Aug. 5, 1969 K. K. MEI 3,460,150

BROADSIDE LOG-PERIODIC ANTENNA

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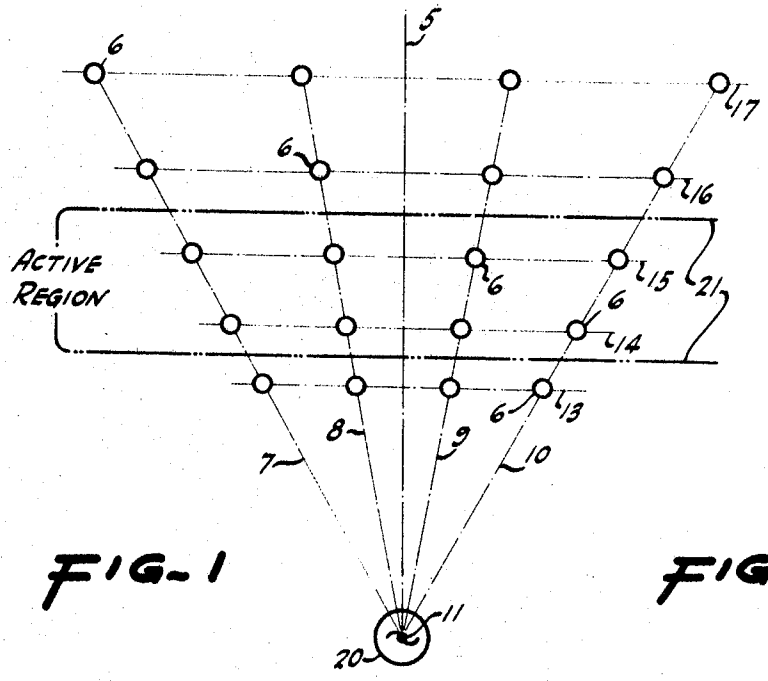


