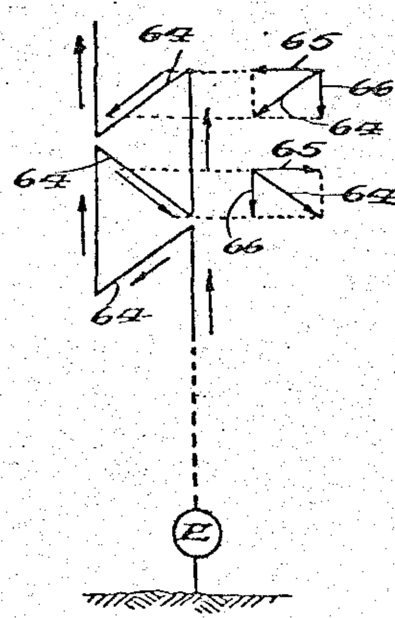
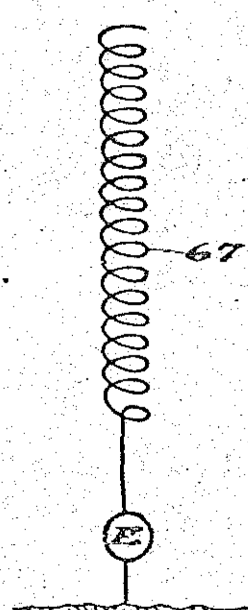


Fig. 18.



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RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

Filed April 10, 1934 6 Sheets-Sheet 6

Fig. 19.

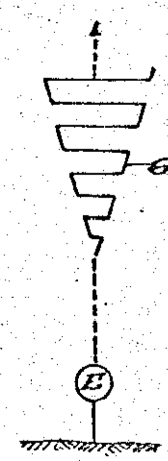


Fig. 20.

Fig. 21.

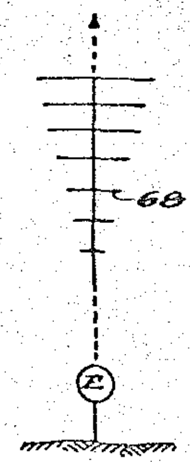


Fig. 22.

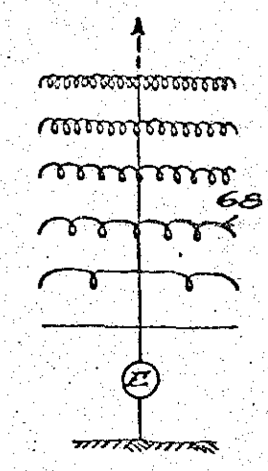


Fig. 23.

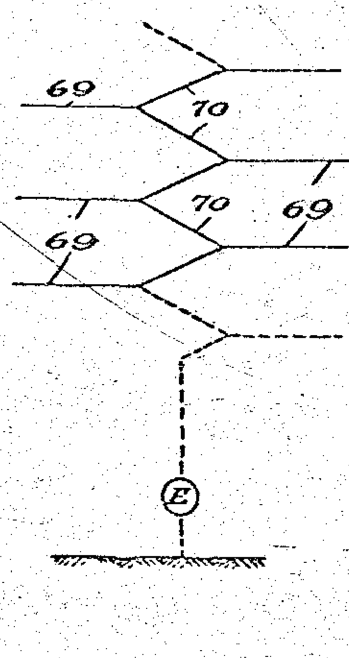
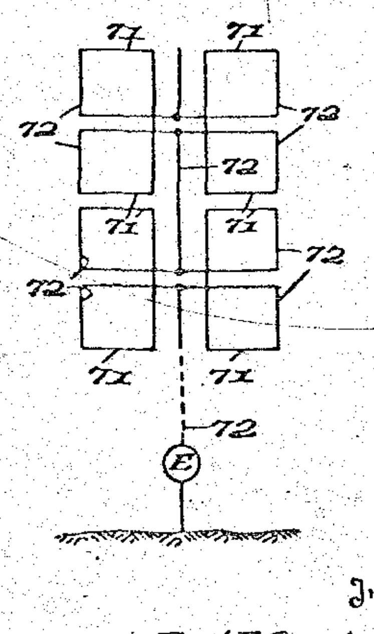


Fig. 24.



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Patented June 8, 1937 2,083,260

UNITED STATES PATENT OFFICE

2,083,260

RADIATING SYSTEM FOR ELECTROMAGNETIC WAVES

Paul F. Godley and Edmund A. Laport, Montclair, N. J.

Application April 10, 1934, Serial No. 719,931

3 Claims. (Cl. 250—33)

This invention relates to antenna systems and more particularly to a novel method of propagating electromagnetic waves from the system in a more desirable and efficient manner than heretofore obtained.

One object of the invention is to provide a novel method of controlling the distribution of radiant energy in space, and this object is accomplished by controlling the distribution of current in various portions of the antenna system.

Another important object of the invention is to provide a novel arrangement of apparatus for obtaining a wide variety of forms of current distribution in the antenna system employed.

Another object of the invention is to provide a novel system of the character designated in which the radiant energy emitted toward the zenith is reduced in order that the energy shall be concentrated at angles which are low with respect to the horizon and thereby minimize any deleterious effects of fading.

Another object of this invention is to provide an antenna system of the character designated, which shall increase the radiation efficiency of the antenna employed.

A further object is to provide a novel form of vertical antenna construction in which the height shall be only a fraction of the wave length.

These and other objects of the invention will be more apparent from the following specification and drawings, and specifically set forth in the claims.

As a preferred embodiment, we have shown the principles involved in our invention as applied to a vertical antenna but it will be readily apparent to those skilled in the art that many of these principles map be applied to other types of antennae.

It is well known in the antenna art that the transmitted power radiated from the antenna may be variously distributed in free space, with various intensities occurring at various angles with respect to the antenna. Waves emitted parallel to the ground are commonly referred to as ground-waves, while all other waves emitted at angles above the ground are called sky-waves. These waves may also be referred to as low-angle and high-angle radiations respectively. Cases frequently arise where it is very desirable to reduce one of the wave components with respect to the other. Thus it has been discovered that a resultant increase in the ratio of low-angle to high-angle emission, effects a reduction in the variation, or "fading", of received signals, or advantageously modifies the areas wherein such fading occurs.

Fading is now known to be the result of wave interference between those waves which pass directly (along the earth's surface) from the transmitter to the receiver and those waves which are propagated from the antenna at angles considerably above the horizontal, but which reach the receiving antenna because of their reflection from the ionosphere. Objectionable fading occurs when the ground wave and the sky wave are substantially of the same order of magnitude. We have discovered that by increasing the low angle emission and reducing the high angle emission the fading is thus diminished.

The desirability of increasing the low angle emission is recognized in the prior art, but none of the systems heretofore proposed accomplish this result in a commercially practical manner and one important feature of our invention is the provision of novel means for controlling the low angle emission by controlling the current distribution in the antenna.

Our invention will more readily be understood by reference to the attached drawings, in which:

Figure 1 shows a curve depicting the nature of the variation of the radiation resistance component of antenna impedance at the base with change of mode of operation.

Figure 2 shows several current distribution curves obtainable by this invention.

Figures 3 and 4 show other obtainable current distribution curves;

Figure 5 shows a comparison between current distribution curves of a uniform straight wire as used in present practice, and an antenna of the same height but built on the basis of this invention;

Figure 6 shows a polar diagram of the distribution of radiation in space as a result of the two conditions of Figure 5;

Figure 7 is a geometric representation of the conditions which produce the various forms of radiation distribution in space by wave-interference;

Figure 8 shows a method of controlling current distribution by folding a relatively long wire to occupy a given height;

Figure 9 shows a method of controlling current distribution by the addition of units of capacitance at intervals along the conductor;

Figure 9—A shows an enlarged sectional view of a special spherical element of capacitance and inductance used in Figure 9;

Figures 10 to 24 inclusive, show other configurations and practical antenna systems for controlling the current distribution in any part of the system.

Referring more particularly to the drawings, Figure 1 shows the manner in which the radiation resistance (R_o) of an antenna system varies with respect to the mode of operation

$$\left(\frac{\lambda}{\lambda_0}\right)$$

in which λ_0 is the antenna fundamental wave length, and λ is the operating wave length. It will be noted that the curve 30 shows the radiation resistance at a maximum at a mode of 0.5 (point 31) which in practice may be many thousand ohms. Since the radiation efficiency is the ratio of the radiation resistance (R_o) to the total antenna resistance (R_t) (including the ground resistance (R_g), conductor resistance (R_c) and all other components of impedance which produce heat losses in the system) it is readily apparent that the building of an antenna which operates at or near the 0.5 mode (where a very high order of radiation efficiency is possible) is desirable.

In Figures 2, 3 and 4 we have shown the manner in which the current distribution may be modified from that obtained with a conventional straight antenna wire, (which has a velocity of propagation nearly equal to that in free space) the frequency of the exciting generator being assumed constant. The curve 32 in Figure 2 represents the normal half-wave distribution of current in a uniform straight wire. Curve 33 represents a half-wave of current distribution obtainable by uniformly increasing the velocity of propagation in the antenna, and curve 34 represents the distribution obtainable by uniformly decreasing the velocity of propagation. Curve 36 (Figure 3) shows the comparative distribution obtainable by an "accelerated" velocity, velocity increasing from current antinode to node. Curve 35 represents distribution resulting when the velocity is accelerated from node to antinode. Curve 37 (Figure 4) is obtained by making use of the tapering effect which will be more fully disclosed under Figures 19, 20, 21 and 22.

There is shown in Figure 6, an example of the change in the distribution of the radiant energy in space from a given antenna composed of a uniform straight wire as used in present practice, (curve 38), with current distribution as shown in Figure 5, and an antenna of the same height but constructed in accordance with this invention (curve 39) for the same frequency of operation but with modified current distribution in the system as shown in Figure 5.

The polar diagrams shown in Figure 6 are in terms of relative signal intensities observed at various angles in space and at constant radius, that is, on the surface of a hypothetical hemisphere with the antenna at its center. A glance at the two diagrams shows that curve 39 is concentrated at lower angles than curve 38, so fading would thereby be diminished, as well as the effectiveness of the antenna being increased by producing a high field intensity along the ground for a given power input.

The equation which gives the polar diagram of relative field strength distribution in space about a vertical antenna is:

$$H=aI\cos\theta\sqrt{(1+k\cos\phi)^2+(k\sin\phi)^2}$$

where

$$\phi=\frac{4\pi D}{\lambda}\sin\phi$$

Referring to Figure 7 for the nomenclature of the above equation, we assume that the distance to the point P is great enough so that lines drawn from P to the point of maximum current in the antenna, and to that due to the image, are parallel. D is the distance in meters of the center of current above ground level. The electrical distance in radians (in terms of free space velocity) between the center of current in the antenna and that in the image is:

$$\frac{4\pi D}{\lambda}$$

The wave length of operation λ is in meters. At the point P, image radiation lags behind radiation from the antenna by a certain distance "X", which, after accounting for the wave length, and velocity of propagation in free space, is interpreted as an angle φ, which is the angle between the vectors which represent, respectively, the field intensity of radiation due to the antenna, and that due to the image.

The above equation shows that, up to the point where D becomes a quarter wave length, an increase in D flattens the curves of field strength distribution as shown in Figures 5 and 6. As D exceeds this quarter wave length limit, the radiation distribution continues to flatten, but a parasitic lobe of high angle radiation forms, and continues to grow, gradually robbing energy from the main horizontal lobe. In broadcast antenna design, D would therefore be confined to a value of approximately a quarter wave-length, or slightly more, depending upon how large the parasitic lobe could be allowed to form before its presence became detrimental to be objectives of the case. An optimum compromise between these two factors is obtained when the height of the current antinode is approximately 0.28 wave length above ground. In the above equation, "K" represents the coefficient of reflection from the surface of the earth. For a perfectly conducting surface this is unity, and for high conductivity earth may approach unity closely.

The velocity of propagation (V) of currents in a linear antenna system is proportional to the expression:

$$\frac{1}{\sqrt{LC}}$$

where L and C are the inductance and capacitance per unit length of the system. To increase V, the product LC must be reduced; to decrease V, this product must be increased. The former is accomplished by adding units of capacitance at close intervals along a conductor in series with the distributed inductance of the wire, or inductance connected in parallel with the distributed capacitance of the wire to ground. Conversely, to decrease V, capacitance is added in parallel with the wire and inductance added in series. Still another method of reducing V is to increase the length of the conducting path included within a given height by folding the wire in a variety of ways.

Figures 8 to 23 inclusive show methods for taking advantage of the physical principles discussed above. Several general conceptions of practical antenna designs are shown in Figures 8 and 9. In Figure 8 the means for reducing the velocity of propagation (V) and thereby controlling current distribution is had by folding a relatively long wire 40 to occupy a given height and, by the proportions of the configuration, to produce a desired current distribution. Folding a wire for the purpose of securing a greater electrical length is known in the art but so proportioning the folds that a desired predetermined current distribution is obtained is novel and forms an important part of our invention. In Figure 8 the antenna 40 is supported by a triatic 41 which is suspended between suitable elevated supports (not shown). Between the folds of the antenna 40 are rigging wires 42 connected to the antenna by insulators 43. Further supporting the antenna are rigging wires 44 broken into short electrical sections by insulators 45.

In Figure 9, the means for controlling current distribution by reducing the velocity of propagation is by the addition of units of capacitance at close intervals along the conductor and by the addition of units of inductance. The antenna 46 is supported by a triatic 47 suspended between suitable elevated supports (not shown). Rigging wires 48 broken into electrically short sections by insulators also support the antenna 46. At suitable intervals along the antenna 46 there are located inductance and capacitance units. While any suitable inductance and capacitance units may be used, we prefer to use a special inductance unit 50, housed within spherical elements of capacitance 51 and which is essentially toroidal in form. These units are in parallel with the distributed capacitance of the wire to ground and, by virtue of the relative proportions of the units of capacitance as well as the units of inductance in series thereto, produce a desired predetermined distribution of the current throughout the system. The use of capacitors and inductors distributed along a transmission line to change the velocity of propagation is, of course, well known in the telephonic art, but so far as we are aware, the use of inductors and capacitors so distributed along an antenna (perhaps at irregular intervals and of various magnitudes of capacitors and inductors) to produce a predetermined current distribution is novel.

By way of illustration, further examples of other configurations and practical means for obtaining any desired current distribution by controlling the velocity of propagation in any part of the antenna system are shown in Figures 10 to 24 inclusive. In those figures which show schematically the folding of the wire, arrows indicate the direction of current in the wire. In all of these figures, as well as in Figures 8 and 9, the antenna may be energized by means of a generator E (radio transmitter) connected in series with it at the base. In all of these figures also, it is assumed that the antenna is always less than 0.55 wavelength, a restriction of particular interest in broadcast applications as the cost of supporting towers is reduced to a minimum.

In Figure 10 it will be noted that the flow of currents in the vertical elements 52 are all in the same direction, while the currents in the horizontal sections 53 are successively in opposite directions, and being electrically close together, neutralize each other so far as external effects are concerned if of equal magnitudes. The wire folds are made sufficiently short electrically so that the currents in successive horizontal sections are of essentially equal magnitude. If desired, the sections 53 may be of unequal magnitude, thus producing a further variety of current.

In Figure 11 all the elements 54 are diagonal. These resolve themselves into vertical components 55 and horizontal components 56. From this point on, the problem is the same as in Figure 10 and many variations of current distribution forms may be obtained as heretofore pointed out.

In Figure 12, the currents flowing into the branches 57 are made to oppose each other with neutral external effect, by placing branches opposite to each other as shown. In this case when the branches are less than one-quarter wavelength, they act as capacitances in parallel, this effect being due to reflections in the branches. If the length of the branches were between one-quarter and one-half wavelength, they would produce the effect of inductances in parallel with the antenna wire—an effect opposite from that produced by parallel capacitance. Radiation from these branches is maintained at a very low magnitude by making the branches short, and by placing branches in opposite directions at a given point. It is readily apparent from the preceding physical discussion that by using branches of various electrical lengths, uniform or of changing proportions, and by using various separations along the main antenna wire between branches, that a variety of different current distributions are obtained at will in the main antenna wire.

In Figures 13 and 14, there are shown illustrative examples of securing a major increase in the effect of the branches 58 upon the system without a like increase in their length, wherein conducting plates 59 or spheres 60 form a portion of the branch circuits.

In the forms shown by Figures 15 and 16, in addition to the horizontal components 61 balancing out, the one downward vertical component 62 balances out one of the two vertical upward components 63 so that there remains one active vertical upward component producing useful radiation, but with a much reduced velocity of propagation in the antenna system.

In Figure 17, the angular elements resolve themselves into horizontal components 65 and vertical components 66. Thus the problem is the same as in Figures 15 and 16.

In Figure 18, the relatively long wire 67 is spirally disposed, but it may be so proportioned as to obtain any of a number of current distribution forms. There have been applications of folded and spiralled wires for short wave antennae in the previous practice of the art, but primarily for reduction of or elimination of radiation from dipole elements in a radiating system, which contained reversed currents.

