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LOBE SWITCHING DIRECTIONAL ANTENNA WITH DIRECTIONAL
COUPLERS FOR FEEDING AND PHASING SIGNAL ENERGY

Filed Jan. 4, 1960

2 Sheets-Sheet 1

Fig. 1

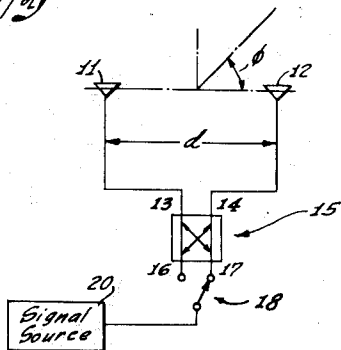


Fig. 2

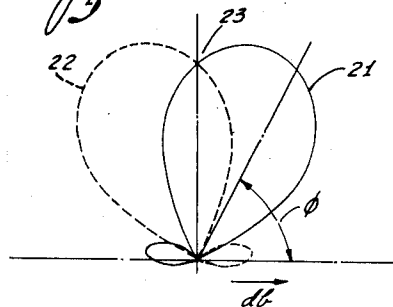
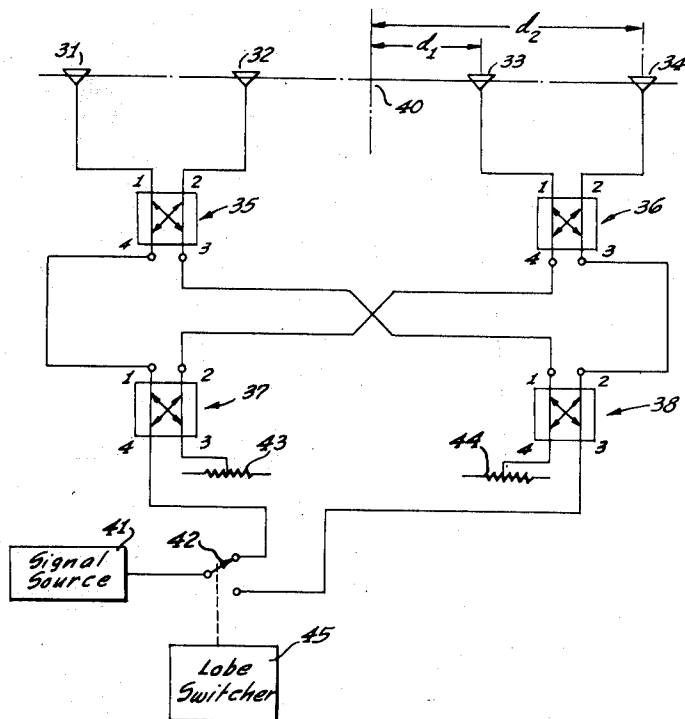