FIG. 1

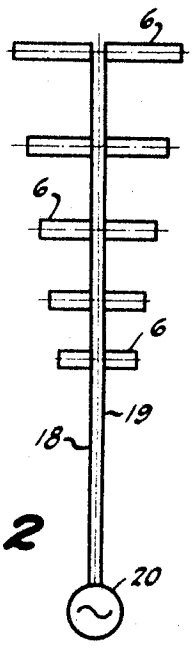


FIG. 2

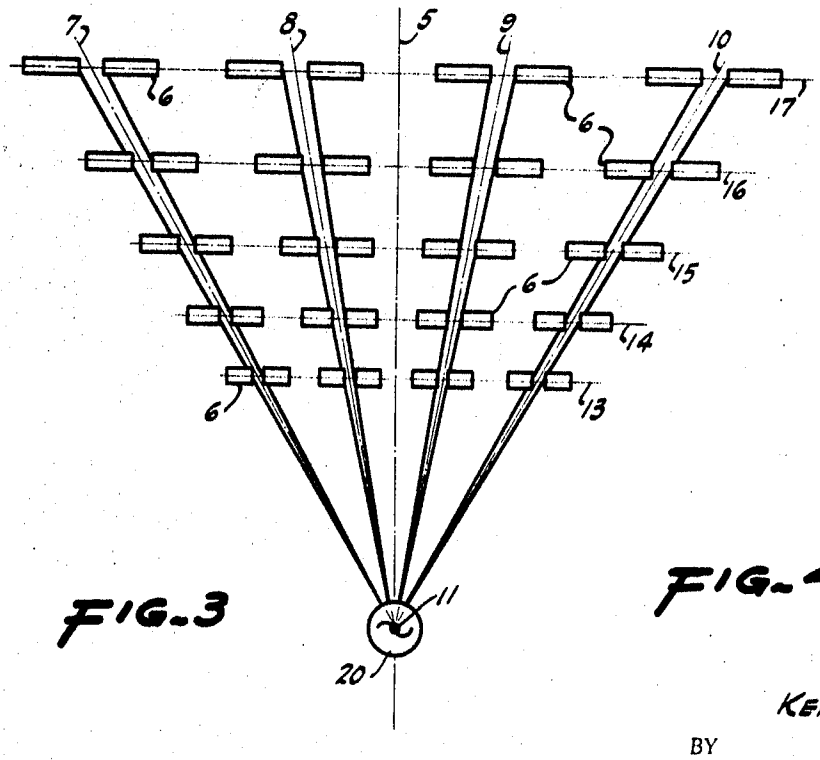


FIG. 3

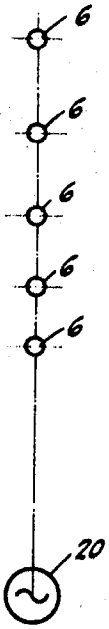


FIG. 4

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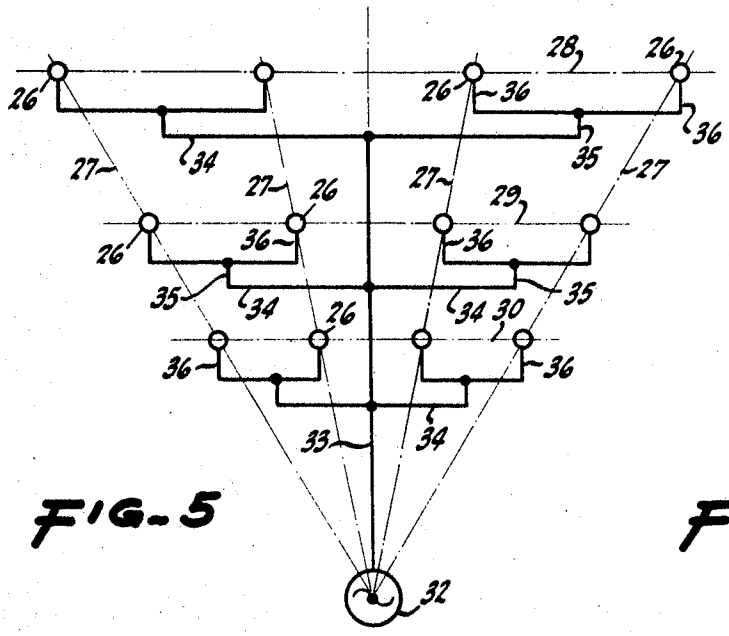