Figures 19, 20, 21 and 22 show schematically the folding or spiralling of the wire composing the antenna 68 in such a manner as to produce a gradual acceleration in the velocity of propagation, positive or negative, as desired. By utilizing the new possibilities resulting from this tapering effect, various useful forms of current distribution, such as shown in curves 35 and 36 (Fig. 3) and curve 37 (Fig. 4) as well as others may be obtained. The form shown by curve 37 of Figure 4 is of primary importance in designing broadcasting antennae, which are relatively low, but which may be made to have a relatively great effective height by raising the center of current 69 (Fig. 4) above that which is obtained by common existing antenna practice. Figure 5 shows qualitatively a modification of current distribution which produces very desirable results for broadcast antennae. Curve 38 represents the current distribution resulting from the commonly used uniform straight wire antenna of approximately ⅜ wavelength height. Curve 39 represents a modification of current distribution (such as may be had by the application of our invention) in an antenna of the same height. With curve 39 of Figure 5, the center of current 69 is very much higher above ground level than is the case in curve 38. The relative distribution of field intensities for various angles above the horizon for the two current distributions 38 and 39 are shown in Figure 6.

By means of the control of the velocity of propagation, the current entering the ground terminal is reduced by producing a current node at the ground terminal thereby further increasing the efficiency of the antenna system. This is another important feature of our invention.

The principles of this invention may be further utilized in a variety of ways by combinations of two or more methods of arranging the conductors of the antenna, examples of which are shown in Figures 23 and 24. In Figure 23, side branches 69 are attached at the junctures of angular elements 70 to produce a novel current distribution form. In Figure 24, some of the horizontal components 71 and some of the vertical components 72 are cancelled out, thus shortening the height needed. The utility of any particular form is dependent upon the circumstances in each particular design problem.

A multiplicity of radiators of the type described herein may be beneficially applied as radiating elements in a directive antenna array.

It will thus be apparent to those skilled in the art that we have described means for obtaining a very wide range of desired current distribution forms in an antenna. Some of these apparent desirable results obtained by the novel method of controlling current distribution in an antenna system are raising the center of current, decreasing the loss in the ground connection by decreasing the current flow therein, and eliminating fading by increasing the low angle emission, and also increasing the efficiency of the antenna system. This also becomes useful in solving special problems that frequently arise in connection with reception.

This invention is not limited in its application to the particular construction or constructions herein illustrated, as various changes might be made in the construction or constructions shown, without departing from the spirit of this invention, as set forth in the appended claims.

Having thus fully described our said invention, what we claim as new and desire to secure by Letters Patent is:

1. In an antenna system having one or more reactance units in various sections of the antenna, the method of obtaining non-sinusoidal current distribution which comprises gradually increasing the reactance values in successive units as the distance from the center is increased, whereby a natural velocity of propagation is maintained in the lower sections of the antenna and reduced toward the upper end.

2. In a vertical low velocity antenna of the grounded type for producing uniform radiation in all directions in a horizontal plane, means for controlling the distribution of current in said system whereby the radiated energy in vertical planes is concentrated at low angles, and means associated with said controlling means whereby the center of current is caused to approach an optimum height above the reflecting ground level of approximately 0.28 wavelength.

3. In a vertical antenna of the grounded type for producing uniform radiation in all directions in a horizontal plane and of a length less than one-half wavelength, means for controlling the distribution of current in said system whereby the radiated energy in vertical planes is concentrated at low angles, and means associated with said controlling means whereby the center of current is caused to approach an optimum height above the reflecting ground level of approximately 0.28 wavelength.

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Certificate of Correction

Patent No. 2,083,260. June 8, 1937.

PAUL F. GODLEY, ET AL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 2, first column, line 75, last portion of equation, for "sin ϕ" read *sin* θ; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 24th day of August, A. D. 1937.

[SEAL]

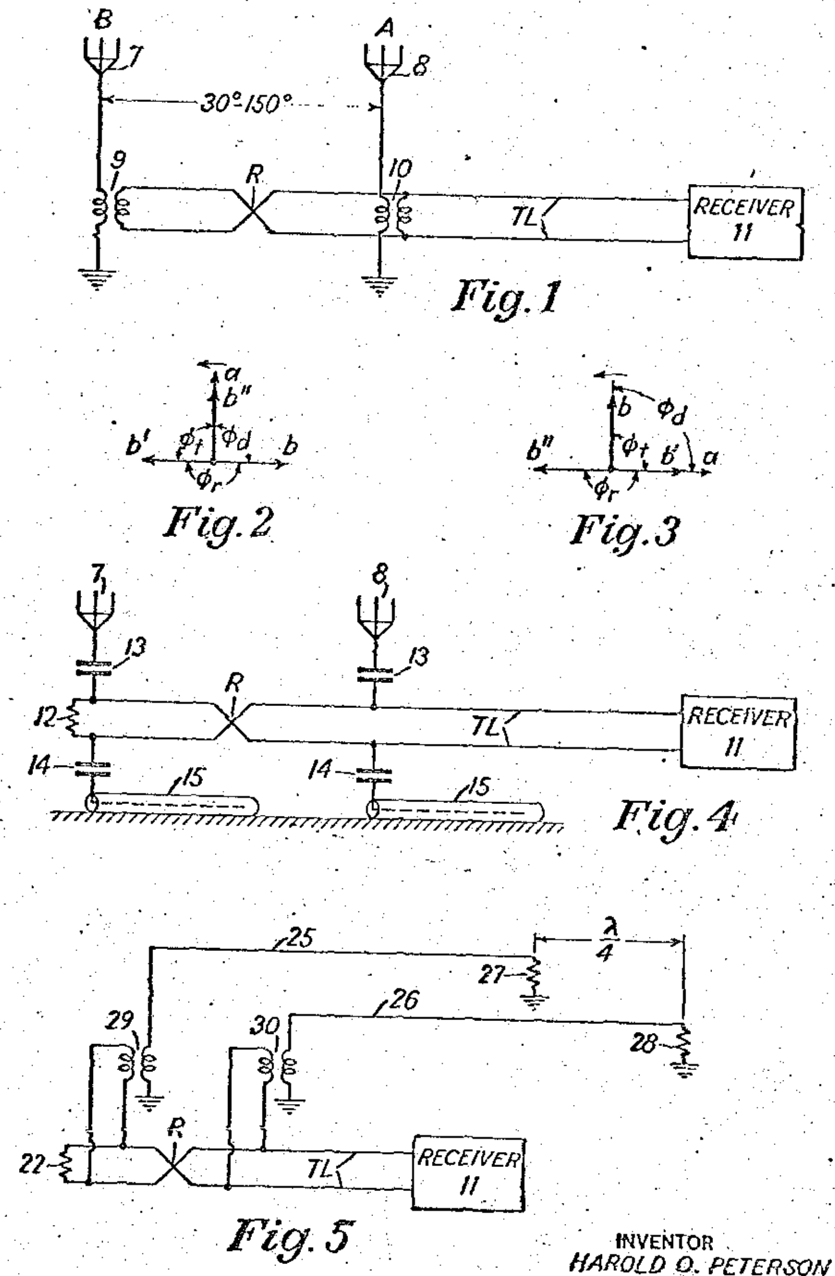
LESLIE FRAZER,
Acting Commissioner of Patents.

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO. 17
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

May 8, 1945. H. O. PETERSON 2,375,580

DIRECTIVE ANTENNA

Filed June 25, 1942 2 Sheets-Sheet 1



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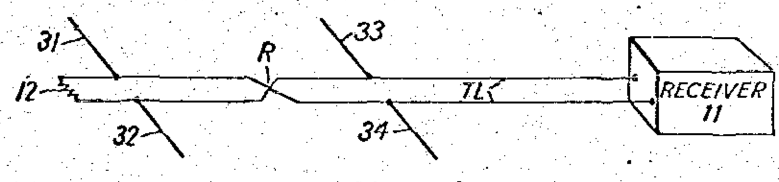

Fig. 6

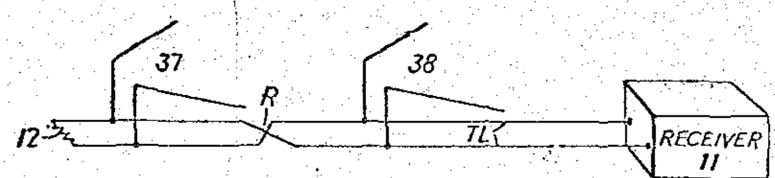

Fig. 7

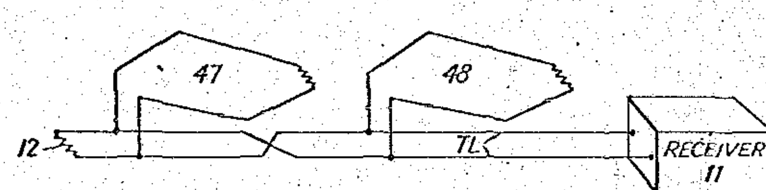

Fig. 8

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Patented May 8, 1945 2,375,580

UNITED STATES PATENT OFFICE

2,375,580

DIRECTIVE ANTENNA

Harold O. Peterson, Riverhead, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application June 25, 1942, Serial No. 448,341

16 Claims. (Cl. 250—11)

The present invention relates to directive antennas and, more particularly, to broad band directive antenna array systems.

An object of the present invention is the provision of a method of arranging two antennas to produce a unidirectional directivity pattern.

Another object of the present invention is to provide an antenna system giving a unilateral response over a broad band of frequencies.

Still another object is the provision of a unilaterally directive antenna system which is not critical as to frequency and which does not need readjustment when the operating frequency is changed. In systems heretofore used it has been possible to produce a unidirectional pattern but the effect has generally only occurred at one particular frequency for which the system was designed.

The foregoing objects are attained, in accordance with the principles of the present invention, by providing a plurality of antennas displaced along the line of signal travel. The antennas are connected through a transmission line to the receiver with phase reversing structure between the antennas. The spacing between the antennas and the length of transmission line are so related that signals arriving from the desired direction combine in additive relationship while signals from the opposite direction combine in an opposing phase relationship thus giving a directivity pattern which is substantially unidirectional in shape.

The present invention will be more fully understood by reference to the following detailed description, which is accompanied by drawings in which Figure 1 illustrates diagrammatically one form of the present invention, while Figures 2 and 3 are vector diagrams explanatory of the principle of operation of the present invention, while Figures 4 to 8, inclusive, diagrammatically illustrate modifications of the form of the invention shown in Figure 1.

In Figure 1 are shown two antennas 7 and 8 at locations A and B spaced from one another. Each antenna is coupled into a transmission line TL by means of coupling transformers 9 and 10. Receiving equipment, conventionally indicated by box 11, is connected to the end of the transmission line nearest the source of the desired signals. Phase reversing structure R is inserted in the transmission line between the points of coupling of antennas 7 and 8. Antennas 7 and 8 are spaced along the line of travel of the desired signal by a distance ranging from somewhat less than 30 electrical degrees to approximately 150 electrical degrees, 360 electrical degrees being one wavelength. Thus the desired unidirectional effect may readily be obtained over a frequency range of greater than 5 to 1.

The vector diagrams shown in Figures 2 and 3, explaining the principle of operation of the antenna of Figure 1, are for the sake of convenience, drawn for the condition where the distance between antennas 7 and 8 is 90 electrical degrees or one quarter wavelength.

Figure 2 shows the condition for a signal travelling in the direction from A to B. The signal first reaches antenna 8 at location A inducing a voltage represented by a in Figure 2. 90 degrees later the wave front reaches antenna B inducing a voltage b 90 degrees behind that induced in antenna A, as indicated by angle ϕ_d. The voltage indicated by b is further changed 180 degrees in phase, as indicated by the angle ϕ_r due to the reversal in the coupling system and is indicated by vector b'. This voltage suffers a further 90 degree lag in travelling back over the transmission line from location B to location A, as indicated by the angle ϕ_t, making a total phase change of 360 degrees which places the voltages from antennas 7 and 8 in phase at location A. This is represented by the coincidence of vectors a and b''. The voltage represented by the addition of vectors a and b'' consequently is transmitted over transmission line TL to receiver 11.

In Figure 3 is shown the condition for a signal travelling in the direction from location B to location A. The wave front first induces a voltage in antenna 7 indicated by vector b and 90 degrees later, as indicated by angle ϕ_d, a voltage represented by vector a in the antenna 8. The voltage represented by vector b originally induced in antenna 7 at location B loses 90 degrees in travelling along the transmission line TL over the distance from B to A, as indicated by the angle ϕ_t and is identified by vector b'. Another 180 degrees of phase change, indicated by the angle ϕ_r, is caused by the phase reverser R. Consequently, the voltage b'', which was induced in antenna B, is exactly 180 degrees out of phase with the voltage a contributed by the antenna at location A when it arrives at that position and, therefore, the two cancel each other and no signal is received at receiver 11. If the velocity of propogation along the transmission line is substantially equal to that of light, signals received in the direction from B to A will always cancel each other due to the reversal in the coupling system within the range of spacings I have indicated, whereas the additive effect for signals travelling in the other direction, that is, from A to B will generally amount to an appreciable value depending, to some extent, upon the distance between locations A and B.

In Figure 4 I have shown another arrangement of antennas based on the same principle as Figure 1. In this case, the antennas 7 and 8 are coupled to the transmission line through coupling condenser 13, while balancing condensers 14 are connected between the transmission line and artificial lines 15. Condensers 14, together with the artificial lines 15, are so arranged as to balance the reactance of the antenna loading of the other side of the line. The artificial line sections 15 may have an electrical length equivalent to the electrical length of antennas 7 and 8 and include resistance components such as to perfectly match the impedances of antennas 7 and 8. In some cases it may not be necessary to actually use artificial line sections 15 but the condensers 14 may be directly connected to ground. In this figure I have shown the transmission line TL as being terminated by a damping resistance 12 having a value equal to the surge impedance of the transmission line.

Figure 5 shows the principle of the present invention as applied to a pair of wave antennas 25 and 26 which, by virtue of their damping impedances 27 and 28, are, in themselves, relatively unidirectional. The wave antennas are several wavelengths long and may be built on pole lines spaced 15 to 50 feet apart. The end-on displacement between the two antennas may be of the order of a quarter wavelength for the most generally used frequency. The wave antennas 25 and 26 are coupled to transmission line TL through coupling transformers 29 and 30. The damping resistance 22 is connected across the short end of the transmission line for the same purpose as damping resistance 12 in Figure 4.

The system of the present invention may also, as shown in Figure 6, be applied to balanced antenna systems. In Figure 6 the balanced antennas consist of doublets 31, 32 and 33, 34. While they are indicated in perspective as being horizontally arranged they may, of course, for vertically polarized waves, be vertically arranged.

Except for the difference in types of antennas shown, the operation of the modification of Figure 6 is the same as that of Figure 1.

Furthermore, the system of the present invention may be applied to a pair of V antennas 37, 38 of Figure 7 and, as before, the antennas connected to a transmission line TL having a phase reversing arrangement R between the two antennas.

Similarly, as shown in Figure 8, the system may be applied to a pair of rhombic antennas 47 and 48.

While the system of the present invention has been described particularly with reference to receiving antennas it may, of course, be equally well applied to transmitting antennas. Furthermore, a combination of two antennas set up according to the principles heretofore described may be duplicated by another group of similar antennas displaced from the first group and the two groups in turn combined according to the principles above set forth.

While I have shown and particularly described several embodiments of my invention, it is to be distinctly understood that my invention is not limited thereto but that modifications within the scope of my invention may be made.

I claim:

1. A unilaterally directive antenna system including transducer equipment, a transmission line extending from said equipment along a line away from the direction of maximum response, a plurality of antennas located at spaced points along said line and coupled to said transmission line, and phase reversing means in said transmission line between said antennas, the distance between said antennas and the length of transmission line therebetween being so related that said system has a maximum response to signals from only one direction.

2. A unilaterally directive antenna system including transducer equipment, a transmission line extending from said equipment along a line away from the direction of maximum response, a plurality of antennas located at spaced points along said line and coupled to said transmission line, and phase reversing means in said transmission line between said antennas, the distance between said antennas and the length of transmission line therebetween being so related that said system has substantially no response to signals travelling in the direction from the free end of said transmission line toward said transducer equipment.

3. A unilaterally directive antenna system including transducer equipment, a transmission line extending from said equipment along a line away from the direction of maximum response, a plurality of antennas located at spaced points along said line and coupled to said transmission line, and phase reversing means in said transmission line between said antennas, the distance between said antennas and the length of transmission line therebetween being between 30 and 150 electrical degrees.

4. A unilaterally directive antenna system including transducer equipment, a transmission line extending from said equipment along a line away from the direction of maximum response, a pair of antennas located at spaced points along said line and coupled to said transmission line, and phase reversing means in said transmission line between said antennas, the distance between said antennas and the length of transmission line therebetween being between 30 and 150 electrical degrees.

5. A system, as set forth in claim 4, wherein said transmission line is terminated at its other end by a resistor having a resistance equal to the surge impedance of said line.

6. A system, as set forth in claim 4, wherein each of said antennas is a long wire antenna having its free end in the direction of maximum response.

7. A system, as set forth in claim 4, wherein each of said antennas is a long wire antenna having its free end in the direction of maximum response, each of said free ends being connected to ground through a resistor having a resistance equal to the characteristic impedance of said antenna.

8. A system, as set forth in claim 4, wherein each of said antennas is a horizontally disposed dipole.

9. A system, as set forth in claim 4, wherein each of said antennas is a vertically disposed dipole.

10. A system, as set forth in claim 4, wherein each of said antennas is a V antenna.

11. A system, as set forth in claim 4, wherein each of said antennas is a rhombic antenna having its end remote from its coupling to said transmission line directed in the direction of maximum response.