Fig. 3



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Fig. 4

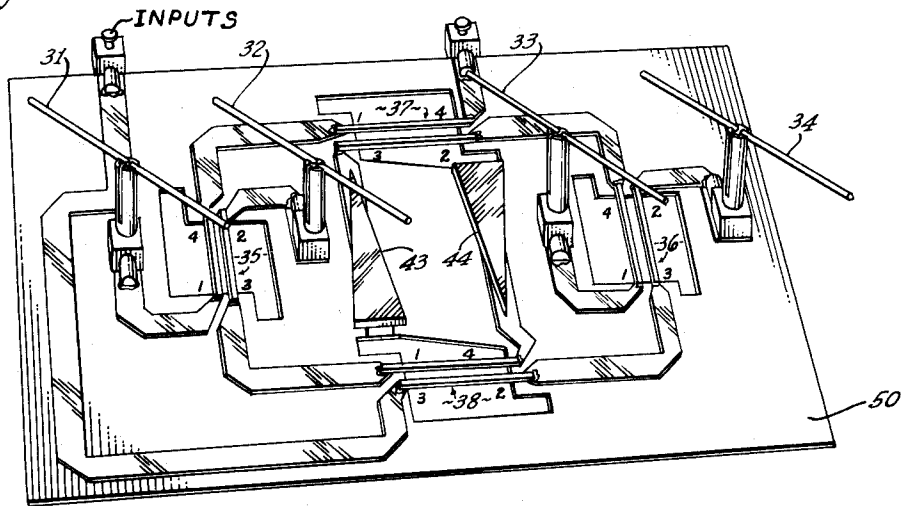
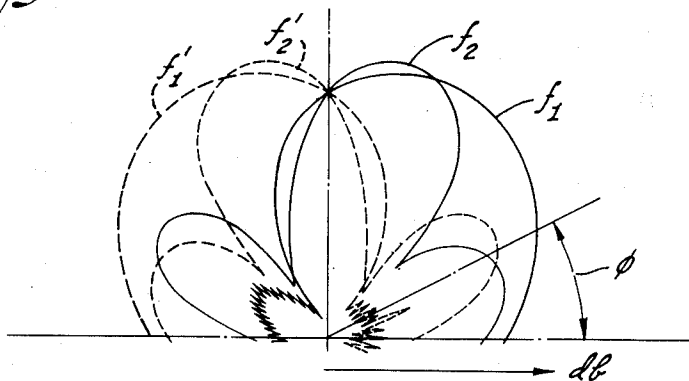


Fig. 5



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LOBE SWITCHING DIRECTIONAL ANTENNA WITH DIRECTIONAL COUPLERS FOR FEED- ING AND PHASING SIGNAL ENERGY

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The present invention relates to directional antennas, and more particularly to an inherently broadband, lobe-switching directional antenna.

In utilizing radio techniques to determine the direction of arrival of radio energy, advantage is generally taken of the directional radiation characteristics of antennas themselves. Among the broad classes of radiation patterns utilized in the past are those which comprise a single narrow beam which can be positioned in the desired direction, and those comprising a broad radiation pattern of unique shape such that a particular directional response can be differentiated from all other responses. A serious disadvantage of the former class is that antennas of large aperture are required to generate narrow beams, and their size may be prohibitive at frequencies of interest.

One of the most accurate methods of the latter group for deriving directional information with the smallest aperture antenna is the lobe-switching method. This method utilizes an antenna system having a radiation pattern comprising two radiation lobes whose maxima are displaced from each other by a small angle such that the two patterns provide signals of equal amplitude along a line between the lobes, and signals of unequal amplitude elsewhere. By moving the antenna or the signal source and comparing the signals attributable to each lobe, the direction of equal signals may be readily established in space.

A major disadvantage of the narrow beam directional antennas heretofore known in the past is the fact that such antennas are inherently narrow band, their directional properties and consequent usefulness generally being restricted to the specific frequency for which they were designed. In the case of lobe-switching antennas, the amplitude of signals at the equi-signal line, known as the "crossover level", and the rate at which the signal level changes with direction, known as the "crossover slope", are important design parameters. These parameters are also functions of frequency, and have similarly restricted broadband operation of the lobe-switching antennas heretofore known to a specific frequency. Similarly, where the directional properties of an antenna array depend on the excitation of the elements of the array in a particular phase relationship, the use of frequency sensitive phase shifting elements has frequently restricted the frequency range over which such antennas may be usefully operated.

The above and other disadvantages of the prior art are overcome, in accordance with the present invention, by providing a directional antenna which is inherently broadband, and theoretically has an infinite bandwidth. The lobe-switching directional antenna of the present invention has a substantially constant crossover level throughout its operating range, and a crossover slope over the same range which always exceeds preselected values. Such results are achieved in accordance with the present invention by providing an array of conventional radiating elements arranged with a particular spacing and fed signals of selected amplitude and phase. The antenna further includes feed means as disclosed herein, adapted to maintain such amplitude and phase relationships over the frequency band for which operation of the antenna is contemplated.