FIG. 5

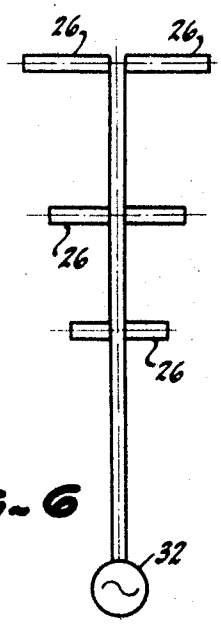


FIG. 6

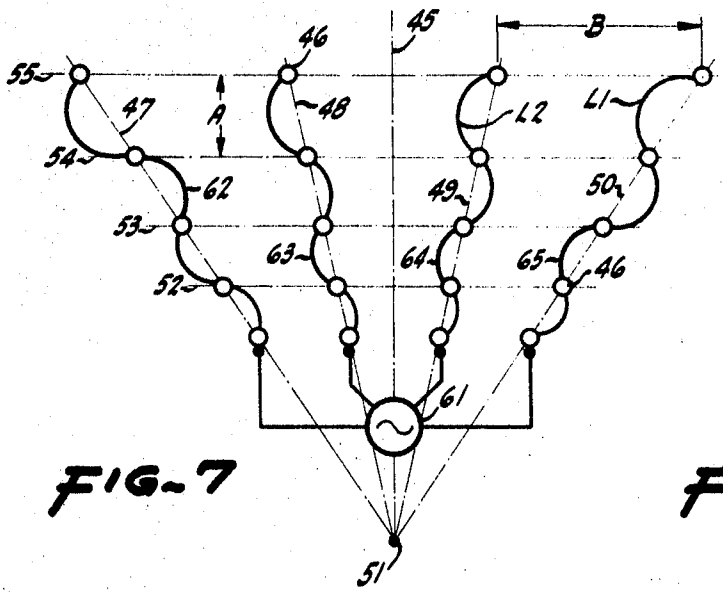


FIG. 7

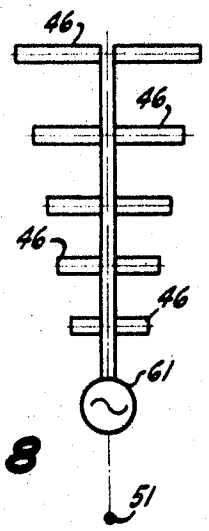


FIG. 8

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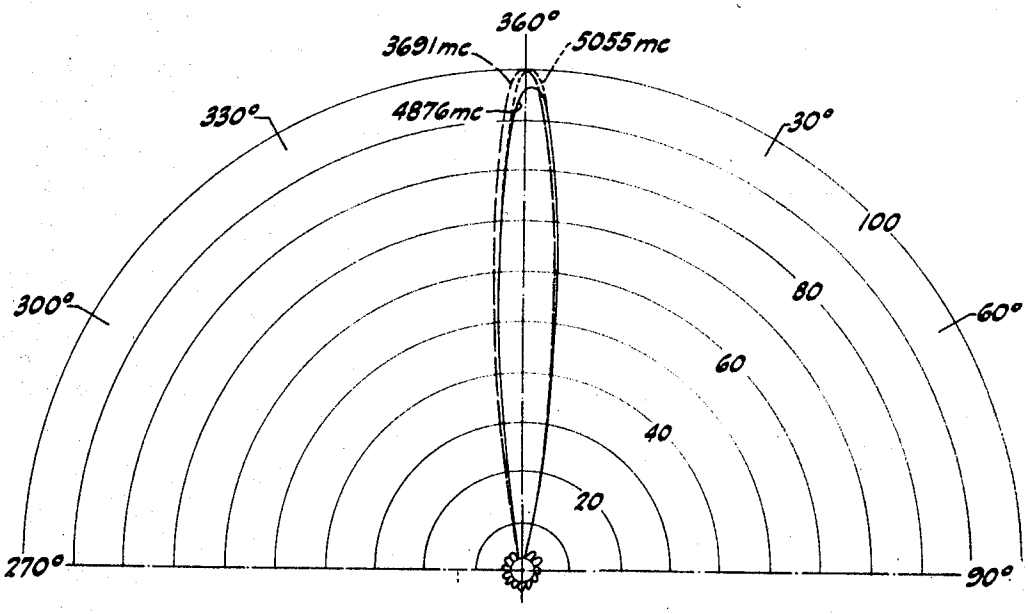


FIG-9

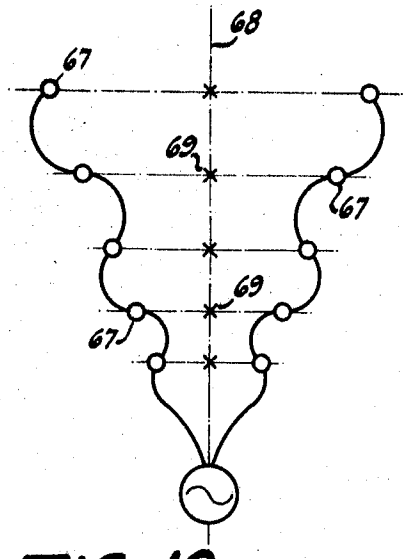


FIG-10

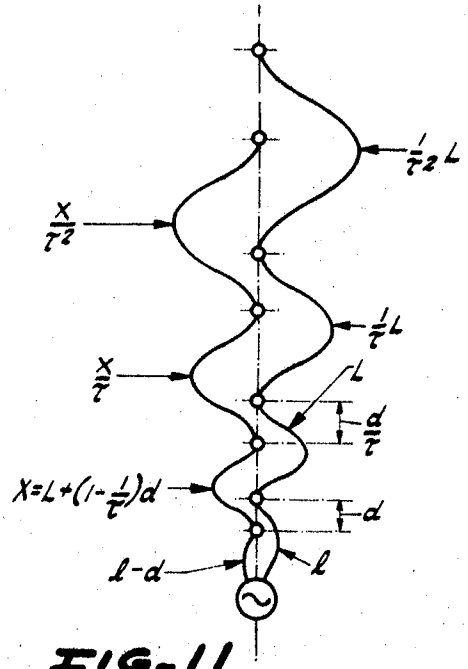


FIG-11

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FIG. 12

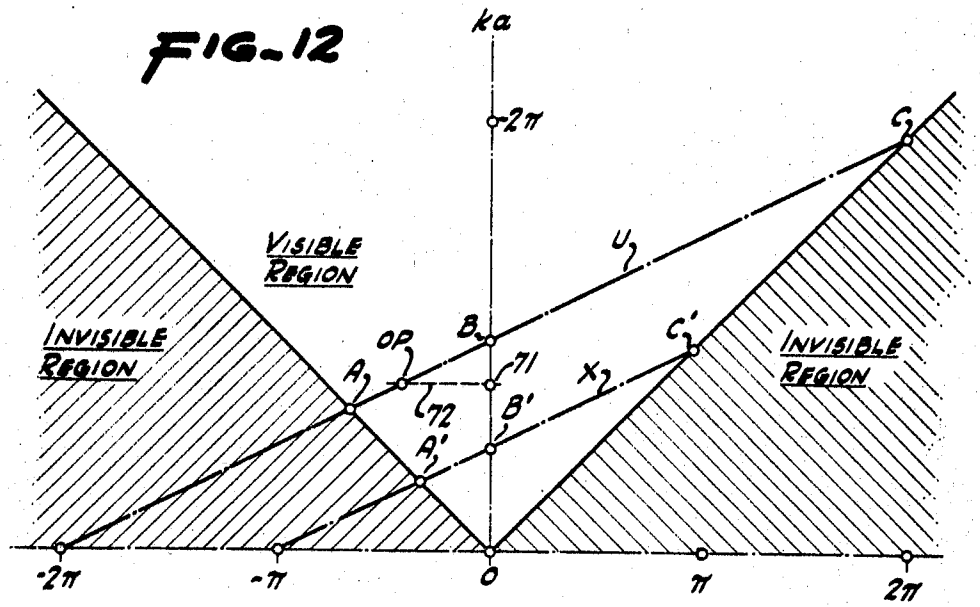
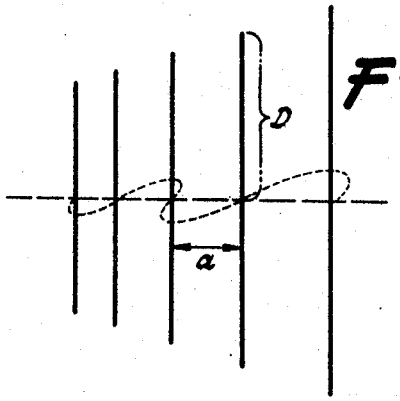