12. A unilaterally directive antenna system in-

cluding transducer equipment, a transmission line extending from said equipment along a line away from the direction of maximum response, a plurality of antennas located at spaced points along said line and coupled to said transmission line, and phase reversing means in said transmission line between said antennas, the distance between said antennas and the length of transmission line therebetween being of the order of a quarter wavelength whereby said system has substantially no response to signals travelling in the direction from the free end of said transmission line toward said transducer equipment.

13. A unilaterally directive antenna system including transducer equipment, a transmission line extending from said equipment along a line away from the direction of maximum response, a plurality of antennas located at spaced points along said line and coupled to said transmission line, and phase reversing means in said transmission line between said antennas, the distance between said antennas and the length of transmission line therebetween being of the order of a quarter wavelength.

14. A system, as set forth in claim 12, wherein said transmission line is terminated at its other end by a resistor having a resistance equal to the surge impedance of said line.

15. A system, as set forth in claim 12, wherein each of said antennas is a long wire antenna having its free end in the direction of maximum response.

16. A system, as set forth in claim 12, wherein each of said antennas is a long wire antenna having its free end in the direction of maximum response, each of said free ends being connected to ground through a resistor having a resistance equal to the characteristic impedance of said antenna.

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BROAD BAND ANTENNA SYSTEM

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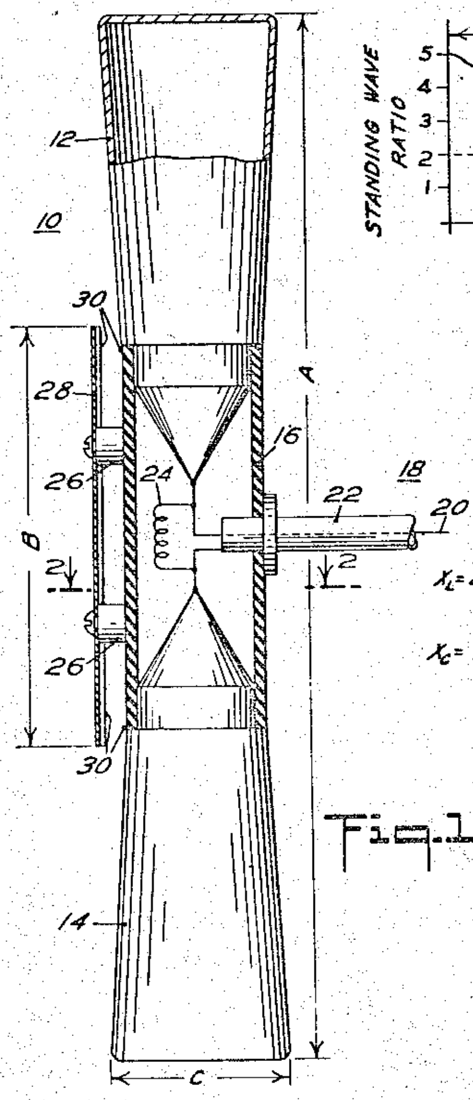

Fig.1.

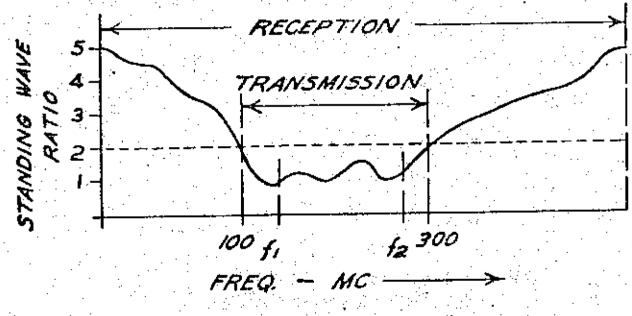

Fig.3.

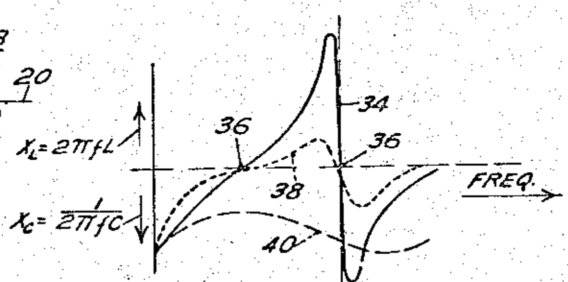

Fig.4.

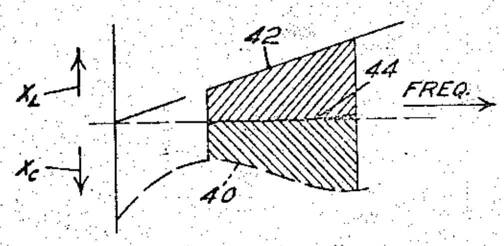

Fig.5.

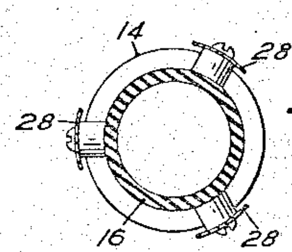

Fig.2.

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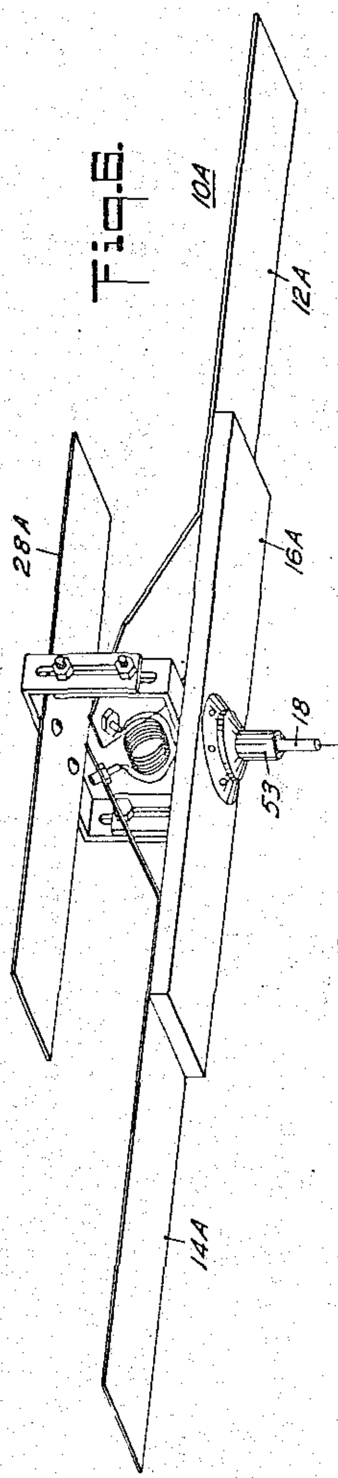

Fig. 6.

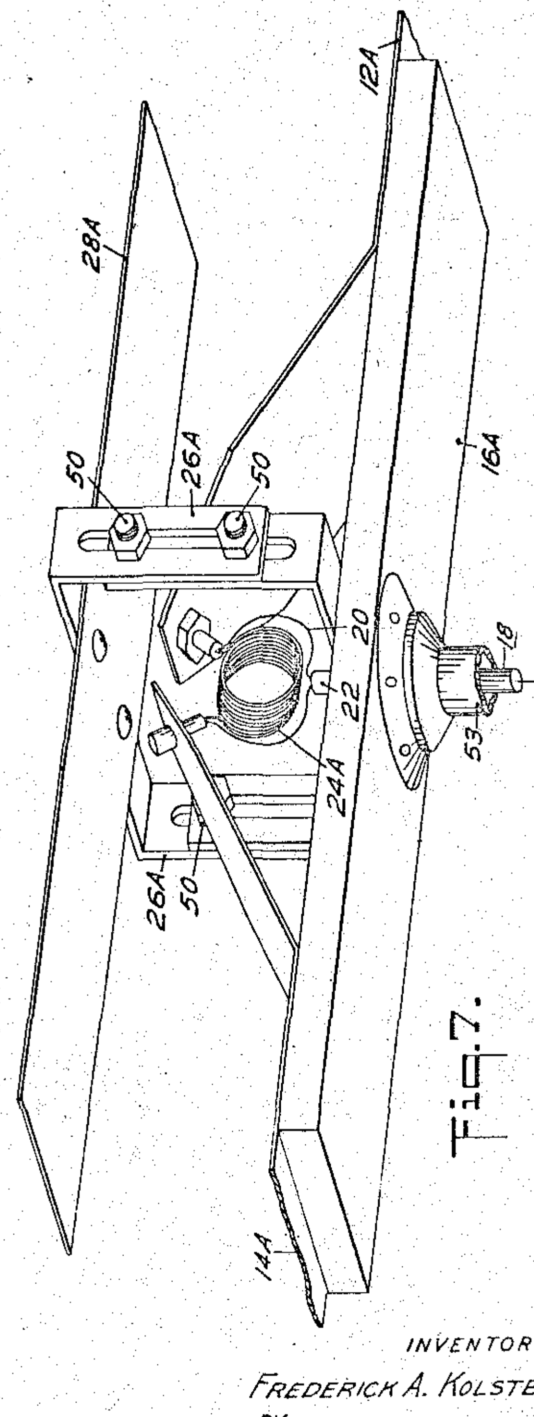

Fig. 7.

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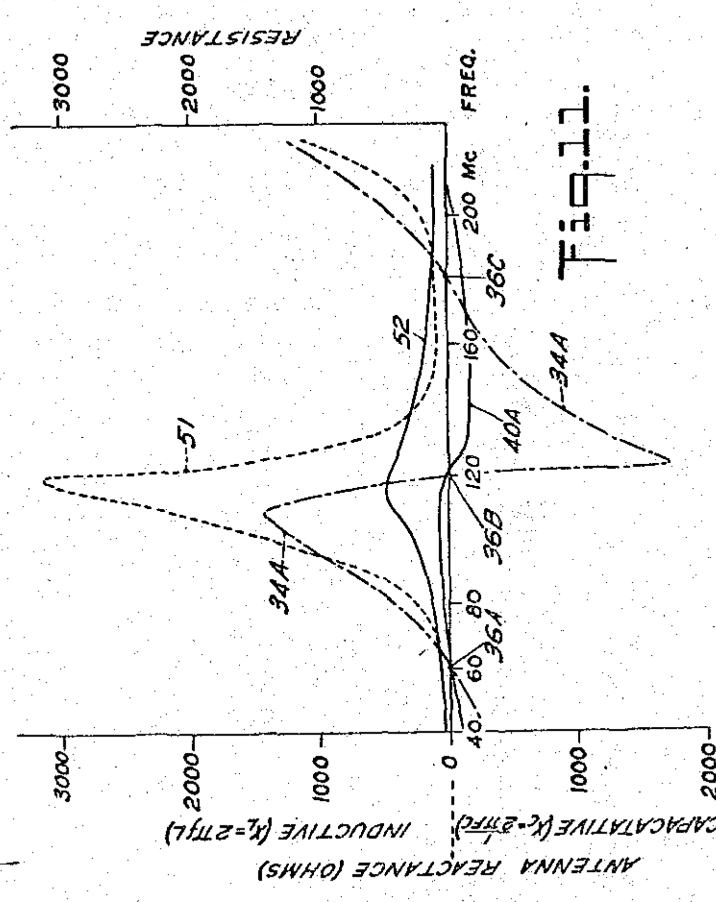

Fig. 11

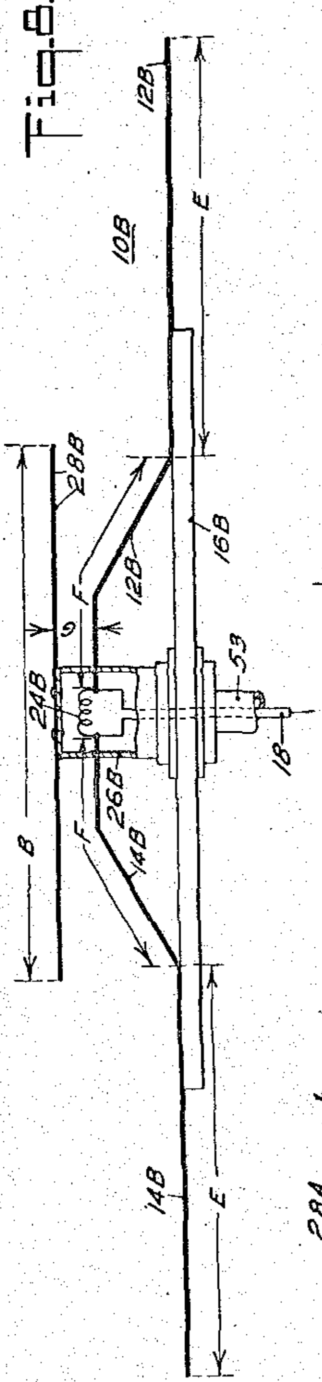

Fig. 8

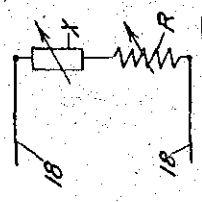

Fig. 10

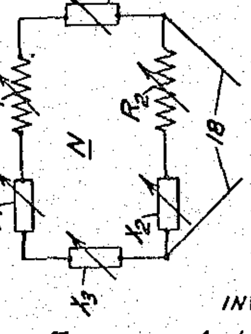

Fig. 9

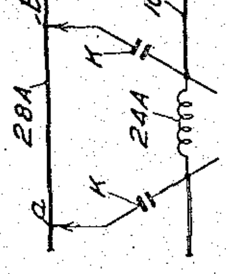

Fig. 8-A

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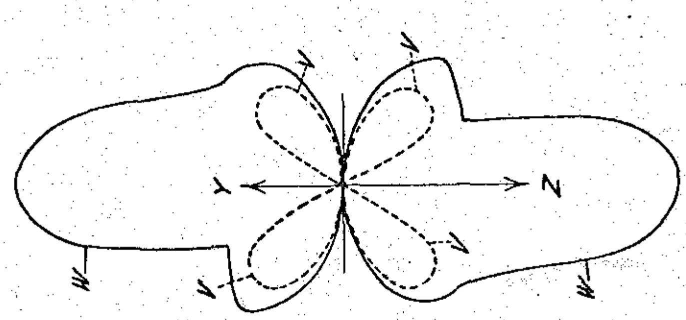

Fig. 16.

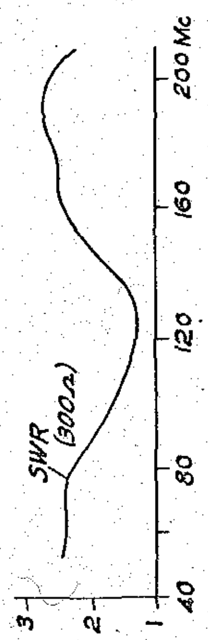

Fig. 12.

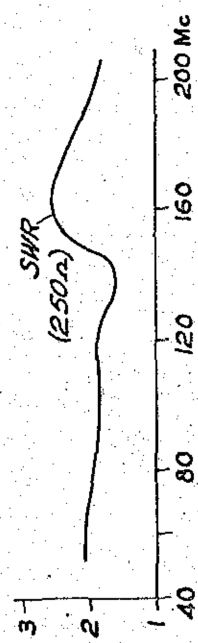

Fig. 13.

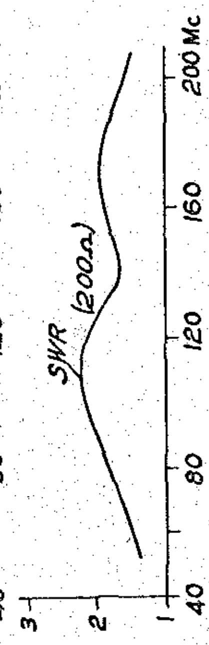

Fig. 14.

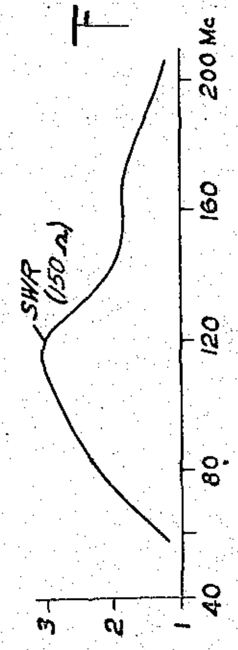

Fig. 15.

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Patented Jan. 1, 1952 2,580,798

UNITED STATES PATENT OFFICE

2,580,798

BROAD-BAND ANTENNA SYSTEM

Frederick A. Kolster, San Francisco, Calif.; Muriel Kolster administratrix of said Frederick A. Kolster, deceased

Application May 22, 1947, Serial No. 749,699

15 Claims. (Cl. 250—33.59)

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This invention relates to antenna systems, and particularly to antenna systems suited for efficient operation throughout, or anywhere within, a wide band of frequencies.

Generally in accordance with the invention, to provide an antenna system efficiently operative throughout a wide band of frequencies or at any frequency within a wide band, there are utilized two or more low "Q" dipoles of substantially different length so coupled that their net reactance as seen by the associated transmission line is low at all frequencies within that band.

More specifically, the self and mutual impedances of the dipoles effectively form a band-pass network which when reduced to its simple equivalent series circuit for each frequency of the band appears to the transmission line as a low reactance in series with a resistance of such magnitude that for all frequencies of the band the impedances of the antenna and line are suitably matched to insure a low standing wave ratio.