It is therefore, an object of the present invention to provide an improved directional antenna.

A further object of the present invention is to provide an improved directional antenna which maintains its directional properties over a broadband of frequencies.

Another object of the present invention is to provide an improved broadband directional antenna for producing a lobe-switched antenna pattern which utilizes all radiating elements of the array to generate each of the primary lobes of the lobe-switched pattern.

Still another object of the present invention is to provide an improved broadband directional antenna whose pointing accuracy for a given array size is much greater than that heretofore known in the art.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which several embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only, and are not intended as a definition of the limits of the invention.

FIGURE 1 is a schematic diagram of one embodiment of the present invention.

FIGURE 2 is a polar diagram of a radiation pattern typical of those produced by the various embodiments of the present invention.

FIGURE 3 is a schematic diagram of another embodiment of the present invention.

FIGURE 4 is a diagram of an embodiment of the invention according to the schematic diagram of FIGURE 3.

FIGURE 5 is a polar diagram of radiation patterns typical of those produced by the embodiment of the invention shown in FIGURE 4.

Referring now to the drawings, wherein like reference characters designate like or corresponding parts throughout the several figures, there is shown in FIGURE 1 a schematic diagram of one embodiment of a lobe-switching directional antenna in accordance with the present invention. As shown in FIGURE 1, the embodiment comprises first and second radiating elements **11** and **12** connected to receive equal amplitude signals in phase quadrature from the two arms **13** and **14**, respectively, of a directional coupler **15**. Directional coupler **15** has its remaining arms **16** and **17** alternately connected by means of a switch **18** to receive signals from a signal source **20**. As will be explained more fully hereinafter, lobe-switching in the present invention is achieved by alternately connecting signal source **20** to one and another of the arms **16** and **17** of directional coupler **15**.

More particularly, radiating elements **11** and **12**, which are assumed to be isotropic, are spaced apart a distance d to radiate signals at an angle ϕ with respect to a line joining the two elements. Directional coupler **15** may be any of the broadband hybrid junctions now known to the art which function to present, in response to signals applied to a first input arm, signals at a pair of output arms which are of equal amplitude, and in phase quadrature of a first relative phasing, and to present at the same output terminals, in response to signals applied to a second input terminal, signals of equal amplitude and in phase quadrature of another relative phasing. For example, directional coupler **15** may be similar in structure and function to the directional coupler shown and described in an article entitled "Strip-Line 3-db Directional Coupler," appearing at pages 4-15 of Part 1 of the 1957 IRE Wescon Convention Record, and is arranged to respond to signals applied to its input arm **16** to produce

signals at arms 13 and 14 of equal amplitude 3-db less than the amplitude of the applied input signals and in phase quadrature with respect to each other. If the coupler 15 is arranged to produce signals at arm 14 which lag those at arm 13 by 90° when input signals are applied to arm 16, application of input signals to arm 17 will cause the signal produced at arm 13 to lag those at arm 14 by 90°.

Referring now to FIGURE 2, there is shown a typical polar diagram of a radiation pattern which may be produced utilizing the embodiment of the invention shown in FIGURE 1. In deriving the data upon which FIGURE 2 is based, it has been further assumed that elements 11 and 12 each have primary radiation patterns of the form

$$g(\phi) = E \sin \phi, \text{ for } 0^\circ < \phi < 180^\circ \quad (1)$$

and

$$g(\phi) = 0, \text{ for } 180^\circ < \phi < 360^\circ \quad (2)$$

wherein

E is the amplitude of voltage fed to the element, ϕ is the space angle measured from the array line to a point in space at which $g(\phi)$ is measured.

The use of elements having such radiation patterns will effectively suppress the portion of the array pattern between $\phi = 180^\circ$ and $\phi = 360^\circ$ and side-lobes in the regions $0^\circ < \phi < 45^\circ$ and $135^\circ < \phi < 180^\circ$ will be considerably reduced.