FIG. 13



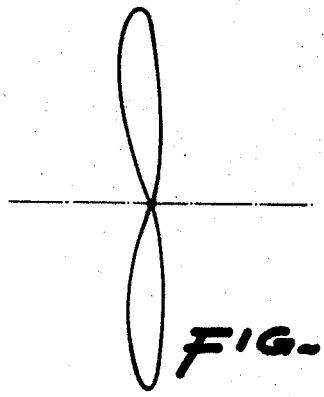
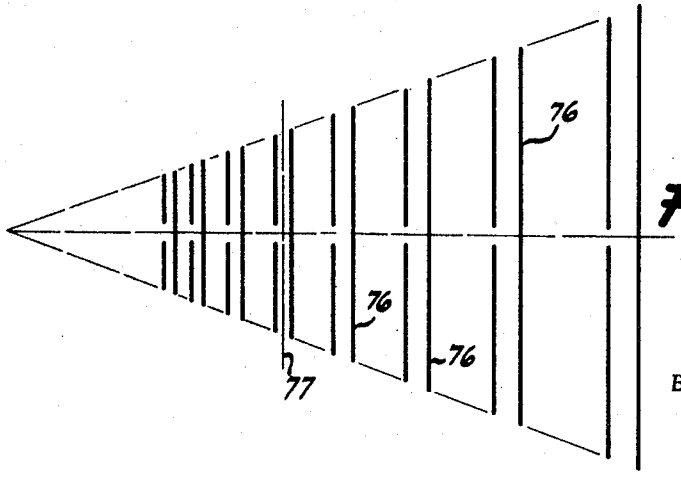


FIG. 15

FIG. 14



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FIG-16

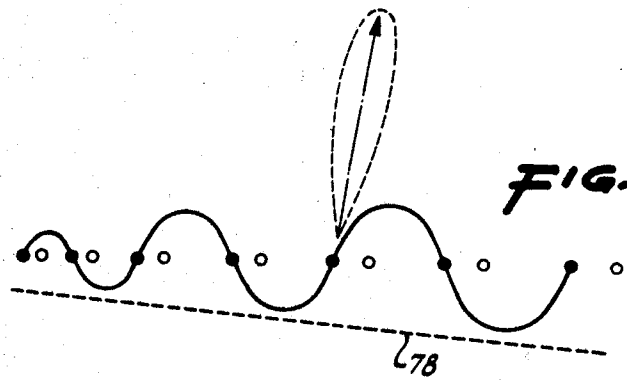
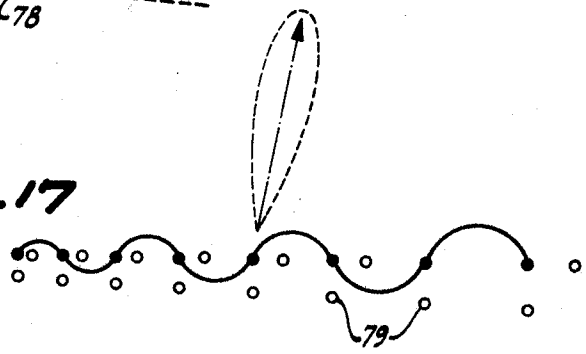