Further in accordance with the invention, the shorter dipole controls the amplitude and phase of current in the longer dipole, particularly at and near the harmonic frequencies thereof, to prevent occurrence of undesirable nulls in the field pattern of the antenna and so insure that throughout the wide frequency coverage of the antenna it always favors, or nowhere discriminates against, reception or transmission in the desired direction.

The invention further resides in features of construction and operation hereinafter described and claimed.

For an understanding of the invention and for illustration of embodiments thereof, reference is made to the accompanying drawings, in which:

Fig. 1, partly in section, illustrates one form of broad-band antenna;

Fig. 2 is a sectional view taken on line 2—2 of Fig. 1;

Fig. 3 is a frequency versus standing-wave-ratio curve discussed in connection with Fig. 1;

Fig. 4 comprises frequency versus reactance curves discussed in connection with Fig. 1;

Fig. 5 graphically represents modification of the antenna characteristic by addition of loading inductance;

Fig. 6 is a perspective view of another broad-band antenna embodying the invention;

Fig. 6A is an explanatory figure referred to in discussion of Figs. 6 and 8;

Fig. 7, in perspective and on enlarged scale, shows constructional details of the antenna of Fig. 6;

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Fig. 8 is an elevational view of a further modified form of broad-band antenna;

Fig. 9 is a complex network referred to in discussion of Figs. 6 to 8;

Fig. 10 represents the series circuit equivalent of Fig. 9;

Fig. 11 is an explanatory figure referred to in discussion of the reactance-frequency and resistance-frequency characteristics of the antennae of Figs. 6 to 8;

Figs. 12 to 15 are frequency versus standing-wave-ratio curves discussed in connection with Figs. 6 to 8; and

Fig. 16 comprises field patterns discussed in connection with the antennas of Figs. 6 to 8.

In the embodiment of the invention shown in Figs. 1 and 2, the dipole 10 consists of two antenna elements 12 and 14 supported by tube 16 of suitable insulating material. The antenna elements are conductively connected to the associated receiving or transmitting apparatus by a transmission line 18 which may be, as shown, a concentric line consisting of an inner conductor 20 and an outer conductor 22 respectively connected to the adjacent ends of the antenna elements 12, 14.

Preferably and for reasons later discussed, an inductance 24 is connected in parallel with the transmission line at its antenna termination. The antenna may, however, be used without such inductance with realization of some but not all of the advantages attained when the inductance is used.

The insulating spacers 26 supported by cylinder 16 in turn support auxiliary dipole elements 28, each capacitively coupled at its opposite ends 30 to the transmission line 18 through the capacitance between the ends of the auxiliary dipole and the adjacent main dipole elements 12 and 14 respectively.

Though, as in Fig. 1, the main dipole elements may be somewhat conical in shape, they may be of practically any cross sectional form provided the average transverse section is sufficiently great to obtain a low "Q," and to enable adequate capacitive coupling at points 30. If desired, for example, the antenna elements may each be formed in the shape of a right circular cylinder, or may be of diamond or elliptical vertical section: preferably, as in later embodiments exemplified by Figs. 6, 7 and 8, they may be wide flat strips.

Though the auxiliary dipoles 28 are preferably longitudinal strip conductors, as shown in this and other modifications of the invention, they may be of other physical shape. The strips 28, Fig. 2, may be increased in width circumferentially of the main dipole elements if desired. It is also possible to use but one auxiliary dipole 28 or to replace all of them by a cylindrical conductor of the same length disposed concentrically about the main dipole elements 12 and 14. The band-pass characteristics of the antenna may be varied by bending the ends of dipoles 28 toward or away from the main dipole 10 to increase or decrease the capacity coupling between them.

For use in transmission, excitation is applied to the antenna through the transmission line 18. Assuming the excitation frequency is in the neighborhood of the natural or fundamental resonant frequency of dipole 10, it will radiate but since this frequency is much lower than the natural frequency of the auxiliary dipoles, they produce very little radiation at such frequency. However, because the dipoles 28 are capacitively coupled to both of the radiating elements 12 and 14, the capacitance between the latter is effectively increased and the resonance band of dipole 10 is effectively widened.

Assuming now the excitation frequency is much higher (approximately the natural or fundamental frequency of the auxiliary dipoles 28), the main dipole 10 produces very little radiation; however, the auxiliary dipoles 28, each excited through the capacitance at points 30, produce considerable radiation at such high frequency.

At all frequencies intermediate their natural frequencies, the dipoles 10 and 28 act in supplementary manner to produce satisfactory radiation or absorption characteristics of the composite antenna formed by them, and in fact, as later discussed in connection with Fig. 3, the antenna system of Fig. 1 has very satisfactory characteristics considerably below the natural frequency of dipole 10 and considerably above the natural frequency of dipole 28.

In one physical embodiment of Fig. 1, the overall length A of the main dipole 10 was approximately 42 inches, the length of each auxiliary dipole was approximately 17 inches and the maximum diameter C of each main dipole element was approximately 8 inches. The antenna so dimensioned had satisfactory radiation characteristics throughout the range of from 100 megacycles to 300 megacycles which covers a large number of channels assigned to public, private and government services for many uses including television broadcast, frequency-modulated broadcast, and point to point communications. It should be noted the ratio of the terminal frequencies of this band is 3 to 1, whereas with previous so-called broad-band antennas the ratio of terminal frequencies was at best only about 1.25 or 1.5 to 1 and that obtainable only by recourse to dipole elements of excessively large cross-sectional dimensions, prohibitive, on shipboard for example, where space is at a premium and in all cases creating difficult mounting and construction problems. It should further be noted that the operating range of such previous so-called broad-band antennas did not extend through any harmonic or multiple resonance frequency of the antenna.

An antenna constructed in accordance with the invention is not dimensionally critical: that is, the shape and size of the dipole elements may be varied within reasonable limits without adversely affecting the radiation or absorption characteristics which can be adjusted for attainment of the desired band-pass by bending or deforming the auxiliary dipoles or by changing the value of inductance 24.

For efficient transfer of energy between any antenna and the associated transmission line, the standing-wave-ratio, later herein defined, must be low and ideally is unity. However, an antenna is considered an efficient radiator if the standing-wave-ratio (SWR) does not exceed 2 or 3 and as a satisfactory absorber if the standing-wave-ratio is not much greater than 5.

Fig. 3 is the SWR curve of an antenna constructed in accordance with Fig. 1 and having the dimensions above given. The main dipole 10 was dimensioned to resonate at frequency f_1, somewhat higher than 100 megacycles and the auxiliary dipoles 28 were dimensioned to resonate at frequency f_2 somewhat lower than 300 megacycles. As shown in Fig. 3, the standing-wave-ratio, though varying within the limits 100 to 300 megacycles, did not, at any frequency within those limits, exceed 2 and did not exceed 5 throughout a much wider range of frequencies extending well below 100 megacycles and substantially above 300 megacycles. For this curve, the characteristic impedance of the line 18 used with the antenna was about 50 ohms.

During either radiation, for transmission, or absorption, for reception, the antenna of Fig. 1 acts as, and may be considered the operating equivalent of, a band-pass filter with broad-band characteristics. This is true not only of the particular construction shown in Fig. 1, but of all modifications including those later herein disclosed and described.

The curve 34, Fig. 4, is exemplary of the reactive impedance characteristic of a dipole having small transverse cross section, for example, a wire or rod of small diameter. At each of points 36 where the curve 34 crosses the horizontal axis, the slope of the curve is steep, indicating sharp resonance. An antenna having such sharp resonance is wholly unsuited for efficient radiation at frequencies appreciably displaced from its fundamental resonant frequency because of the resulting large mismatch between its impedance and that of the associated transmission line.

Broadening the dipole elements into a large surface of revolution, as in Fig. 1, effects flattening of the reactive impedance of the antenna, generally as shown by curve 38. The greatly decrease slope of curve 38 at each of points 36 where the curve crosses the horizontal line (zero reactance) indicates a condition of substantial resonance exists over a fairly broad band, insufficient, however, to attain the results here sought. The expedient of increasing the thickness or cross section of a single dipole cannot, practically be extended to attain band widths of the magnitude obtained by my composite antenna. By the further addition of capacitance by addition of the auxiliary dipoles 28 to the primary dipole 10, there is produced the characteristic curve 40, indicating my antenna, Fig. 1, has net capacitive reactance throughout the frequency range of 100 to 300 megacycles, and that the magnitude of the changes in reactance throughout the range is very materially reduced.

Having in mind the composite antenna including the auxiliary dipoles and widened main dipole has the frequency-reactance characteristic exemplified by curve 40, the effect of the inductance 24 having the rising frequency-reactance characteristic 42 is evident from Fig. 5. It is pointed out the uncorrected antenna reactance characteristic 40, throughout a wide range of frequencies, closely approximates a mirror image or reflection of curve 42 about the horizontal axis. Consequently, within that range and by use of suitable inductance 24, the resultant antenna reactance is a nearly straight line 44 practically coincident with the horizontal axis; otherwise stated the antenna has very small net reactance throughout a broad frequency band. To attain this characteristic with the antenna constants above given, the coil 24 had an inductance of about 0.3 microhenry.

The inductance 24 may, as shown in Fig. 1, be connected across the terminals of the transmission line 18; to improve the symmetry when the transmission line is, as preferably, of the concentric conductor type the outer conductor 22 of the line may be connected to the center of inductance 24, the other connections remaining unchanged.

Though the construction and operation of the antenna has been described with inductive reactance 24 connected between the main dipole elements, it has been found that a capacitive reactance, or condenser, may be so connected in lieu of coil 24. The effect of such insertion upon a dipole antenna having a characteristic such as exemplified by curve 38 of Fig. 4 is to reduce the upper or positive peak value and, with addition of auxiliary dipoles, the resultant characteristic will approximate curve 40. In other words, the antenna reactance with a condenser substituted for coil 24 is low.

From the foregoing, it is evident a broad band antenna need not have the excessive dimensions otherwise required in absence of the capacitive and radiating effects of the auxiliary dipoles 28. Moreover and from a mechanical standpoint, the antenna may be of simple durable construction, easily installed and can be manufactured inexpensively and without need to hold close tolerances.

The modification shown in Fig. 1 is disclosed in my copending application Serial No. 622,657, now abandoned, of which this application is a continuation in part.

Subsequent embodiments of the invention which are not only of even less expensive and simpler construction but which still further and very materially increase the frequency coverage are shown in Figs. 6, 7 and 8.

In the modification shown in Figs. 6 and 7, the main dipole 10A comprises two elements 12A, 14A each consisting of a wide flat strip of aluminum or other suitable metal. The inductance per unit length of each element is low and the capacitance per unit length is high, i. e., the ratio of inductance to capacitance per unit length is low. The "Q" of each dipole is therefore low, for example, of the order of 5 and preferably much less. The two strips 12A, 14A are held in axial alignment by their attachment to a strip or plate 16A of suitable insulating material. near their adjacent ends, the strips 12A and 14A are bent away from their support 16A to afford capacitive coupling to the auxiliary dipole 28A.

In this modification, like that of Fig. 8 later described, the ends of the auxiliary dipole are well away from the main dipole so that in effect each of the main dipole elements 12B, 14B is respectively coupled by capacity to an intermediate point of the overlying half of the auxiliary dipole. The band characteristic is generally that of two low Q dipoles 10A, 28A which are parallel throughout (Fig. 6A), but interconnected by condensers K, K to points *a* and *b* selected to obtain a satisfactory impedance match between the antenna and line at the higher frequencies of the band for which the auxiliary dipole is effective as a radiator or absorber.

The coupling capacities are also significant at the lower frequencies of the band. For example, the coil 24A may be selected so that with these capacities it forms a loop circuit which is resonant at about the frequency for which the main dipole exhibits fundamental resonance. Therefore, at that frequency, this loop circuit is the equivalent of a very high shunt impedance and the main dipole consequently performs much as a simple center-fed half-wave dipole. At lower and higher frequencies, this loop circuit exhibits inductive and capacitive reactance respectively so that the main dipole again becomes resonant at a frequency below its natural frequency and exhibits reduced impedance at frequencies above its natural frequency.

The auxiliary dipole 28A is also a wide strip of aluminum or other suitable metal having small inductance and large capacitance per unit length. It is supported centrally of the main dipole 10A with its longitudinal axis substantially in alignment with and parallel to the axis of the main dipole by a metal bracket 26A which comprises two U-shaped members respectively fixedly attached to dipole 28A and the support 16A and adjustably attached to each other as by bolts 50. The wide faces of the strips 12A, 14A and 28A are parallel to each other for large mutual coupling reactance of the dipoles. The adjustment afforded by the split bracket permits variation of capacitive coupling between the dipoles in empirical attainment of the desired band width.

The antenna assembly is supported by the mast 53, preferably tubular for enclosure of the transmission line. The mast may be fixedly or rotatably fastened at or near its base to a tower, roof, vehicle body or other fixed or mobile structure. In this and other modifications disclosed, the axis of the antenna may be vertical or horizontal in dependence upon the polarization of the waves to be transmitted or received.

Preferably and as shown, the adjacent ends of the main dipole elements 12A, 14A are connected to an inductance 24A having generally the purpose of coil 24 of Fig. 1. It is preferably included as one element of the broad band-pass network N, Fig. 9, comprising the self and mutual reactances of the two dipoles and their effective resistances. As is later more fully discussed in connection with the quite similar antenna construction shown in Fig. 8, this network as seen by the transmission line 18 is the equivalent of a reactance X and a resistance R in series, Fig. 10. The effective magnitude of the resistance R and the magnitude of the reactance X vary with frequency but the main and auxiliary dipoles are so dimensioned and coupled that the vector sum of the resistance and reactance remains quite constant throughout an extremely wide band of frequencies.

In the embodiment shown in Fig. 8, the main dipole 10B comprises two wide strips 12B, 14B of suitable conductors affording a dipole having a low "Q" and an auxiliary dipole 28B, also a wide conductive strip to obtain a low "Q." The auxiliary dipole 28B is supported by housing 23B in that position with respect to the main dipole 10B which by virtue of the dimensions of the dipoles and the coupling between them affords the desired band-pass characteristic. For that purpose, the housing 26B is suitably fastened to the supporting strip 16B of the main dipole. The housing 26B, preferably of good high-frequency insulating material, also forms an enclosure for the loading reactance 24B, and for the connections of transmission line 18 to protect them from weather conditions otherwise temporarily or permanently affecting the operating characteristics of the antenna.

Both the main dipole 10B and the auxiliary dipole 20B have small inductance and large capacitance per unit length so that considered individually neither of them exhibits sharp resonance at any frequency. The complex network N, Fig. 9, formed by the self and mutual reactances X_1, X_2 and X_3X_4 of the dipoles and their effective resistances R_1, R_2 may be represented by an equivalent circuit, Fig. 10, comprising reactance X and resistance R in series across the antenna end of the transmission line 18. The magnitudes of reactance X and resistance R are different for different frequencies, but in accordance with this invention the reactance X is low for all frequencies within a very wide band and at each frequency within that band the magnitudes of reactance and resistance are such that their vector sum closely approximates their vector sum at all other frequencies within the aforesaid wide band. The significant difference between the characteristics of my antenna system, Figs. 6, 7, 8, and that of the usual dipole can best be illustrated by specific examples based on measurements.

Referring to Fig. 11, the dot-dash curve 34A is the frequency-reactance curve of a dipole of ⅜" diameter copper tubing which is a half-wavelength long at a frequency of about 60 megacycles. As evident from the curve, within a frequency range of from about 40 to 200 megacycles, the reactance varies from well over 1000 ohms (inductive) to well over 1000 ohms (capacitive) and rapidly changes with frequency particularly in the vicinity of points 36A, 36B and 36C corresponding with frequencies of about 60, 120 and 180 megacycles respectively.

Within the range of 40 to 200 megacycles, the reactance of the dipole swings back and forth in sign, that is, it changes to positive or inductive reactance from negative or capacitive reactance as the frequency is increased from below to above about 60 megacycles, reverses back to capacitive reactance as the frequency is increased from below to above 120 megacycles, and again shifts to inductive reactance as the frequency shifts from below to above 180 megacycles. In other words, the effective reactance of the dipole changes sign, and changes rapidly in magnitude, at frequencies corresponding with the fundamental and harmonic wavelengths of the dipole.

Furthermore, the effective resistance of the single thin dipole varies widely over this same range of frequencies; as shown by curve 51, Fig. 11, the effective resistance is low, less than 100 ohms, for frequencies at which the antenna is a half-wavelength long, but is very high, about 3,000 ohms, for frequencies at which the antenna is a full wavelength long.

Still referring to Fig. 11, the solid line curve 40A is the frequency-reactance curve of an antenna constructed in accordance with Fig. 8 and having the following dimensions for service as a transmitting antenna in the frequency range of from about 40 to 200 megacycles: each of the dipole elements 12B, 14B and 20B was a strip of aluminum one-eighth of an inch thick and four inches wide: the dimensions E and F of each main dipole element were 34 inches and 14 inches respectively: the length B of the auxiliary dipole was 28 inches: and the spacing G was 2½ inches.