The plot of FIGURE 2 depicts contours of relative signal output versus the angle ϕ for signals applied alternately to arms 16 and 17, pattern 21 being produced when signals are applied to input 16 while pattern 22 is produced when signals are applied to input 17. It will readily be recognized that patterns 21 and 22 are mirror images of each other about a line corresponding to $\phi = 90^\circ$, and that the primary lobes of the patterns cross at a point 23, defined as the "crossover point" which lies along the line $\phi = 90^\circ$.

The total field of this embodiment of the invention may be mathematically represented by the expression

$$G(\phi) = 2E \cos \left(\frac{Kd}{2} \cos \phi + \frac{\psi}{2} \right) \quad (3)$$

wherein

$$K = \frac{2\pi}{\lambda}$$

λ being the wavelength of the applied signal E , λ is the phase angle between feed coefficients, and the remaining symbols have the significance heretofore noted.

A particular feature of the embodiment of the invention thus described is the fact that the crossover point falls along the line $\phi = 90^\circ$ over an extremely broadband of frequencies, so long as the signals applied to elements 11 and 12 are maintained of equal amplitude and in phase quadrature. Such a mode of operation may be achieved over a broadband of frequencies by utilizing an essentially broadband directional coupler for coupler 15, and by providing that the lines from coupler 15 to each of elements 11 and 12 are of equal length. The directional coupler described in the above cited article may be readily designed to have a 2 to 1 or greater operating bandwidth, and is therefore admirably suited for use in the present invention.

A further feature of the embodiment of the invention of FIGURE 1 is the fact that the crossover level is not a function of the spacing d between the antenna elements, but is a constant 3-db down with respect to beam maximum regardless of antenna spacing. On the other hand, the slope at crossover, which determines the accuracy with which the crossover point can be detected, is a direct function of radiator spacing, and can be increased by increasing the spacing between elements. At the same time,

increasing the spacing d results in the increased production of sidelobes in each of patterns 21 and 22, which may produce "false" crossover points indistinguishable except in amplitude or phase from crossover point 23. In order to maintain the crossover slope of the two element array at usable levels, and to reduce the possibility of multiple lobing and false crossover points, the use of a two-element array should be restricted to spacing d between $\lambda/4$ and $\lambda/2$ for the wavelengths λ of interest.

The above and other limitations of the two-element array may be overcome by replacing each of elements 11 and 12 with a pair of radiating elements, each fed signals of equal amplitude again in phase quadrature. Such an embodiment of the present invention is shown in FIGURE 3, and includes radiating elements 31, 32, 33, and 34 and four directional couplers 35, 36, 37, and 38 for lobe-switching and phasing. As depicted in the figure, elements 31 through 34, which may comprise the isotropic radiators heretofore described, are arrayed along a line, elements 32 and 33 each being disposed a distance d_1 with respect to a center point 40 of the array, while elements 31 and 34 are each disposed a distance d_2 from the center point. Each of the radiating elements is coupled to receive signals of equal amplitude from the output arms of directional couplers 35 and 36, the elements being connected in the sequence, 31 to 35-1, 32 to 35-2, 33 to 36-1, and 34 to 36-2. As heretofore set forth, application of input signals to either of the remaining arms of the directional couplers will produce signals of equal amplitude but in phase quadrature for exciting the radiating elements connected thereto.

In order to provide for excitation of each of radiating pairs 31, 32, 33, and 34 in phase quadrature, one of the remaining arms 35-4 and 36-4 of each of directional couplers 35 and 36 is connected to an output arm 37-1 and 37-2, respectively, of directional coupler 37, which has one of its input arms 37-4 connectable to signal source 41 through a switch 42. Switch 42 is a single pole double-throw switch which may be actuated by a lobe-switcher 45 to accomplish the lobe-switching function of the present invention. The remaining arm 37-3 of coupler 37 may be connected to a matching load 43.