FIG-17



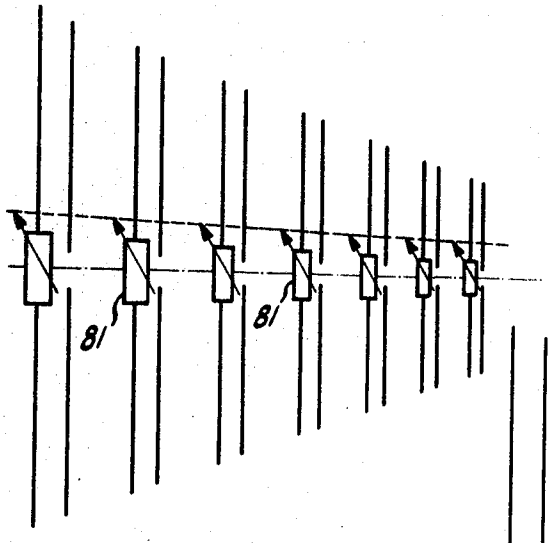
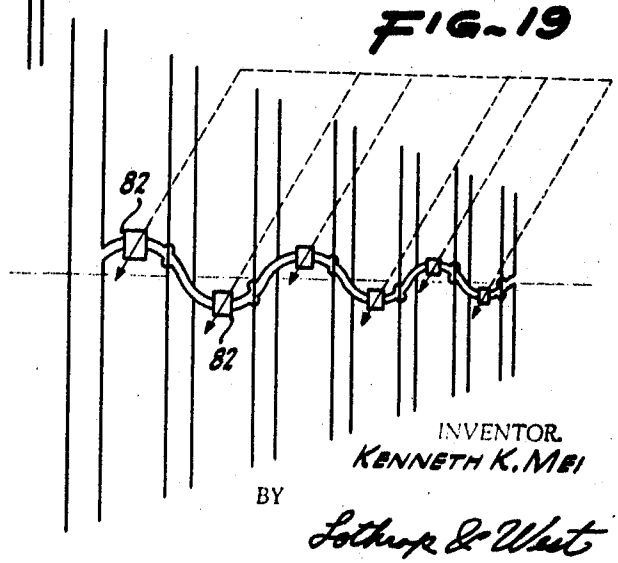


FIG-18

FIG-19



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United States Patent Office

3,460,150

Patented Aug. 5, 1969

3,460,150

BROADSIDE LOG-PERIODIC ANTENNA

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Filed Jan. 21, 1966, Ser. No. 522,170
Int. Cl. H01q 11/10
U.S. Cl. 343—792.5 6 Claims

ABSTRACT OF THE DISCLOSURE

A high gain frequency independent antenna includes an array of dipoles arranged in rows and files in substantially a common plane, the files radiating from a common origin and the rows being transverse and being spaced apart according to a logarithmic function. A pair of conductors electrically connects the dipoles in each file to a source of energy, the conductors having substantially equal effective length between said dipoles in any adjacent ones of said rows.

The invention relates to means for propagating and receiving electromagnetic energy, particularly waves of relatively short length and particularly under circumstances wherein considerable directivity of the antenna is desired and in which a high gain is a requisite.

Represented in the literature and in practice are various antenna arrangements utilizing logarithmic periodic spacing of the antenna elements. These offer a broad beam of radiation which is disadvantageous in that the directivity of the antenna is poor and the power radiated in any given direction is a small fraction of the power input. A prinicipal arrangement is of several end-fire elements in a fan-shaped or arcuate array about a central point in order to increase the gain. While there is some benefits in this practice, it is not as great as desired since the active region of the various antenna elements is arcuate or curved and so the array is not highly directional.

It is therefore an object of the invention to provide a high gain and frequency independent antenna array which is highly directional.

Another object of the invention is to provide a high gain, frequency independent antenna arrangement in which the directive pattern is substantially entirely in a selected direction and of the desired narrow width.

Another object of the invention is to provide a directive, frequency independent high gain antenna which can be steered electronically.

Another object of the invention is in general to provide a simple, straightforward, economically manufactured and readily maintained antenna of the general characteristics mentioned.

A still further object of the invention is to provide an improved high gain, directive, frequency independent antenna, particularly one subject to electronic steering.

Other objects together with the foregoing are attained in the embodiments of the invention described in the accompanying description and illustrated in the accompanying drawings, in which:

FIGURE 1 is a diagram showing in plan one form of antenna according to the invention;

FIGURE 2 is a side elevation of the FIGURE 1 arrangement;

FIGURE 3 is a plan of a modified form of the arrangement of FIGURE 1;

FIGURE 4 is a side elevation of the FIGURE 3 arrangement;

FIGURE 5 is a plan of a different form of antenna;

FIGURE 6 is a side elevation of the FIGURE 5 arrangement;

FIGURE 7 is a plan of an antenna with snake connections;

FIGURE 8 is a side elevation of the FIGURE 7 arrangement;

FIGURE 9 is a plane pattern of radiated power from a typical antenna at three frequencies;

FIGURE 10 is a schematic plan of a two-element snake broadside antenna;

FIGURE 11 is a schematic plan of an end-fire log-periodic antenna;

FIGURE 12 is a k–B diagram;

FIGURE 13 shows spacing and radiator length of a log-periodic antenna;

FIGURE 14 shows a log-periodic array with parasitic elements, the feeding system being omitted;

FIGURE 15 shows a plot of power radiated from an actual broadside log-periodic antenna as shown in FIGURE 14;

FIGURE 16 shows a single beam broadside log-periodic antenna with a reflecting screen;

FIGURE 17 shows the antenna of FIGURE 16 but with a second set of parasitic elements;

FIGURE 18 is a schematic plan of an electronically steerable log-periodic antenna, the feeding system being omitted; and

FIGURE 19 is a schematic plan of an electronically steerable log-periodic antenna steerable by tuning the feed lines.