Throughout the range of frequencies from 40 to over 200 megacycles, the equivalent series reactance X of that antenna system as evident from inspection of curve 40A, was low and nowhere in that range varied rapidly. Moreover, the effective resistance R of that antenna system, as shown by curve 52, Fig. 11, was throughout that range of frequencies of such magnitude at each frequency that the effect of the variations in reactance upon the effective antenna impedance was minimized. The variation in magnitude of the effective resistance with frequency is far less than the usual dipole throughout the frequency range of 40 to 200 megacycles.

In brief, my antenna system, and particularly as exemplified by Figs. 6, 7 and 8 comprises multiple low "Q" dipoles of different lengths so coupled that their self impedances and mutual impedances form a network (*n*, Fig. 9) which when reduced to its simple equivalent series circuit (Fig. 10) for each frequency will provide at the terminals of the transmission line a low reactance X and a series resistance R of such magnitude that for all frequencies throughout an extremely wide range, the effective antenna impedance

$$[Z=\sqrt{X^2+R^2}]$$

will so closely match the characteristic impedance of the transmission line that the stand-wave-ratio will be low throughout that wide range of frequencies.

The standing-wave-ratio (SWR) may be defined es

$$(1)\qquad SWR=\frac{1+K}{1-K}$$

wherein

$$(2)\qquad K=\sqrt{\left[\frac{R^2-Z_0^2+X^2}{(R+Z_0)^2+X^2}\right]^2+\left[\frac{2Z_0X}{(R+Z_0)^2+X^2}\right]^2}$$

in which

Z_0=characteristic impedance of transmission line

R=equivalent series resistance of antenna (Fig. 10)

X=equivalent series reactance of antenna (Fig. 10)

By substitution in Equation 2 of the magnitudes of effective reactance and resistance ascertainable from curves 40A and 52 of Fig. 11 for the frequencies within the range of from 40 to over 200 megacycles, it is apparent the standing wave ratio is less than 3 when the characteristic impedance of the transmission line is 300 ohms. This was verified by actual measurements which as plotted resulted in curve SWR of Fig. 12. This antenna system is therefore efficient for transmission at any frequency within the range of 40 to well over 200 megacycles; i. e., over better than a 5 to 1 frequency coverage, and is efficient for reception over a much wider range.

Furthermore, and as evident from inspection of Figs. 13 to 15, the characteristic impedance of the transmission line 18 is not critical when this antenna is used. Throughout the same extremely wide frequency range, the standing-wave-ratio (SWR) is suitably low, less than 3, when the antenna is used with transmission lines having impedances of 250, 200 and 150 ohms, and also, as can be verified, with higher and lower impedance lines although if the line impedance is too far above 300 ohms or too far below 150 ohms, the standing-wave-ratio for this particular antenna will be excessive.

From the general rules above given, illustrated by specific example, those skilled in the art may readily design and construct other broad band antennas suited individually to cover a wide range in this and other portions of the radio frequency spectrum and which throughout that range will satisfactorily match the characteristic impedance of the associated transmission line.

The auxiliary dipole or dipoles not only provide for efficient radiation or absorption over a broad band of frequencies but may be dimensioned concurrently to insure that throughout the band the field pattern is free of nulls in the desired direction of reception or transmission. For example, with the particular composite antenna discussed in connection with Fig. 11, at each of various frequencies in the lower frequency portion of the band, say from 40 to 100 megacycles, at which the main dipole is primarily effective, the field pattern is approximately the same as those of an ordinary dipole; that is, it has two lobes forming a figure eight, affording best reception or transmission in a line of direction normal to the longitudinal axis of the antenna.

At the higher frequencies of the range, the field pattern of the main dipole, of and by itself, assumes different forms having marked nulls in the desired direction of operation. For example, the field pattern of the main dipole at about 120 megacycles is a four-lobed, or clover-leaf pattern exemplified by the broken line curve V of Fig. 16, having wide, deep nulls in both the Y and Z directions normal to the antenna axis. At still higher frequencies, say about 200 megacycles, the field pattern of the main dipole is a six-lobed figure similar to curve V plus two minor lobes normal to the line Y—Z.

At the higher frequencies, however, the auxiliary dipole becomes increasingly effective so that its individual directional characteristic modified that of the main dipole with the result that at all the higher frequencies at which undesirable nulls would otherwise occur, the combined field pattern of the dipoles is one affording satisfactory reception or transmission in the desired direction. For example, the radiation characteristic of the combined antenna system at 120 or 200 megacycles, as generally exemplified by the solid line curve W of Fig. 16, has substantial directional selectivity favoring reception or transmission in the desired line of direction Y—Z, whereas the main dipole itself, at that same frequency markedly discriminates against reception or transmission in that same line of direction.

Generally and in brief, the auxiliary dipole not only provides for proper matching of the antenna and its transmission line over a wide band of frequencies, but also controls the amplitude and phase of the current in the main dipole, particularly at its harmonic frequencies, thus to prevent serious lobing and appearance of undesirable nulls in the field pattern at any frequency within that wide band.

In view of the foregoing description of their dimensions, spacing and characteristics, the auxiliary dipoles of Figs. 1, 2, 6, 7 and 8 should not be confused with the directors or reflectors used in directional antenna arrays to attain enhanced directional selectivity at a particular frequency. In physical and electrical length, directors and reflectors differ only a few per cent, or less, from the associated driven dipole so that their individual field patterns at different frequencies and their individual frequency-reactance characteristics are practically identical with those of the main dipole. Consequently, unlike the auxiliary dipoles of this invention, reflectors and directors further increase the sharpness of resonance of the main dipole and so further reduce the already narrow frequency range in which it can efficiently radiate or absorb radio-frequency energy; moreover, reflectors and directors do not avoid nulls in the desired direction of reception or transmission should the antenna be used at harmonics of its fundamental frequency of resonance.

It shall be understood the invention is not limited to the specific embodiments disclosed and that changes and modifications may be made within the scope of the appended claims.

What is claimed is:

1. A broad-band antenna system for efficient transmission or reception throughout a wide band of frequencies including many channels and in a desired direction comprising mutually coupled low Q dipoles of such substantially different length that they respectively exhibit fundamental resonance at frequencies whose ratio is greater than 1.5, the field patterns of said dipoles complementarily combining at each of all frequencies of the band in avoidance of nulls in said desired direction and the self and mutual reactances of said dipoles combining at each of all frequencies of the band to provide an equivalent reactance which is low, said dipoles being spaced apart in parallel axial alignment to permit capacitive coupling therebetween, and a transmission line connected to the center point of the longer dipole.

2. A multi-channel broad-band antenna system for efficient transmission or reception in a desired direction and throughout a band the ratio of whose terminal frequencies is greater than 2 comprising mutually coupled low Q dipoles having substantially different lengths, an insulating support between said dipoles for maintaining them in parallel axial alignment and capacitively coupled, said dipoles respectively exhibiting fundamental resonance at frequencies corresponding with said terminal frequencies, the shape and relative size of the field patterns of the individual dipoles insuring the joint pattern at each of all frequencies of the band shall be free of a null in said desired direction, a transmission line connected to the center point of said longer dipole, an inductance connected in parallel across said transmission line of sufficient magnitude to compensate for the capacitive reactance of the coupled dipoles substantially through said band, the self and mutual impedances of said dipoles insuring the effective impedance of the antenna system is for each frequency of said band the equivalent of a reactance in series with a resistance, said reactance and resistance being of such a value that on a given transmission line the standing-wave-ratio will be low over a wide band of frequencies.

3. A multi-channel broad-band antenna system for efficient transmission or reception in a desired direction and throughout a band the ratio of whose terminal frequencies is greater than 2 comprising a pair of mutually coupled low Q dipoles of substantially different lengths, an insulating support between said dipoles for maintaining them in parallel axial alignment and capacitively coupled, one of said dipoles exhibiting fundamental resonance at a frequency in said band for which another of them exhibits harmonic resonance in avoidance of nulls in said

desired direction, and a transmission line connected to the center point of said longer dipole for effecting interchange of energy with said dipoles, an inductance sufficient to compensate for the capacitive reactance of said coupled dipoles connected in parallel across said transmission line, the self and mutual impedances of said dipoles forming a complex band-pass network whose series equivalent at the transmission line terminals appears at each frequency of said band to be a reactance in series with a resistance of such magnitude that the standing-wave-ratio is not greater than 3 for transmission or 5 for reception.

4. A multi-channel broad-band antenna system having low net reactance throughout a band of frequencies the ratio of whose maximum frequency to minimum frequency is greater than 1.5 comprising a first center-fed dipole resonant at a frequency substantially the said minimum frequency, a number of further dipoles circumferentially arranged about said first dipole, said number of further dipoles being greater than 2, said further dipoles being shorter in length than said first dipole and resonant at a frequency substantially the said maximum frequency, said further dipoles being capacitively coupled at their ends to areas intermediate the ends of the conductors of said first dipole.

5. A multi-channel antenna system broadly resonant over a band of frequencies the ratio of whose terminal frequencies is greater than 1.5 comprising a first center-fed dipole resonant at a frequency within said range, a second end-fed dipole capacitively coupled to said first dipole resonant at a substantially different frequency within said range, and inductance connected to the center of said first dipole of magnitude to compensate for capacitive reactance of the coupled dipoles substantially throughout said band.

6. A multi-channel broad-band antenna system comprising a first dipole consisting of a first radiating element of large transverse cross section and a second radiating element of large transverse cross section in axially-abutting relation, an insulating support joining said radiating elements, a plurality of shorter dipoles mounted on said support circumferentially and equally spaced about said radiating elements, a transmission line connected to the first and second radiating elements at their abutting ends, and an inductance connected across said transmission line in parallel with said radiating elements, the ends of said plurality of shorter dipoles being in capacitively-coupled relation respectively with areas intermediate the remote ends of said radiating elements and coacting therewith to provide for low net reactance of the antenna system over a band of frequencies whose maximum frequency to minimum frequency is greater than 1.5.

7. A multi-channel antenna system comprising a plurality of cooperatively associated main and auxiliary low Q dipoles of substantially different length and maintained in parallel axial alignment, said main dipole being of large transverse cross-section and said auxiliary dipoles being a plurality of shorter dipoles placed circumferentially and equally spaced around the large main dipole and capacitively coupled thereto at their ends, a transmission line connected to the center of said main dipole, and a lumped inductance at the center of said main dipole connected in parallel thereto across said transmission line, the reactances of all of said dipoles cooperating to produce a substantially resonant condition throughout a wide band of frequencies the ratio of whose terminal frequencies is greater than 2.

8. A multi-channel transmitting-receiving antenna construction forming a band-pass network comprising main and auxiliary low Q dipoles of substantially different length and maintained in parallel alignment, said dipoles being flat strips whose inductances per unit length are small and whose capacities per unit length are large, a transmission line connected to the center of one of said dipoles, lumped inductance at the center of one of said dipoles connected in parallel thereto across said transmission line, the ends of the auxiliary dipole being capacitivity coupled to the main dipole, all of said reactances cooperating to produce a substantially resonant condition throughout a wide band of frequencies, the ratio of whose terminal frequencies is greater than 2.

9. A multi-channel antenna system broadly resonant throughout a band of frequencies the ratio of whose maximum frequency to minimum frequency is greater than 1.5 comprising a pair of low Q dipoles of substantially different physical and electrical lengths, an insulating support between said dipoles for maintaining parallel alignment so that said dipoles are capacitively coupled, a transmission line center feeding one of said dipoles, and lumped inductance connected across said transmission line, said different lengths of said dipoles respectively corresponding with substantially different resonant frequencies within said band and having such individual and mutual reactances that said system exhibits low net reactance throughout said band.

10. A multi-channel antenna system broadly resonant throughout a band of frequencies the ratio of whose maximum frequency to minimum frequency is greater than 1.5 comprising dipoles individually resonant at substantially different frequencies, said dipoles being of substantially different length and positioned for capacitive coupling therebetween, a transmission line for center-feeding one of said dipoles, and inductance of magnitude to compensate for capacitive reactance of the coupled dipoles substantially throughout said band connected to said transmission line, said dipoles having such individual and mutual reactances that said system exhibits low and capacitive reactance throughout said band of frequencies.

11. A multi-channel antenna system broadly resonant throughout a band of frequencies the ratio of whose maximum frequency to minimum frequency is greater than 1.5 comprising dipoles individually resonant at substantially different frequencies, said dipoles being of substantially different length and positioned for capacitive coupling therebetween, a transmission line for center-feeding one of said dipoles, said dipoles having such individual and mutual reactances that said system exhibits low and capacitive reactance throughout said band of frequencies, and lumped inductance at the center of one of said dipoles connected in parallel across said transmission line compensating for said low capacitive reactance.

12. A broad-band antenna for efficient transmission or reception throughout said band comprising a pair of axially aligned broad strips forming a center-fed dipole, and a second shorter dipole exhibiting fundamental resonance at a frequency within said band for which said first-named dipole exhibits harmonics resonance, said second-named dipole comprising a broad strip

having its wide face parallel to and spaced from the wide faces of said pair of strips to provide mutual capacitive reactance which with the self-reactances of the dipoles insures low effective reactance at the center of said first-named dipole at all frequencies within said band.

13. A broad-band antenna comprising a pair of broad strips forming a low Q center-fed dipole, a transmission line connected to adjacent ends of said strips, an insulating support mechanically connecting said strips in axial alignment, an insulating housing on said support and enclosing said ends of said strips and the transmission line connections thereto, and a second shorter low Q dipole comprising a broad strip supported by said housing with its wide face parallel to the wide faces of said pair of strips to provide capacitive coupling thereto.

14. A broad-band antenna system affording a standing-wave-ratio not greater than 2 over a frequency band the ratio of whose maximum frequency to minimum frequency is greater than 1.5 comprising a first center-fed dipole having an inductance connected at its center in parallel across the feed line, a plurality of shorter dipoles placed circumferentially and equally spaced about said first dipole in parallel axial alignment therewith, said shorter dipoles being capacitively coupled to said first dipole at their ends, said first dipole being of length for acting as the primary radiator at the lower frequencies of said band and said shorter dipoles acting as the primary radiators at the higher frequencies of said band.

15. A broad-band antenna system comprising a first center-fed dipole of large average transverse cross section and having an inductance connected at is center across the feed line, a plurality of shorter dipoles positioned circumferentially about said first dipole, said shorter dipoles arranged about said first dipole in spaced parallel relation and capacitively coupled therewith to provide for low net reactance of said system throughout a band of frequencies the ratio of whose maximum frequency to minimum frequency is greater than 1.5.

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BROAD-BAND END-FIRE TELEVISION ANTENNA

Filed Nov. 14, 1956

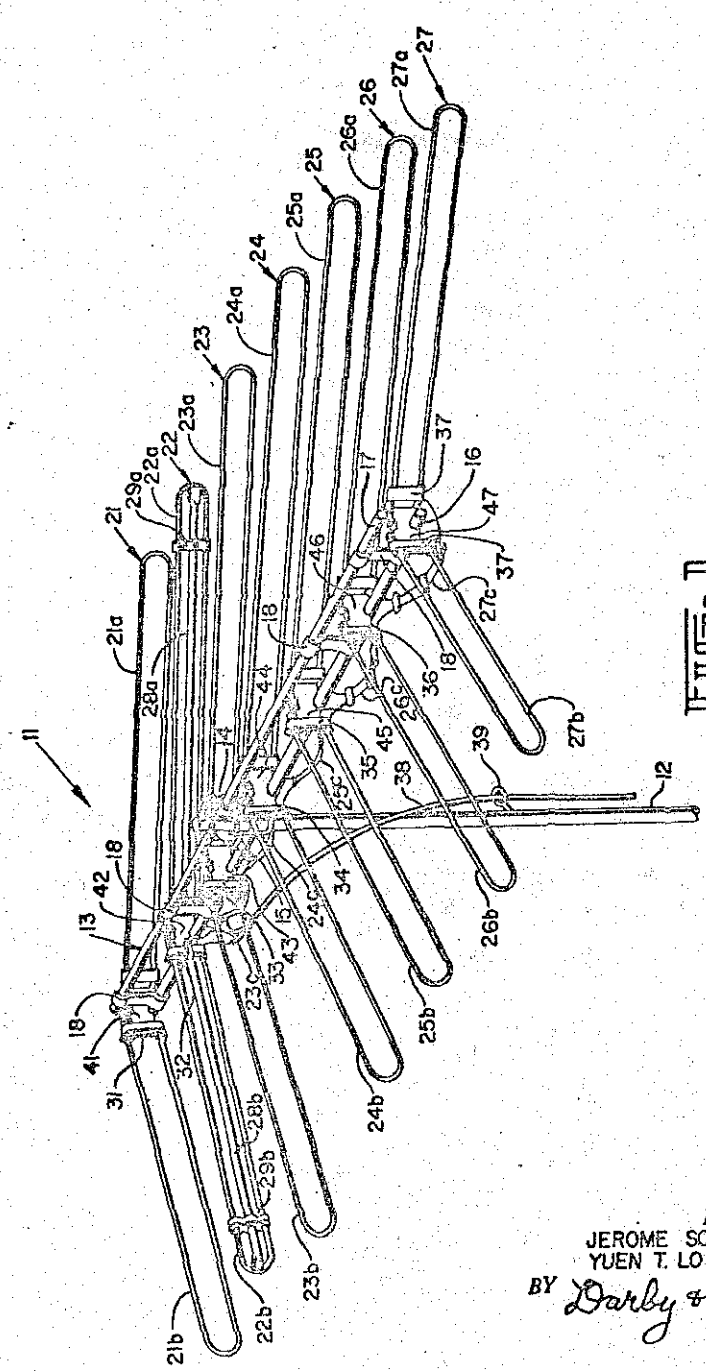

FIG. 1

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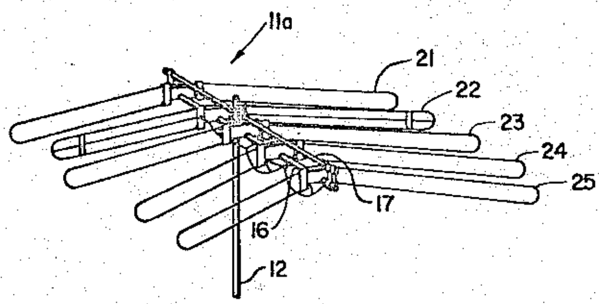