The application of input signals from source 41 to the antenna system thus described will, as may easily be shown, produce signals at each of elements 31-34 of equal amplitude, and, for equal lengths of connecting lines between the directional couplers, and the directional couplers and the elements, of the following relative phase relationship.

Element:	Angle, degrees
31 -----	0
32 -----	-90
33 -----	-90
34 -----	-180

The radiated pattern of the elements, in response to such excitation, will substantially correspond to pattern 21, or one primary lobe of the desired lobe-switched pattern.

In order to provide the remaining primary lobe of the lobe-switched pattern, the embodiment of the invention shown in FIGURE 3 includes directional coupler 38, which has its output arms 38-1 and 38-2 connected to the remaining input arms 35-3 and 36-3 of directional couplers 35 and 36, respectively. Input arm 38-3 in turn is arranged to be connected to source 41 through switch 42, which provides for alternate excitation of the array from source 41 through directional coupler 38. The remaining arm 38-4 of coupler 38 may be connected to a matching load 44.

It will readily be recognized that the application of input signals from source 41 to directional coupler 38 will produce signals at each of elements 31-34 of equal amplitude, and for equal lengths of connecting lines between the directional couplers, and the directional cou-

plers and the elements, of the following relative phase relationships.

Element:	Angle, degrees
31 -----	-180
32 -----	-90
33 -----	-90
34 -----	0

The radiation pattern of the elements in response to such excitation, will substantially correspond to pattern 22, or the remaining primary lobe of the desired lobe-switched pattern. It will thus be seen that alternate excitation of the array through directional couplers 37 and 38 will produce a complete lobe-switched pattern similar to that shown in FIGURE 2.

The general equation of the pattern of the embodiment of the invention shown in FIGURE 3 is of the form

$$G(\phi) = \cos(Kd_1 \cos \phi) - \sin(Kd_2 \cos \phi) \quad (4)$$

where the symbols have the significance heretofore assigned.

It will readily be recognized that $G(\phi)$ is only a function of d_1 and d_2 , and that when $\phi=90^\circ$, $G(\phi)=1$, while $G(\phi)_{\max}=1.8$. By differentiation it may also be readily established that at $\phi=90^\circ$,

$$\frac{dg(\phi)}{d\phi} = Kd_2 \text{ relative volts/radian} \quad (5)$$

The embodiment of the invention shown in FIGURE 3 will exhibit the radiation pattern shown over a broadband of frequencies if the directional couplers themselves are broadband, and the remaining elements of the system, such as the coupling leads, do not introduce frequency-dependent phase and amplitude variations.

The antenna array of FIGURE 3 displays substantially constant crossover level as does the embodiment of FIGURE 1. By selecting (d_2-d_1) greater than $\lambda/4$, where λ is the longest wavelength to be handled, the minimum possible crossover level will be 5-db down with respect to beam maximum, regardless of the pair spacing.

At the same time, the slope at the crossover point is only a function of d_2 , and accordingly, the position of elements 32 and 33 may be freely chosen to produce the greatest suppression of sidelobes. In order to have at least 0.3 db per degree slope, d_2 should be equal to or greater than $\frac{3}{8}$ wavelength at the lowest operating frequency, while (d_2-d_1) should be approximately $\frac{1}{4}$ wavelength.

Referring now to FIGURE 4, there is shown a diagram of an embodiment of the present invention constructed in accordance with the circuit diagram of FIGURE 3, and wherein corresponding parts have been given the same reference characters. In the view shown in FIGURE 4, only the radiating elements, stripline conductors and directional couplers of the feed network are shown, the ground planes, one of which also serves as a common reflector for the radiating elements, having been removed to afford a clearer view of the network itself. Sheet 50 is a supporting insulating material for the stripline conductors. The operation of the embodiment of FIG. 4 of the invention corresponds to that previously given for its circuit diagram, FIG. 3.