Pursuant to a principal concept of the present invention, in one example (FIGURES 1 and 2) there is arranged an antenna array symmetrical about an axis **5** and comprising a number of dipole antenna radiators **6** disposed (for example, vertically) in a plurality of radial files **7**, **8**, **9** and **10**, for example. Each file radiates from a common origin **11** on the axis **5**. The dipoles **6** in each of the files are arranged so that they also lie in transverse rows **13**, **14**, **15**, **16** and **17**, for example. The spacing between the individual rows is made to accord with a logarithmic function. This spacing of the rows is usually referred to as log-periodic. The individual dipoles **6** in each one of the transverse rows **13**, **14**, **15**, **16** and **17**, for example, are of the same length (or height, assuming the radiators have their axes vertical) but the lengths (or heights) of the dipoles in the successive rows very with the same logarithmic function as does the spacing of the rows. The various dipoles are supplied through a pair of transmission conductors **18** and **19** coincident with the file lines **7** running from a suitable source such as an oscillator **20**. The dipoles can be replaced by monopoles in a similar pattern and with a ground plane structure all connected to a suitable energy source. Also, the dipoles may be arranged with their axes horizontal rather than vertical, as shown in FIGURES 3 and 4.

The effect of these arrangements is to afford a substantially linear, transverse, active region **21** and thus to afford a straight, broadside propagation of the electromagnetic energy with a highly directional pattern and with the pattern varying inconsequentially or not at all over a relatively wide range of frequencies.

An arrangement producing similar results is illustrated in FIGURES 5 and 6 in which the geometrical or physical location or arrangement of a number of dipoles **26** is log-periodic in a number of radial files **27** and also in a number of transverse rows **28**, **29** and **30**, for example. A source of energy, an oscillator **32**, is connected by a symmetrical transmission line **33** including a pair of conductors running along the axis and having branches **34** in axial symmetry connecting to leads **35** and connectors **36** likewise in symmetry on opposite sides of the center axis of the mirror image array. In this instance also, since the actual dipole pattern is comparable to that of FIGURES 1 and 2, the array is properly a log-periodic, broadside array of the dipoles with an active region comparable to that in FIGURE 1. Again, a monopole, ground plane construction can be utilized if desired. It has been developed experimentally that the arrangement shown in FIGURES 5 and 6 is also effective over a very wide frequency range to afford a highly directional beam and a high gain.

The theoretical handling of the parameters of the antennae heretofore described is relatively difficult, and reproduceable results with various different dimensions are difficult to obtain, although excellent experimental results have been obtained with certain individual versions of the illustrated arrays.

It is possible and desirable to vary the arrangements somewhat in order to reduce the complexity of the calculations and to make readily reproduceable within a narrow range an antenna array which has all of the desired characteristics.

As particularly illustrated in FIGURES 7 and 8, about an axis **45** there are symmetrically arranged a number of dipoles **46** located in radial files **47**, **48**, **49** and **50** having a geometrical origin **51** and likewise log-periodically arranged in transverse rows such as **52**, **53**, **54** and **55**. In this instance, while the geometrical or space arrangement of the dipoles **46** is similar to the previous arrangements, the transmission of the energy thereto is different. In this case, the energy is derived from a common source such as an oscillator **61**, as before, or from a plurality of sources in phase individually connected to the individual files of dipoles.

The transmission lines such as **62**, **63**, **64** and **65**, however, are not direct but are themselves arranged so that the length of all of the lines between any successive dipoles in any adjacent pair of the rows is identical despite the position of the various dipoles in their own files. That is to say, length L_1 of the transmission line **65** between two of the dipoles in the adjacent rows **54** and **55** and in file **50** is exactly the same as the length L_2 of the transmission line between the dipoles in the same two rows **54** and **55** but in the file **49**. This is accomplished by curving the individual, identically long transmission lines into generally S shapes. This kind of transmission line configuration is referred to as a "snake" connection. The line "length" can also be adjusted electronically as well as physically or by a combination of both electronic and physical adjustments. The relationship between the physical or electrical length L_1, for example, of the transmission line and a space distance A measured normally between the successive rows such as **54** and **55** affords a slowness factor. The relationship of L_1 and A is made to afford the desired slowness factor and to put all of the dipole radiators in any one row in approximately the same phase. Their phases all would be identical except that end effects make the mutual impedance slightly different at the outside elements.