FIG. 2

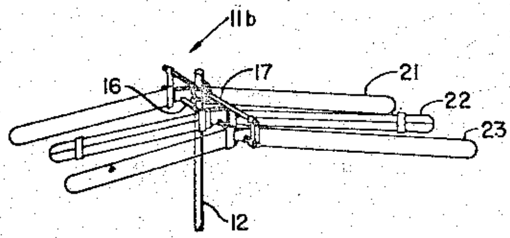

FIG. 3

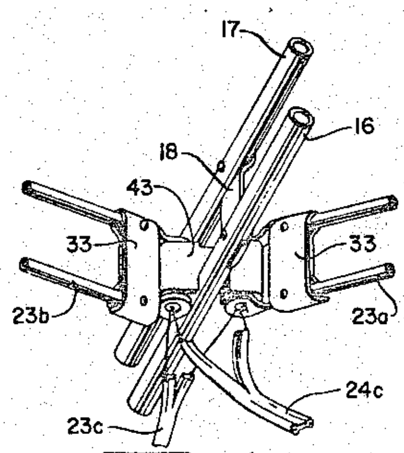

FIG. 4

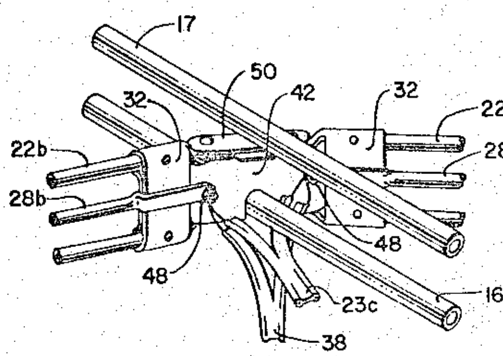

FIG. 5

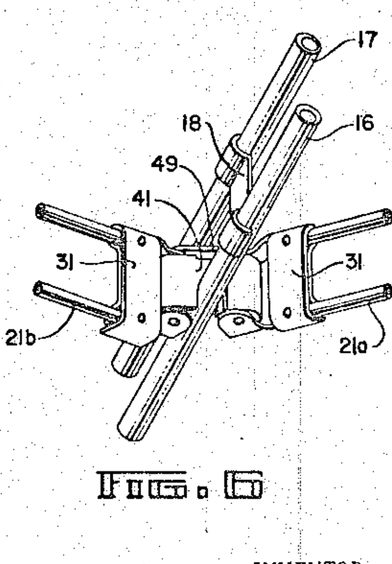

FIG. 6

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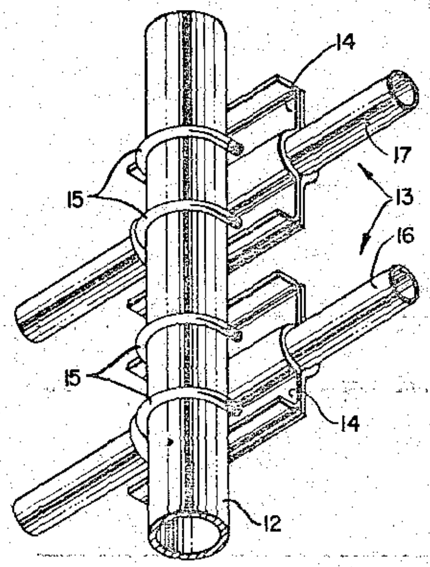

FIG. 7

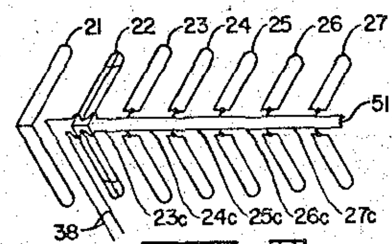

FIG. 8

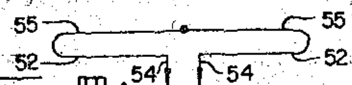

FIG. 9A

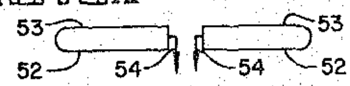

FIG. 9

FIG. 10

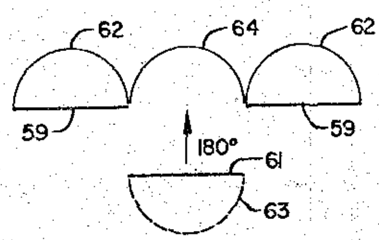

FIG. 11

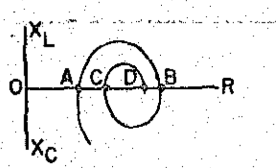

FIG. 13

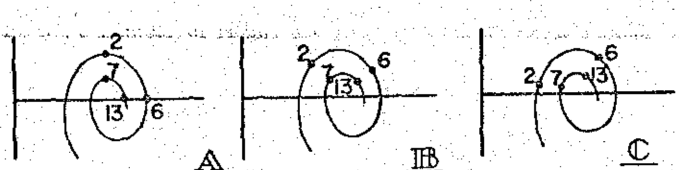

FIG. 14

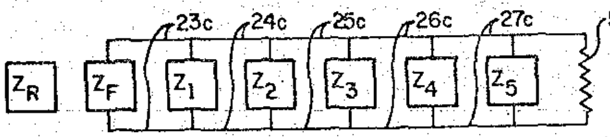

FIG. 12

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Patented Dec. 17, 1957

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BROAD-BAND END-FIRE TELEVISION ANTENNA

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Application November 14, 1956, Serial No. 622,073

26 Claims. (Cl. 343—814)

The present invention relates to high-gain broad-band television antennas with multiple in-line active elements, and more particularly to such antennas in which the active elements are constructed so that the amount of radio frequency current produced by each in response to excitation by radiated radio frequency energy is substantially the same.

A particularly effective television antenna is most necessary in so-called fringe areas, which because of their great distance from the television transmitter, or for other reasons, receive a very weak television signal. In such areas an antenna having considerable gain is required (gain being the antenna's signal gathering ability compared to a standard dipole antenna). It is normally not sufficient that an antenna in such areas have a high gain for only a few of the channels in the band which it is designed to cover. On the contrary, it is desired that an antenna for such an area have a high gain at each channel to be received and that the gain across the complete band or bands formed by all the various channels be substantially constant or "flat."

A further feature of increasing importance in television antennas is the so-called "front-to-back-ratio." High gain antennas are highly directive, so that signals from a particular direction are received with a gain many times as great as the gain for signals from other directions from the antenna. The direction from which signals are best received is designated the "front" of the antenna. Most antennas are also somewhat sensitive in other directions and particularly to the direction opposite to the "front," namely the "back" of the antenna. In fact, for most antennas, the second most sensitive direction is the "back" of the antenna, which in some cases may have a gain equal to the "front" gain unless special provision is made, as by use of a reflector.

As the number of television stations has increased and television stations have increased their power, the problem of interference between stations has increased. Interference may occur between two television stations on the same channel or on adjacent channels. An interfering station is seldom located in the same direction as the desired station, and thus an antenna with a high degree of directivity is very effective in eliminating this interference except from the "back" direction. The degree of directivity of antennas as to the "back" direction is frequently defined in terms of relative sensitivity in the forward and reverse directions, called "front-to-back ratio." An antenna with a high front-to-back-ratio is therefore very desirable, particularly in fringe areas where problems of co-channel and adjacent channel interference arise most often.

The basic type of antenna previously considered to be most effective in overcoming the problems described above is the so-called "broad-band" Yagi antenna. Many variations of this type of antenna exist, but it may be identified generally by several parallel parasitic dipole elements (directors) arranged in-line in front of an active element, usually with a single parasitic reflector element behind the active element. (By "in-line" is meant in a common horizontal plane with elements spaced in the front-to-back direction.)

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In spite of its superiority in some respects over many other types of antennas, the broad-band Yagi is still subject to many limitations. A basic theoretical condition for maximum receiving antenna performance in a multi-element antenna is that every element should produce an equal amount of current in the proper phase relationship. The broad-band Yagi antenna cannot fulfill this condition on more than one or two channels because the current and phase relationships do not hold constant across the V. H. F. band. Since it cannot make full use of the transmitted energy at all frequencies, this atnenna type cannot realize uniform gain on every channel and is not properly called "broad-band."

The ability of the Yagi antenna to produce a high front-to-back-ratio on all channels is also inherently limited. The impedance of each parasitic element and the physical spacing between them, determine both the phase and the amplitude of the current flowing in the parasitic elements since no electrical connection is provided to them.

Ideally, automatic compensation should be provided to maintain substantially equal current in the proper phase for changes in frequency. However, the physical character of the parasitic element is fixed and therefore changes in current magnitude and phase must invariably occur with changes in frequency.

Antennas according to the present invention are not subject to the inherent limitations of the broad band Yagi antenna due to the fact that the present antenna does not rely on forward parasitic elements (directors) to increase the antenna gain. On the contrary, all the elements of the antenna are active with the exception of a single rear parasitic element (reflector). Since the forward elements of the antenna are all thus connected by an electrical transmisson line, the current and phase relationships of each element are not determined solely by its physical dimensions but also by the current flowing in the transmission line. Proper design of the present antenna can therefore provide an antenna in which every element provides a substantially equal amount of current for all channels in the band.

It is accordingly an object of the present invention to provide a television antenna having multiple in-line active elements wherein each element produces substantially an equal amount of current in the proper phase relationship at every channel in the band.

It is a further object of the present invention to provide a television antenna having a number of in-line dipole elements wherein all of the elements except a reflector element are active elements connected to a transmission line.

It is still another object of the present invention to provide a television antenna having several in-line active dipole elements wherein the impedances of the active elements are different, with the rear active element having the highest impedance and each successive element in front of the rear element having a successively lower impedance with this relationship maintained over the entire operating range.

It is still another object of the present invention to provide an antenna of the above type wherein the transmission line connecting the active elements is of different characteristic impedance at different points along its length to better balance the active elements of different impedance.

It is a further object of the present invention to provide a television antenna having several in-line active dipole elements of the V-type wherein the impedances of the active elements are different, with the rear active element having the highest impedance and each successive element in front of the rear element having a successively lower impedance at all operating frequencies.

It is a further object of the present invention to provide a television antenna of the above type wherein the forward elements are constructed with a smaller included V angle and the rear elements are constructed with a larger V angle so that the currents in the elements are maintained more nearly equal throughout the band and the proper phase relationship is better maintained throughout the band.

It is a still further object of the present invention to provide a television antenna having several in-line active elements with the rear active element having the greatest impedance and the impedances of the remaining elements being graduated toward the front of the antenna at all operating frequencies, and further having a terminating resistor at the forward end of the antenna for eliminating reflection and improving the front-to-back-ratio of the antenna.

It is a still further object of the present invention to provide a television antenna wherein all of the elements of the antenna are physically folded elements in a vertical plane so that each of the elements is in effect a truss-like member having a greater resistance to downward bending.

Further objects and advantages of the present invention will be apparent from a consideration of the following description in conjunction with the appended drawings, in which:

Fig. 1 is a perspective downward view of a 7-element television antenna according to the present invention;

Fig. 2 is a perspective partly schematic view of a 5-element television antenna according to the present invention;

Fig. 3 is a perspective partly schematic view of a 3-element television antenna according to the present invention;

Fig. 4 is an enlarged fragmentary perspective view of the mounting structure of the hairpin dipole elements of the antennas shown in Figs. 1, 2 and 3;

Fig. 5 is an enlarged fragmentary perspective view showing the mounting structure for the three-conductor dipole element of the antennas in Figs. 1, 2 and 3;

Fig. 6 is an enlarged fragmentary perspective view of the mounting structure for the reflector element of the antennas in Figs. 1, 2 and 3;

Fig. 7 is an enlarged fragmentary perspective view of the U-bolt and cross-arm mounting clamps of the antennas of Figs. 1, 2 and 3;

Fig. 8 is a schematic diagram of a 7-element antenna according to the present invention useful in explaining the theory of operation of the antenna;

Fig. 9 is a schematic diagram of the hairpin-type dipoles used in the present invention;

Fig. 9*a* is a schematic diagram of a conventional folded dipole;

Fig. 10 is a schematic diagram of a V-type dipole antenna showing the current distribution for the antenna;

Fig. 11 is a diagram of the current distribution in a circuit equivalent to the V-type dipole presented to demonstrate the theory of operation of the V-type dipole;

Fig. 12 is a schematic circuit diagram of a substantially equivalent electrical circuit for a 7-element antenna according to the present invention;

Fig. 13 is an impedance curve of a typical dipole antenna presented to aid in the explanation of the theory of operation of the present antenna;

Figs. 14*a*, 14*b* and 14*c* are impedance curves of respective ones of the dipoles of an antenna according to the present invention presented to explain the theory of operation of the antenna.

Referring now to Fig. 1 and to Fig. 7, a 7-element antenna according to the present invention is shown at **11**. The antenna **11** is supported by a mast **12**; a double cross-boom **13** is connected to the mast **12** by means of a cross-arm clamp **14** and U-bolts **15**. The cross-boom **13** is constructed of a lower cross-arm **16** and a similar upper support-arm **17**. The cross-arm **16** and the support-arm **17** are rigidly secured together in spaced relationship by a number of truss members **18**.

The provision for two structural arm members, namely the cross-arm member **16** and the support-arm member **17** renders the structure of antenna unusually sturdy by utilizing the truss principle of construction.

The electrically operative portion of the antenna consists of seven V-type reflector and dipole elements **21, 22, 23, 24, 25, 26** and **27**. The V-type reflector **21** is composed of two arms **21*a*** and **21*b*** located at an obtuse angle to one another and forming the arms of the V. The dipole elements **22, 23, 24, 25, 26** and **27** are similarly composed of two arms **22*a*** and **22*b***, **23*a*** and **23*b***, **24*a*** and **24*b***, **25*a*** and **25*b***, **26*a*** and **26*b***, and **27*a*** and **27*b***, respectively. Each of the arms of elements **21** and **23—27** is formed of a single conductor doubled back on itself to form a fold or "hairpin."

The manner in which the antenna elements are secured and connected may best be seen by reference to Figs. 4, 5 and 6. Each of the arms **21*a*** and **21*b*** is secured to a respective mounting strap **31**, and the mounting strap **31** is further secured to a mounting block **41** secured to the cross-arm **16** of the antenna **11**. The other pairs of arms are similarly secured to respective mounting blocks **42, 43, 44, 45, 46** and **47** by means of respective mounting straps **32, 33, 34, 35, 36** and **37**. The mounting blocks **42—47** are formed of a dielectric insulating material. The arms **21*a*** and **21*b***, the straps **31** and the blocks **41** may be connected together by riveting, bolting or any other suitable means. The mounting block **41** is also connected to the cross-arm **16** by riveting, bolting or other suitable means. The other elements **22—27** are assembled and secured to the crossarm **16** in a similar manner. The straps **31—37** are of conductive material and serve the purpose of providing an electrical connection to complete a closed electrical loop for each of the dipole arms.

Dipoles **21** and **22** are provided with connecting bars **49** and **50** respectively for electrically connecting the arms of the dipoles at their centers. The bars **49** and **50** are fastened between straps **31** and between straps **32** respectively so that the reflector arms **21*a*** and **21*b*** and the dipole arms **22*a*** and **22*b*** are each electrically connected at their centers. The other five elements are center-fed hairpin dipoles and are therefore not provided with connecting bars.

The dipole **22** differs from the other elements in that it is provided with center conductors **28*a*** and **28*b***. The center conductors **28*a*** and **28*b*** are conductively connected at their outer ends to the respective outer bends of the dipole arms **22*a*** and **22*b***. In addition a shorting bar **29*a*** of conductive material interconnects the two outer conductors of dipole arm **22*a*** and its center conductor **28*a*** at a point near the end of the dipole arm **22*a***. A similar shorting bar **29*b*** is similarly connected across *the dipole arm* **22*b*** *and the center conductor* **28*b***. The inner ends of the center conductors **28*a*** and **28*b*** are not electrically connected to the straps **32** as may be seen in Fig. 5. Electrical terminals **48** are provided at the inner ends of the center conductors **28*a*** and **28*b*** for connecting an electrical transmission line **38** to the dipole **22**. The significance of this particular construction of the dipole element **22** will be explained in connection with the explanation of the electrical theory of operation of the antenna below.