An "S" band model of the embodiment of the invention shown in FIGURE 4 was constructed with dimensions $d_1=.982$ inch and $d_2=2.418$ inches, and was found to display substantially constant crossover level, and a crossover slope which permitted a pointing accuracy of $\pm 0.5^\circ$, over a bandwidth of 2.2 to 1. FIGURE 5 illustrates in a single figure a typical polar diagram of the radiation pattern of such an array, at the two frequency extremes over which the array was to be operated. The close correspondence of the patterns, insofar as crossover level and slope are concerned, at the two frequencies f_1 , and f_2 ($=2.2 f_1$) will readily be recognized.

While the various embodiments of the present invention have been shown to include radiating elements and sources for their excitation, it will readily be appreciated that the use of such embodiments as receiving antennas is entirely obvious, and accordingly no further description of such operation is set forth herein.

When operated as a receiving system, the directional couplers combine the received signals vectorially, producing at their input terminals the sum of the signals applied to one of the output terminals and the signals applied to the other output terminal shifted in phase by 90° .

There has thus been described a directional antenna which is inherently broadband, and is particularly adapted for use as a lobe-switched directional antenna operating over a broadband of frequencies.

What is claimed as new is:

1. A directional antenna array of the lobe-switching type comprising: first, second, third, and fourth radiating elements arrayed in order along a common line; first, second, third and fourth directional couplers, each having first and second input arms and first and second output arms, and being responsive to signals applied to each of said input arms for producing output signals of equal amplitude in phase quadrature over a broad, continuous band of frequencies at each of said output arms, said output signals having a first relative phase when signals are applied to said first input arm and another relative phase when signals are applied to said second input arm, first, second, third and fourth means having equal electrical length for coupling said first and second radiating elements to said first and second output arms of said first directional coupler, and said third and fourth radiating elements to said first and second output arms of said second directional coupler; fifth and sixth means having equal electrical length for coupling said first input arms of each of said first and second directional couplers to said first and second output arms of said third directional coupler, respectively; seventh and eighth means having equal electrical length to said fifth and sixth means for coupling said second input arms of each of said first and second directional couplers to said first and second output arms of said fourth directional coupler, respectively; and means for alternately applying input signals to the first input arm of said third directional coupler and the second input arm of said fourth directional coupler.

2. The directional array set forth in claim 1, wherein each of said coupling means couples signals applied thereto without introducing relative phase shift or amplitude change between such signals.

3. A lobe switching antenna comprising: first, second, third, and fourth antenna elements, a first directional coupler for applying and receiving signals of equal amplitude but in phase quadrature to said first and second antenna elements, a second directional coupler for applying and receiving signals of equal amplitude but in phase quadrature to said third and fourth antenna elements, a third directional coupler for applying signals of equal amplitude but in phase quadrature to said first and second directional couplers, and a fourth directional coupler for applying signals of equal amplitude but in the opposite phase quadrature to said first and second directional couplers, a common terminal, and switching means for selectively interconnecting said common terminal to said third and fourth directional couplers; said first, second, third, and fourth directional couplers being substantially insensitive to frequency over a broad band of frequencies and providing a fixed quadrature phase shift within said band of frequencies.

4. A lobe switching antenna comprising: first, second, third, and fourth antenna elements, first means for applying and receiving signals of equal amplitude but in phase quadrature to said first and second antenna elements, second means for applying and receiving signals of equal amplitude but in phase quadrature to said third and fourth antenna elements, third means for applying

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signals of equal amplitude but in phase quadrature to said first and second means, and fourth means for applying signals of equal amplitude but in the opposite phase quadrature to said first and second means, a common terminal, and switching means for selectively interconnecting said common terminal to said third and fourth means; said first, second, third, and fourth means being substantially insensitive to frequency over a broad band of frequencies and providing a fixed quadrature phase shift within said band of frequencies.

5. In the antenna of claim 4, said antenna elements being arrayed along a common axis.

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