In an actual working example of the array shown in FIGURES 7 and 8, the normal distance A was 3.43 centimeters. The distance between the end radiating dipoles in the row **55** indicated by the measurement B was 13.4 certimeters. The slowness factor or ratio of L_1 over A for equivalent air-filled line was 1.88. The characteristic impedance of the lines equalled 70 ohms. The length (or height) of one of the reference radiators **46** in the row **55** was 3.35 centimeters and the diameter of the reference radiators was 0.18 centimeters. Since this is completely a log-periodic array, all of the dimensions vary in proportion to their distance from the file origin **51**.

As an example of the radiation patterns for the four-element arrays of FIGURES 1 to 8, there are illustrated in FIGURE 9 three actual patterns, superposed, and individually representing power radiation at 3691 megacycles, 4876 megacycles and 5055 megacycles. It will be observed that these patterns are very nearly alike, that the directional characteristic of all of them is substantially the same, that the energy is very nearly all beamed in one direction, and that other directional lobes of the radiation pattern are extremely small and of inconsequential character.

While for illustration in the preceding there have been shown arrays including only a few rows and only a few files, the general principles involved are not so limited and a large number of rows and files within practical limitations are entirely possible. Stated differently, there are no theoretical limitations on the number of radiators in a pattern or array of the sorts disclosed. This is because the active region of all of the arrays is substantially rectilinear and transverse or broadside and can be laterally extended indefinitely for as much gain as is desired.

The design of a broadside two-element log-periodic array, such as shown in FIGURE 10, is the same as the design of a single snake array with the radiators **67** coincident with the axis **67** since the locations of the radiators in their files project into comparable axial positions **69**. For an end-fire array, the second snake can be designed from the first one as shown in FIGURE 11.

The following data uniquely determine a log-periodic array:

(1) The ratio constant t.

(2) The slowness factor (the ratio of length of the transmission line connecting the adjacent elements and the direct free space distance between those elements).

(3) The angle a (the angle between the axis and the ends of the radiators or dipoles normal thereto).

(4) The transmission line impedance.

In an actual example, the transmission line impedance is chosen to be near the resonance impedance of the dipole, about 50 to 100 ohms.

Now referring to a uniform periodic structure rather than to a log-periodic structure, a k-B diagram can be drawn as in FIGURE 12. In this diagram k is the wave number in free space expressed as $k=w/c$. In this expression w is angular frequency and c is the velocity of light. In this diagram $B=wl/ac'$. In this expression a is the spacing between adjacent radiators, l is the length of the transmission line between adjacent elements and c' is the velocity of the signal in the transmission line. The shaded areas in the diagram are the "invisible" regions and the intervening, non-shaded area is the "visible" region. A uniform periodic structure with straight connections can be approximately represented on this diagram by a straight line U the slope of which is inversely proportional to the slowness factor of the structure. A uniform periodic cross fire, snake structure is represented on this diagram by a straight line X. For any frequency f a number ka equal to $2\pi fa/c$ is located at a point **71** on the vertical axis of the diagram and determines a horizontal line **72** passing through the

point. That horizontal line intersects the line U at a point OP called the operating point. If the operating point falls in the shaded, invisible region the antenna does not radiate; when the operating point is in the visible region, near A, the anenna backfires or radiates rearwardly; when the operating point is in the visible region, near B, the antenna radiates broadside; and when the operating point is in the visible region, near C, the antenna fires or radiates forwardly. Thus, as the frequency increases, the antenna radiates first backwardly, then broadside, then forwardly. If the structure is cross connected rather than straight connected, the same principle applies except that the *k*-B line is shifted horizontally by π.

The same diagram can be applied to a log-periodic structure by considering the operation to be at a particular frequency. As the signal travels down the structure, the spacing between the elements changes so a point on the *ka*-B*a* line represents an actual operating point of a particular section of the log-periodic structure. The point A on the diagram then represents a section of the actual log-periodic antenna effective to fire or radiate backwardly. If this direction of radiation is desired, the most efficient antenna or radiator, the quarter wave length antenna, is positioned in this corresponding location. The length D of this particular radiator or antenna, FIGURE **13**, with reference to the spacing *a* is taken either from the *ka*-B*a* diagram or from the formula

$$D=\frac{a}{4}\frac{l+s}{(s)}$$

for straight connection or from the formula

$$D'=\frac{a}{2}\frac{l+s}{(2)}$$

for cross connection wherein *s* is the slope of the *k*-B line. The determination of this antenna size completes the design. Since the *k*-B diagram is only an approximation, the results are only approximate. Some correction is practically necessary, the best element size usually being from 10% to 20% shorter than the computed value.