The transmission line **38** provided for connecting the *antenna* **11** *to a television receiver* is connected to the antenna at terminals **48** of the 3-conductor dipole **22**. A second electrical transmission line section **23*c*** is electrically connected between the terminals **48** of the 3-conductor dipole **22** and respective straps **33** of the dipole element 23. A third transmission line section 24c connects the straps 33 of the dipole 23 to the straps 34 of the dipole 24. A transmission line section 25c similarly connects the dipole 24 to the dipole 25, another transmission line section 26c connects the dipole 25 to the dipole 26, and still another transmission line section 27 connects the dipole 26 to the dipole 27 in a similar manner.

As seen in Fig. 1, 6 of the 7 elements of the antenna are connected by means of successive transmission line sections to the television receiver. The transmission line harness sections 26c and 27c leading to the front two dipoles 26 and 27 are preferably constructed with a wider conductor spacing and thus have a higher characteristic impedance than do other sections of the transmission line. Although this construction utilizing different types of transmission line is preferred, all the transmission line sections may be made of the same type line.

As seen in Fig. 1, the front dipole 27 has arms 27a and 27b which are shorter than the arms of any of the other dipoles. The arms of the various dipole elements are progressively longer for dipoles 26, 25, 24 and 23. This is a significant feature of the invention and will be explained in detail in connection with the explanation of the theory of operation of the antenna.

In addition, the four front dipole elements 24, 25, 26 and 27 have a smaller V-angle than do the three rear elements 21, 22 and 23. This feature further improves the operation of the antenna, as will be explained below.

Fig. 2 shows an antenna 11a according to the present invention having only 5-elements rather than the 7-elements of the antenna shown in Fig. 1. The antenna of Fig. 2 naturally has less gain than the more elaborate antenna of Fig. 1. However, in some instances a smaller amount of gain is required, and in the development of the very high-gain 7-element antenna desirable attributes were developed which are also useful in antennas of lower gain.

In the 5-element antenna 11a, the element 21 is a reflector element as before, the element 22 is a 3-conductor folded dipole element as before, and the elements 23, 24 and 25 are center-fed hairpin dipoles, all as in antenna 11 of Fig. 1. The major change in the antenna 11a is the elimination of the front two elements of antenna 11, namely, the dipoles 26 and 27. The V-angle of the dipoles 24 and 25 is somewhat less than the V-angle of the rear elements 21, 22, and 23 as was the case with the 7-element antenna 11 in Fig. 1. The length of each of dipole elements 23, 24 and 25 is successively less than that of the preceding one to provide elements of diminishing impedance progressing toward the front of the antenna. The transmission line sections between various antenna elements may be selected to have different impedances to improve the antenna characteristics. The dimensions and characteristics of a particular preferred embodiment of the 5-element antenna is provided in the table below.

Fig. 3 shows a further simplified version of an antenna according to the present invention. A 3-element antenna 11b is shown having only a reflector element 21, a 3-conductor folded dipole element 22 and a hairpin dipole element 23. The 3-element antenna 11b will, of course, have still less gain than the 5-element antenna 11a. The antenna 11b is therefore particularly adapted for situations in which high gain is not required and where the broad-band, flat response and other desirable features of the present antenna will be particularly useful.

Any of the present antennas and particularly the 7-element antenna may be modified to have a higher front-to-back-ratio by providing a terminating resistor connected in parallel with the front element of the antenna. In the 7-element antenna 11, for example, a terminating resistor 51 may be electrically connected between the straps 37 of the forward element 27. The terminating resistor reduces reflection from the forward end of the transmission line by providing an impedance which is more nearly matched to the transmission line at this

point. The terminating resistor may of course, be omitted, and it normally would not be used with the 3-element and 5-element antennas which do not require as high front-to-back ratio in any case.

In view of the fact that the proper operation of any antenna depends to some extent upon the physical dimensions and upon the electrical characteristics of its various elements, three particularly preferred representative constructions for antennas according to the present invention are described in the tables below.

Table I.—7-element antenna

element	length-center to tip, inches	forward tilt of arms, degrees	impedance of transmission line to element	spacing from adjacent element (rear), inches	transmission line length from adjacent element (rear), inches
1 (refl.)	54	30			
2 (3-conductor)	[1] 50	30	300	25	
3 (hairpin)	52	30	300	18½	20 11/16
4 (hairpin)	50	40	300	18½	20⅜
5 (hairpin)	48	40	300	18½	20⅜
6 (hairpin)	46	40	425	18½	19⅜
7 (hairpin)	42	40	425	15	19⅜

[1] Shorting bars 7¼" from ends of dipole arms.

Terminating resistor, if used, should preferably have a value of approximately 500 ohms.

Table II.—5-element antenna

element	length-center to tip, inches	forward tilt of arms, degrees	impedance of transmission line to element	spacing from adjacent element (rear), inches	transmission line length from adjacent element (rear), inches
1 (refl.)	54	30			
2 (3-conductor)	[1] 50	30	300	25	
3 (hairpin)	52	30	300	18½	22⅞
4 (hairpin)	48	40	300	18½	20⅜
5 (hairpin)	48	40	425	18½	20

[1] Shorting bars 8½" from ends of dipole arms.

Table III.—3-element antenna

element	length-center to tip, inches	forward tilt of arms, degrees	impedance of transmission line to element	spacing from adjacent element (rear), inches	transmission line length from adjacent element (rear), inches
1 (refl.)	54	30			
2 (3-conductor)	[1] 49	30	300	25	
3 (hairpin)	50	40	425	20	24 11/16

[1] Shorting bars 6¼" from ends of dipole arms.

Tubing for antenna elements is preferably 7/16" O. D. except for the center conductor of the 3-conductor element which is ⅝" O. D.

Distance between conductors of folded dipoles (outside conductors of 3-conductor dipoles) is preferably 2½" center to center.

A theory of operation of the present antenna will now be explained by reference to Figs. 8 through 12. Fig. 8 shows schematically the approximate equivalent electrical circuit of the 7-element antenna 11 shown in Fig. 1. In Fig. 8 it may be seen that the reflector element 21 is not electrically connected to the other antenna elements but has its arms connected together. The element 22 is a 3-conductor folded dipole in which the center conductors are connected by means of a transmission line to the other active antenna elements. The element 22 is the main element of the antenna, or in other words, the element connected by the transmission line 38 to the television receiver. The antenna elements 23, 24, 25, 26 and 27 are all hairpin dipole elements and are all electrically connected by means of transmission line segments 23c to 27c to the main element 22 and from there to the television receiver. A terminating resistor

51 is connected across the terminals of the forward antenna element 27.

As previously explained, the dipoles 23 to 27 in the preferred embodiments of the antenna are hairpin-type dipoles. The manner in which hairpin dipoles differ from ordinary folded dipoles is shown in Figs. 9 and 9*a*. As shown in Fig. 9 the hairpin dipole has both conductors 52 and 53 of each arm connected together at both ends, and connected at the inner ends to a respective conductor of a transmission line 54. On the other hand, as shown in Fig. 9*a*, an ordinary folded dipole has only one conductor 52 of each arm connected to a respective conductor of a transmission line 54. The outer ends of conductors 52 are joined by a separate single long conductor 55 parallel to conductors 52 to form a single elongated loop from one terminal of the line to the other. The hairpin conductor of Fig. 9 has more desirable impedance characteristics in the present arrangement and it is therefore preferred that such dipoles be utilized in the construction of the present antenna.

In explaining the operation of the antenna it is desirable to first explain the operation of a single one of the V-dipole elements. It is an important feature of the present invention, where the antenna is to be used as a dual-band V. H. F. television antenna, to construct each of the dipole elements with its arms tilted slightly forward toward the source of received signals. V. H. F. television signals are broadcast in two separate bands with channels 2 through 6 being in the lower band between 54 and 88 megacycles per second and channels 7 through 13 in the upper band between 174 and 216 megacycles per second. Approximately half of the television channels therefore have frequencies which are roughly three times the frequencies of the other half of the television channels. It has been found by early workers in the television antenna art that the frequency response curve of a dipole antenna for dual-band V. H. F. television signals can be improved by tilting the arms of the dipole forward at an angle of 30° to 40° or so.

One general theoretical explanation of this phenomenon may be explained by reference to Figs. 10 and 11. A dipole which is one-half wavelength long in the lower band will be three half-wavelengths long in the upper band. A dipole 56 is shown in Fig. 10 with dashed lines 57 indicating current distribution for low band signals and dotted lines 58 indicating current distribution for high-band signals. In a straight dipole anti-phase high band operation would result but in the V-dipole such anti-phase high band operation is made harmless because the center section of the V-antenna is located approximately 180° in space behind the two outer sections. The approximate equivalent of this situation is shown in Fig. 11 where the outer dipole arm sections are shown at 59 and the center section at 61. The current distribution of the outer sections 59 is indicated generally by the solid lines 62. The current distribution of the central section 61 in absence of the space phase difference is indicated by the dotted line 63. The space phase difference of 180° converts the current distribution of 63 into the reverse distribution 64 so that the current of all three sections is in phase and the effect of anti-phase high band operation is avoided. The V-dipole thus operates well on both low and high bands.

All of the dipole elements of the antenna are of the V-type and hence utilize the principles explained above. The V-type dipole cannot be advantageously adapted for use with the Yagi antenna due to the fact that the inter-element spacing of the parasitic elements of the Yagi antenna produces a substantial effect on antenna characteristics. The Yagi antenna can therefore not be designed to operate well on both high and low bands simply by providing V-type elements, since the Yagi is seriously limited by the fact that the proper low-band inter-element spacings will be too great for high-band V. H. F. television signals by a factor of about three.

In order to explain the combined operation of the multiple V-type hairpin dipoles connected as shown in Fig. 8, it is useful to consider for a moment a circuit in which the dipole elements are replaced by their respective impedances at a given frequency. Such a circuit is shown in Fig. 12 where the various antenna elements equivalent impedances are represented schematically. The impedance of the reflector element 21 is represented at Z_R, and it may be noted that the reflector element is not physically connected in the transmission line circuit. The three-conductor dipole 22 is represented by the impedance Z_F. The impedances of the remaining dipole elements are represented by the impedances Z_1, Z_2, Z_3, Z_4 and Z_5. The terminating resistor 51 is shown connected across the terminals of the impedance Z_5.

The basic directivity patterns (and thus the gain) of an antenna are determined by the phases and amplitudes of the currents in the dipoles of the antenna as well as by the position of the dipoles in respect to each other. It has previously been explained that the current in each of the active dipoles of the present antenna is controlled in part by the current flowing in the transmission line sections between the elements of the antenna.

As seen in Figs. 1, 2 and 3, and described above, the transmission line harness length between each pair of adjacent dipoles is greater than the free space distance between the same two dipoles which increases the directivity over a conventional end-fire antenna.

For maximum antenna performance each dipole of the antenna should also have an equal amount of current induced in it. It is therefore desirable to select the impedances shown in Fig. 12 so that this result is obtained. It would at first appear that the current in each of the impedances shown in Fig. 12 (that is, in Z_F, Z_1, Z_2, Z_3, Z_4 and Z_5) would be equal if each of the foregoing impedances were equal. This is not the case, however, due to the fact that the signals involved have wavelengths not substantially different from the spacings of the antenna elements, and thus low-frequency alternating current theory is not applicable.

The proper selection of the impedances in Fig. 12 may be understood by utilizing the concept of reciprocity and considering the 7-element antenna in question as a transmitting antenna for the moment. Considering the antenna as a transmitting antenna, the feed element impedance Z_F should be relatively large so that the major portion of the signal sent into the antenna will not be absorbed and transmitted by the first or feed element Z_F. It is rather desired that only approximately one-sixth of an input signal be absorbed or radiated by the impedance Z_F, and that the remainder be transmitted about the transmission line. As the signal continues down the harness 23*c* it is desired that a greater portion, namely, about one-fifth of the remaining signal be absorbed by the impedance Z_1. Therefore, in order to accomplish the desired result, the impedance Z_1 should be less than the impedance Z_F. At the impedance Z_2 it is desired that approximately one-fourth of the remaining signal be diverted, and so on to the end of the transmission line, so that each impedance Z_F through Z_5 will have received substantially an equal current from the transmission line.

It is impracticable, of course, to arrange that all of the remaining signals be absorbed by the last impedance Z_5 and thus the terminating resistor 51 may be provided to absorb substantially all of the remaining signal and prevent reflections from the end of the transmission line harness which would tend to cause undesirable back-lobes in the antenna pattern which would impair the desired high front-to-back-ratio.

Correlating the principles explained in connection with Fig. 12 with the physical construction of the antenna schematically represented in Fig. 8, the main dipole 22 is a three-conductor dipole and thus has a substantially higher impedance than does a hairpin dipole of the same length. Although the three-conductor dipole 22 is physically somewhat shorter than the longest hairpin dipole 23, the three-conductor dipole 22 has the highest impedance of any of the active dipole elements of the antenna. The rear active hairpin dipole 23 is the longest of any of the hairpin dipole elements and thus has the greatest impedance among them. Each of the dipoles 24, 25, 26 and 27 is successively shorter than its preceding dipole, and hence each has somewhat lower impedance than the dipole immediately to its rear.

Therefore, by comparing the physical structure of the antenna with the theoretical optimum situation explained with reference to Fig. 12, it will be seen that the present antenna is constructed to create a condition where each dipole receives substantially the same current and thus substantially optimum antenna performance may be realized. Although the principle of operation has been explained in terms of transmission, it will be understood that an antenna designed for maximum transmission efficiency will likewise provide maximum reception efficiency in accordance with the principle of reciprocity in antenna design.

It is not sufficient for the equal current conditions discussed above to exist only for a limited frequency range within the frequency band sought to be recovered. Other antennas are able to realize these conditions for limited frequency ranges. The most outstanding advantage of the present antenna resides in the fact that it can maintain substantially equal current in the antenna elements throughout a substantial range of frequencies such as over both the V. H. F. television bands. The manner in which these conditions are thus maintained is explained by reference to Figs. 13 and 14.

Referring first to Fig. 13, there is shown a typical spiral curve of the impedance of a dipole. The line OR represents resistances from zero toward infinity. Inductive reactances X_L, are indicated by distances above the line OR. Capacitive reactances X_C are indicated by distances below the line OR.

It will be observed that the impedance spiral crosses the horizontal line OR at a number of points A, B, C and D and thus the impedances at the given points are effectively resistive and the dipole is resonant.

It may be assumed that the points A, B, C, and D represent the first, second, third and fourth harmonics or in other words, points where a dipole is ½, 1, 1½ and 2 wave-lengths long. It will be seen that the dipole characteristics are about the same between points A and B between points C and D; that is, the total impedance (which is the distance from a point in the curve to point O) diminishes as frequency is decreased, from B to A or D to C. The present antenna takes advantage of this fact in order to provide superior performance over both the low V. H. F. band and the high V. H. F. band, where the two bands have a frequency ratio of approximately 3 to 1.

As previously indicated it is necessary that the decreasing relationship of the impedances of the successive antenna elements must be maintained for all frequencies in the band to be covered. The manner in which the present antenna construction accomplishes this will be understood by reference to Figs. 14a, 14b and 14c which show impedance diagrams with reference to a 5-element antenna, but the same principle would apply to antennas having a greater or lesser number of elements. The feed element 22 represented by the impedance Z_F is constructed as a three-conductor dipole to assure that the feed element 22 will always have a higher impedance than any of the other antenna elements. The particular impedances desired for the three-conductor dipole is attained by suitably positioning the shorting bar 29b across the three-conductor dipole.

The remaining problem then is to assure that the proper impedance relationships are maintained in the three remaining hairpin dipoles, and it is the solution to this problem which is explained by reference to Figs. 14a, 14b and 14c. Fig. 14a represents the impedance spiral of the first hairpin dipole 23. Fig. 14b represents the impedance spiral of the second hairpin dipole 24. Fig. 14c represents the impedance spiral of a third or front harpin dipole 25. In Fig. 14a, four points are represented having reference numerals 2, 6, 7 and 13. These numerals correspond to channel numbers in the V. H. F. television band, channels 2 and 6 being respectively the lowest and highest frequency channels in the low V. H. F. television band, and channels 7 and 13 being respectively the lowest and highest frequency channels in the upper V. H. F. band.

As seen in Fig. 14a the first hairpin dipole element has a length such that a maximum resonant impedance for the element results at a frequency approximately corresponding to channel 6 of the V. H. F. television band. This element is thus "cut" to channel 6. The impedance for lower frequency channel-2 signals is less than that for channel-6 signals, but the impedance for channel-2 signals is more than the impedance minimum corresponding to point A in Fig. 13. The physical configuration of the dipole is such that the channel-13 and of the channel-7 points fall in positions on the inner loop of the impedance spiral generally corresponding to the location of the channel-6 point and the channel-2 point on the outer loop of the impedance spiral.

The second driven hairpin dipole 24 has a physical length somewhat shorter than that of the dipole 23 and the impedance spiral of that dipole is represented in Fig. 14b. Since the dipole 24 has a length which is a somewhat smaller fraction of a wavelength than was the dipole 23, the channel-6 point is moved clockwise around the impedance spiral relative to its location in Fig. 14a. All the other impedance points for the other channels are moved a corresponding distance around the spiral in a counter clockwise direction. In Fig. 14c the impedance spiral of the still shorter element 25 is shown and thus the impedance points for the various corresponding channels are moved still farther in a counterclockwise direction around the impedance spiral of Fig. 14c.

By comparing the relative location of the channel-6 impedance points in Figs. 14a, 14b and 14c, it will be observed that the impedance of the second hairpin dipole as shown in Fig. 14b is less than that of the first hairpin dipole shown in Fig. 14a for channel-6 frequencies. The impedance at channel-6 frequencies of the third hairpin dipole as shown in Fig. 14c is still less than that for the preceding dipoles.

Comparing the impedances of each of the three dipoles at frequencies corresponding to other V. H. F. television channels, it will be seen that regardless of the received frequency (within the V. H. F. television bands) the impedance of the dipole 24 for that particular frequency is less than the impedance of the dipole 23 and the impedance of the dipole 25 is still less than that of the dipole 24. Therefore the present antenna construction utilizes these various principles to achieve an antenna construction wherein the current received in each of the television antenna elements tends to be substantially equal not only for a portion of the V. H. F. television band, but for each channel in both the upper and lower V. H. F. television bands. The present antenna therefore achieves a result which was impossible of accomplishment with previous high-gain antennas such as the Yagi and its variations.

The invention is not limited to the particular means for providing elements of progressively diminishing impedance described above. In addition to varying the length and configuration of the antenna elements in the manner described, other schemes for providing elements of different impedances might be used. The invention is not limited to the use of particular types or numbers of dipole or other elements for the antenna. However, the three-conductor folded dipole 22 with shorting bars 29a, 29b is particularly adapted for use with the present antenna. The three-conductor dipole is a high impedance element and by incorporating shorting bars which may be located at various points near the ends of the dipole, an antenna element of relatively high, adjustable impedance is provided. The shorting bar for the three-conductor dipole is located at slightly different positions in the 3-, 5- and 7-element antennas in order to provide slightly different impedances for the element and thereby obtain optimum antenna characteristics in the respective antenna configurations.

It will also be observed that the use of double- or triple-rod construction for all antenna elements provides an antenna structure of superior physical strength.

The particular embodiments of the antenna described above are designed to operate in conjunction with a 300-ohm transmission line to the television receiver. Antennas utilizing the same principle may of course be designed to have a lower or higher impedance suitable for use in conjunction with transmission lines of lower or higher impedances.

In the foregoing explanation it was shown that the characteristics of the antenna could be improved by utilizing transmission line harness of different characteristic impedances for connecting certain of the antenna elements. Table I, for example, shows that a preferred embodiment of the 7-element antenna utilizes 300-ohm transmission line for the main transmission line harness sections to the third, fourth and fifth elements of the antenna. The sixth and seventh elements at the front antenna are connected, however, by means of higher impedance transmission line, for example of 425-ohms. By utilizing a high impedance harness for the front two antenna elements, these elements absorb the proper amount of power so that the equalized power absorption previously explained is attained.

As also described above, the front elements in the preferred embodiments of the present antenna are tilted forward at a sharper angle. This feature, though not essential for the practice of the invention, does however produce further improvements in the antenna characteristics. Rather than using the two particular angles of 30° and 40° as described in the preferred embodiments above, the antenna elements could be set at more than two different angles, differing more or less from 30° and 40°. The important characteristic of the tilt angles of the antenna elements is that at least one of the forward elements be tilted forward at a sharper angle than other elements to the rear of the forward element or elements. It is thought that the improvement brought about by the difference in tilt angles is due to rather complex interaction between the forward and rear antenna elements. No entirely satisfactory theoretical basis for the improved characteristics afforded by this construction is available.

Although preferred embodiments of antennas according to the present invention have been shown and described in great detail, it should be understood that the invention is not limited to the details described. For example, the specific manner in which the antenna elements are supported in position is obviously not important with respect to their electrical functioning. It is also obvious to those having a knowledge of the antenna art that other types of dipole antenna elements could be substituted for the particular type of elements shown in the preferred embodiment of the present invention. The present invention could be practiced with a greater or lesser degree of success with any of these other type of antenna elements by selecting active elements constructed to have progressively increasing impedances as you approach the rear active element.

It is equally obvious that although the reflector element 21 in the various preferred embodiments of the present antenna is a hairpin dipole type reflector element, other equivalent reflector elements, dipole or otherwise, could also be used in an antenna according to the present invention.

The particular embodiments of the antenna described were designed for use as television receiving antennas primarily. The invention is not limited to antennas for such use, however, and may be used for other purposes including transmission as well as reception.

While the theory of operation of the present antenna has been explained in accordance with the best knowledge available, and the foregoing theory of operation is believed to be correct, the present invention is not to be limited by the theory of operation advanced above.

Thus an antenna is provided according to the present invention which possesses high gain and high front-to-back-ratio as well as other desirable characteristics which are exhibited throughout a wide-band of frequencies such as the V. H. F. television band.

Although particular preferred embodiments of the present invention have been described in detail it will be understood that many modifications could be made by those skilled in the art within the scope of the present invention, and accordingly the present invention is not to be limited by the particular embodiment shown and described. Rather the present invention is to be limited solely by the appended claims.

What is claimed is:

1. A broad-band directive antenna array comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane, the included V-angle of at least one of said V-shaped dipole elements being less than that of others of said elements, said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band, signal transmission means connected to at least two of said dipole elements to receive a signal therefrom and a parasitic reflector antenna element horizontally displaced from an end one of said dipole elements.

2. A broad-band directive anenna array comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane, the included V-angle of at least one of said V-shaped dipole elements being less than that of others of said elements, said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band, signal transmission means connected to at least two of said dipole elements to receive the signal therefrom and a parasitic reflector antenna element horizontally displaced from an end one of said dipole elements, said reflector element having arms respectively parallel to the arms of said end dipole element.

3. A broad-band directive antenna array comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane, the included V-angle of at least one of said V-shaped dipole elements being less than that of others of said elements, said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band, signal transmission means connected to at least two of said dipole elements to receive signals therefrom, said signal transmission means comprising a transmission line connected to a first of said dipole elements and a further transmission line section connecting at least one other of said dipole elements to said first of said dipole elements, said further transmission line section between said elements having a length greater than the physical spacing between said elements, and a parasitic reflector antenna element horizontally displaced from an end one of said dipole elements.

4. A broad-band directive antenna array comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms in said dipole elements disposed in a common plane, the included V-angle of at least one of said V-shaped dipole elements being less than that of others of said elements, and at least one of said elements being a high impedance

type dipole having a higher resonance impedance than others of said dipole elements and said other dipoles having progressively varying impedance from front to back of said antenna at all operating frequencies, signal transmission means connected to at least two of said dipole elements to receive a signal therefrom, and a parasitic reflector antenna element horizontally displaced from an end one of said dipole elements.

5. A broad-band directive television antenna array for both the high and low frequency portions of the V. H. F. television band comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane, the impedances of said dipole elements being different at each antenna frequency within said V. H. F. television band and arranged with increasing element impedance from the front to the rear of the antenna for all frequencies in both said portions.

6. An antenna array as claimed in claim 5 wherein the impedance of each of said dipole elements is selected to maintain substantially equal signal currents in said elements.

7. A broad-band directive antenna array comprising at least three coplanar V-shaped dipole elements arranged in substantially parallel spaced relationship with the bisectors of the V-angles of said elements colinear and the vertex of the V of each element pointed toward the rear of said antenna, a parasitic reflector element in spaced relation with and to the rear of the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements, and further transmission line sections electrically connecting each of said dipole elements to the dipole element to its rear, said further transmission line sections between said elements having lengths respectively greater than the corresponding physical spacings between said elements, said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band.

8. An antenna array as claimed in claim 7 wherein at least one of said further transmission line sections has a characteristic impedance different from said transmission line characteristic impedance.

9. An antenna array as claimed in claim 7 wherein at least one of the rear-most ones of said dipole elements is constructed with an included V-angle greater than the included V-angle of the front one of said dipole elements.

10. An antenna array as claimed in claim 7 further including a terminating resistance element electrically connected between the terminals of the front one of said dipole elements.

11. A broad-band directive antenna array comprising a plurality of dipole elements, each element comprising a pair of outwardly extending arms each formed of elongated loops of conductive material, the loops of each pair of arms being relatively disposed at an angle to provide a V-shaped dipole element, said V-shaped dipole elements being arranged in substantially spaced coplanar relation with the bisectors of the V-angles thereof in colinear relation and with the vertex of the V of each element pointed toward the rear of said antenna array, said dipole elements further having different impedances at all frequencies in the operating band and being arranged in order of increasing impedance toward the rear of said antenna array for all said frequencies, a parasitic reflector element having a pair of extending arms formed of elongated loops of conductive material, said loops being electrically connected at their inner ends and disposed at an angle to provide a V-shaped reflector element, said reflector element being disposed in coplanar parallel spaced relation with, and to the rear of, the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements, and further transmission line sections electrically connecting each of said dipole elements to the dipole element to its immediate rear, said further transmission line sections between said elements having respective lengths greater than the corresponding physical spacings between said elements.

12. A broad-band directive antenna array comprising a plurality of dipole elements, each element comprising a pair of outwardly extending arms each formed of elongated loops of conductive material, the loops of each pair of arms being relatively disposed at an angle to provide a V-shaped dipole element, said V-shaped dipole elements being arranged in substantially spaced coplanar relation with the bisectors of the V-angles thereof in colinear relation and with the vertex of the V of each element pointed toward the rear of said antenna array, said dipole elements further having different impedances at all frequencies in the operating band and being arranged in order of increasing impedance toward the rear of said antenna array for all said frequencies, a parasitic reflector element having a pair of extending arms formed of elongated loops of conductive material, said loops being electrically connected at their inner ends and disposed at an angle to provide a V-shaped reflector element, said reflector element being disposed in coplanar parallel spaced relation with, and to the rear of, the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements, and further transmission line sections electrically connecting each of said dipole elements to the dipole element to its immediate rear, said further transmission line sections between said elements having respective lengths greater than the corresponding physical spacings between said elements, the rear one of said dipole elements having its elongated loops conductively connected together at their inner ends and further including a conductor rod for each of its arms extending substantially the length of the arm adjacent its corresponding elongated loops and conductively connected near the outer end to said corresponding elongated loop and electrically connected near the inner end to a corresponding terminal of said transmission line.

13. An antenna array as claimed in claim 12 wherein at least the one of said further transmission line sections connected to the front one of said dipole elements has a characteristic impedance higher than the characteristic impedance of said first transmission line.

14. An antenna array as claimed in claim 11 wherein at least one of the rear ones of said dipole elements is constructed with an included V-angle greater than the included V-angle of the front one of said dipole elements.

15. An antenna array as claimed in claim 11 further including a terminating resistance element electrically connected between the terminals of the front one of said dipole elements.

16. A broad-band directive antenna array comprising a plurality of dipole elements, each element comprising outwardly extending arms formed of elongated loops of conductive material disposed at an angle to provide a V-shaped dipole element, said dipole elements being arranged in coplanar spaced relation with the bisectors of the V-angles thereof colinear, with the vertex of the V of each element pointed toward the rear of said antenna array, the included V-angle of at least the front one of said elements being less than the included V-angle of the rear one of said antenna elements, said dipole elements further having different impedances at all frequencies in the operating band and being arranged in order of increasing impedance toward the rear of said antenna array for all said frequencies, a reflector element having extending arms formed of elongated loops of conductive material, said loops being electrically connected at their inner ends and disposed at an angle to provide a V-shaped reflector element, said reflector element being disposed in spaced relation with, and to the rear of, the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements for coupling to other apparatus, further transmission line sections electrically inter-connecting each pair of adjacent dipole elements to complete an electrical path from each of said

dipole elements to said first transmission line, said further transmission line sections between said elements having respective lengths greater than the corresponding physical spacings between said elements, and at least the front one of said transmission line sections having a higher characteristic impedance than that of said first transmission line, and a terminating resistor electrically connected between the terminals of the front one of said dipole elements.

17. A broad-band directive television antenna array for both the high and low frequency portions of the V. H. F. television band comprising a plurality of V-shaped dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane, the included V-angle of at least one of the rearmost ones of said dipole elements being greater than the included V-angle of the front one of said dipole elements, the impedances of said dipole elements being different and arranged with increasing impedance from the front to the rear of the antenna at all antenna frequencies within said V. H. F. television band.

18. A broad-band directive antenna array comprising at least three coplanar V-shaped dipole elements arranged in spaced relationship with the bisectors of the V-angle of said elements colinear and vertex of the V of each element pointed toward the rear of said antenna, at least one of the rearmost ones of said dipole elements having an included V-angle greater than the included V-angle of the front one of said dipole elements, said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band, a parasitic reflector element in spaced relation with and to the rear of the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements, and further transmission line sections electrically connecting each of the others of said dipole elements to the dipole element to its rear, said further transmission line sections having lengths between said elements respectively greater than the corresponding physical spacings between said elements.

19. A broad-band antenna array for operation in a given frequency band comprising a plurality of active elements arrayed in file in horizontally spaced coplanar relation, said active antenna elements having different impedances at every antenna frequency in said band and being arranged in order of increasing impedance toward the rear of said antenna array for every frequency in said band, the impedances of said active antenna elements being further selected to maintain substantially equal signal currents in said elements throughout the antenna frequency band, a reflector element horizontally displaced to the rear of the rear one of said active antenna element, and signal transmission means electrically connected to at least two of said dipole elements for coupling said array to other apparatus.

20. A broad-band antenna array comprising a plurality of active elements arrayed in file in horizontally spaced coplanar relation, said active antenna elements having different impedances at all operating frequencies and being arranged in order of increasing impedance toward the rear of said antenna array for all said frequencies, the impedances of said active antenna elements being further selected to maintain substantially equal signal currents in said elements throughout the antenna frequency band, a reflector element horizontally displaced to the rear of the rear one of said active antenna elements, signal transmission means electrically connected to at least two of said dipole elements for coupling said array to other apparatus, said signal transmission means comprising a first transmission line connected to a first of said antenna elements and a further transmission line section connected to at least one other of said active elements, said further transmission line section having a length between said elements greater than the physical spacing between said active elements, and said further transmission line section having a characteristic impedance higher than the characteristic impedance of said first transmission line.

21. A broad-band directive antenna array comprising at least three coplanar V-shaped dipole elements arranged in spaced relationship with the bisectors of the V-angle of said elements colinear and the vertex of the V of each element pointed toward the rear of said antenna, at least one of the rearmost ones of said dipole elements having an included V-angle greater than the included V-angle of the front one of said dipole elements said dipole elements having progressively increasing impedance from front to back of said antenna array at all frequencies in the operating band, a parasitic reflector element in spaced relation with and to the rear of the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements, and further transmission line sections electrically connecting each of said dipole elements to the dipole element to its rear, said further transmission line sections between said elements having lengths respectively greater than the corresponding physical spacings between said dipole elements and at least one of said further transmission line sections having a characteristic impedance different from said transmission line characteristic impedance.

22. A broad-line directive antenna array comprising a plurality of dipole elements, each element comprising a pair of outwardly extending arms each formed of an elongated loop of conductive material with said arms being disposed at an angle to provide a V-shaped dipole element, said dipole elements being arranged in coplanar spaced relation with the bisectors of the V-angles thereof colinear and with the vertex of the V of each element pointed toward the rear of said antenna array, the included V-angle of at least the front one of said elements being less than the included V-angle of the rear one of said elements, said dipole elements further having different impedances at all operating frequencies and being arranged in order of increasing impedance toward the rear of said antenna array at all said frequencies, a reflector element having a pair of extending arms each formed of an elongated loop of conductive material electrically connected at their inner ends and said arms being disposed at an angle to provide a V-shaped reflector element, said reflector element being disposed in spaced relation with, and to the rear of, the rear one of said dipole elements, a first transmission line connected to the rear one of said dipole elements for coupling to other apparatus, further transmission line sections electrically interconnecting each pair of adjacent dipole elements to complete an electrical path from each of said dipole elements to said first transmission line, said further transmission line sections between said elements having respective lengths greater than the corresponding physical spacings between said elements.

23. A multi-band antenna for a high frequency band and a low frequency band, the frequencies of said high frequency band being approximately triple the frequencies of said low frequency band, comprising a plurality of active dipole elements arranged in line, each of said elements having respective half-wavelength, full-wavelength, three-halves wavelength and two-wavelength resonant frequencies, said low frequency band being between said half-wavelength and full wavelength resonant frequencies of all said elements, and said high frequency band being entirely between said three-halves wavelength and two-wavelength resonant frequencies, and said elements being arranged in descending order of resonant frequency from front to back of said antenna, whereby said elements offer progressively increasing impedance from front to back of said antenna at all frequencies of said low and high bands.

24. An antenna as in claim 23 further including an additional active dipole element in back of said plurality of elements and having a higher impedance than all said plurality of elements for all frequencies in both said bands.

25. A wide-band antenna for operation over a given band of frequencies comprising a plurality of active dipole elements arranged in line, all of said elements having resonant frequencies at or outside the extreme edge of said given band, and said resonant frequencies being progressively smaller from front to back of said antenna, whereby said elements offer progressively increasing impedances from front to back at all frequencies of said given band.

26. A wide-band antenna for operation over a given band of frequencies comprising a pair of active dipole elements arranged in line and spaced from the front to back of said antenna, said elements both having resonant frequencies at or outside the extreme edge of said given band, the resonant frequency of said front element being

higher than that of said back element, and a third active dipole element arranged in line with said first two elements and spaced rearwardly of said first two elements, said third element having an impedance at all frequencies of said band greater than the impedances of said first two elements whereby said three elements offer progressively increasing impedances from front to back of said antenna at all frequencies of said given band.

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