If a backfiring antenna array is not wanted, the above formulas should not be used but the *k*-B diagram should be used as follows:

(1) Choose a convenient value for the transmission line and the ratio constant *t* (*t* is equal to or greater than .8).

(2) Choose a slowness factor for the structure and draw the *ka*-B*a* line, remembering that the larger the slowness factor the closer the elements will be spaced.

(3) Determine the operating point and the element or radiator size from the *ka*-B*a* line.

(4) Take measurements of the resulting actual pattern and correct the element length for best performance.

If parasitic elements are used in addition to the connected, active or radiating dipoles of the log-periodic antenna, they act not only as Yagi reflectors or guides, depending upon their spacing and the input impedance, to increase the gain, but also may be used to control the active region of the antenna.

As the signal travels from the smaller end of the log-periodic antenna to the larger end, the operating point moves from the invisible region to the backfire region, then to the broadside region and finally to the forward fire region. Thus, even though the elements in the backfire region may be small, the progression of the operating point through such region causes the leakage of considerable energy before the signal reaches the desired location for the operating point.

This leakage can be reduced or eliminated by using parasitic elements **76** as shown in FIGURE 14 to form a simple Yagi configuration. At a particular frequency the Yagi configurations change from guides to reflectors and the array changes from forward fire to backward fire. Thus, to obtain a log-periodic antenna which radiates off axis the parasitic elements are designed so that the transition region **77** is just in back of the desired active region. Behind the transition region the reflectors fire forwardly while the connected radiators fire in the opposite direction, resulting in no net radiation from this section and hence obviating leakage therefrom. In the active region the reflectors and the connected elements radiate in the same direction; hence the desired radiation takes place and can be directed at any desired angle with respect to the axis is depending upon the relative effect of the parasitic elements and the active elements. An actual result from a broadside, multiple beam radiating log-periodic antenna is shown in FIGURE 15. If only single beam radiation is desired, a reflecting screen **78**, as in FIGURE 16, or another set **79** of parasitic elements, as in FIGURE 17, may be used. In fact, for effective, almost exactly broadside radiation with this antenna, the parasitic elements **79** can be retained, as shown in FIGURE 17, and the remaining parasitic elements, those directly in the file, can be omitted.

From the foregoing it is clear that the direction of radiation of a log-periodic antenna using simple parasitic elements depends upon the location of the transition region in that when the transition region is moved toward the smaller end of the antenna the beam is moved closer to the axis and when the transition region is moved toward the larger end, the beam moves closer to the broadside direction. Thus, by shifting the location of the transition region the beam can be polarly shifted or scanned. The transition region of a simple Yagi configuration in the frequency range in which the parasitic element changes from a guide to a reflector and the behavior of the parasitic element as guide or reflector depends not only on the spacing between the direct radiator and the parasitic element, but also on the input impedance of the parasitic element. When the impedance of the parasitic element is inductive, the element tends to act as a reflector at a closer spacing than when the impedance is capacitative. The input impedance of the parastic element can be varied by changing the length of the element, by the provision of loading means **81**, as seen in FIGURE 18, or by providing tuners **82** for tuning the feed lines as shown in FIGURE 19. Both the effective length of the element and the loading can be controlled electronically by well-known means. By so doing, the transition region of the parasitic elements is moved and the beam of the log-periodic antenna is thus electronically scanned. As shown, the individual loading and tuning means may be ganged.

In the foregoing, reference is generally made to strict log-periodicity in order to have broad band operation, but if broad band operation is not of great importance, the antenna elements need not be so precisely spaced and can even be made of uniform spacing for cheaper manufacture, although at the sacrifice of some band width. This occurs particularly at the higher frequencies. Also, some intermediate spacings between uniform and log-periodic may be used with intermediate results, all pursuant to the foregoing.

What is claimed is:

1. A high gain frequency independent antenna comprising a fan-shaped array of dipoles arranged in a plurality of files radiating from a common origin and disposed in transverse rows spaced apart according to a logarithmic function, and means including a pair of conductors for electrically connecting said dipoles in each of said plurality of files by conectors having substantially equal effective length between said dipoles in any adjacent ones of said rows.

2. A high gain frequency independent antenna according to claim **1** in which connectors for said dipoles in each file have a snake configuration in extending from row to row.

3. A high gain frequency independent antenna according to claim 1 in which each of said dipoles is provided with a parasitic element.

4. A high gain frequency independent antenna according to claim 1 in which tuning means are provided in said connecting means between each of said rows.

5. A high gain frequency independent antenna according to claim 1 in which tuning means are provided for said dipoles in each of said rows.

6. A high gain frequency independent antenna according to claim 1 in which connectors for said dipoles in each file are dielectrically loaded.

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ELI LIEBERMAN, Primary Examiner

U.S. Cl. X.R.

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