March 9, 1971 E. A. N. WHITEHEAD 3,570,007

PLURAL BEAM COUPLED WAVEGUIDE ANTENNA

Filed April 11, 1968 3 Sheets-Sheet 1

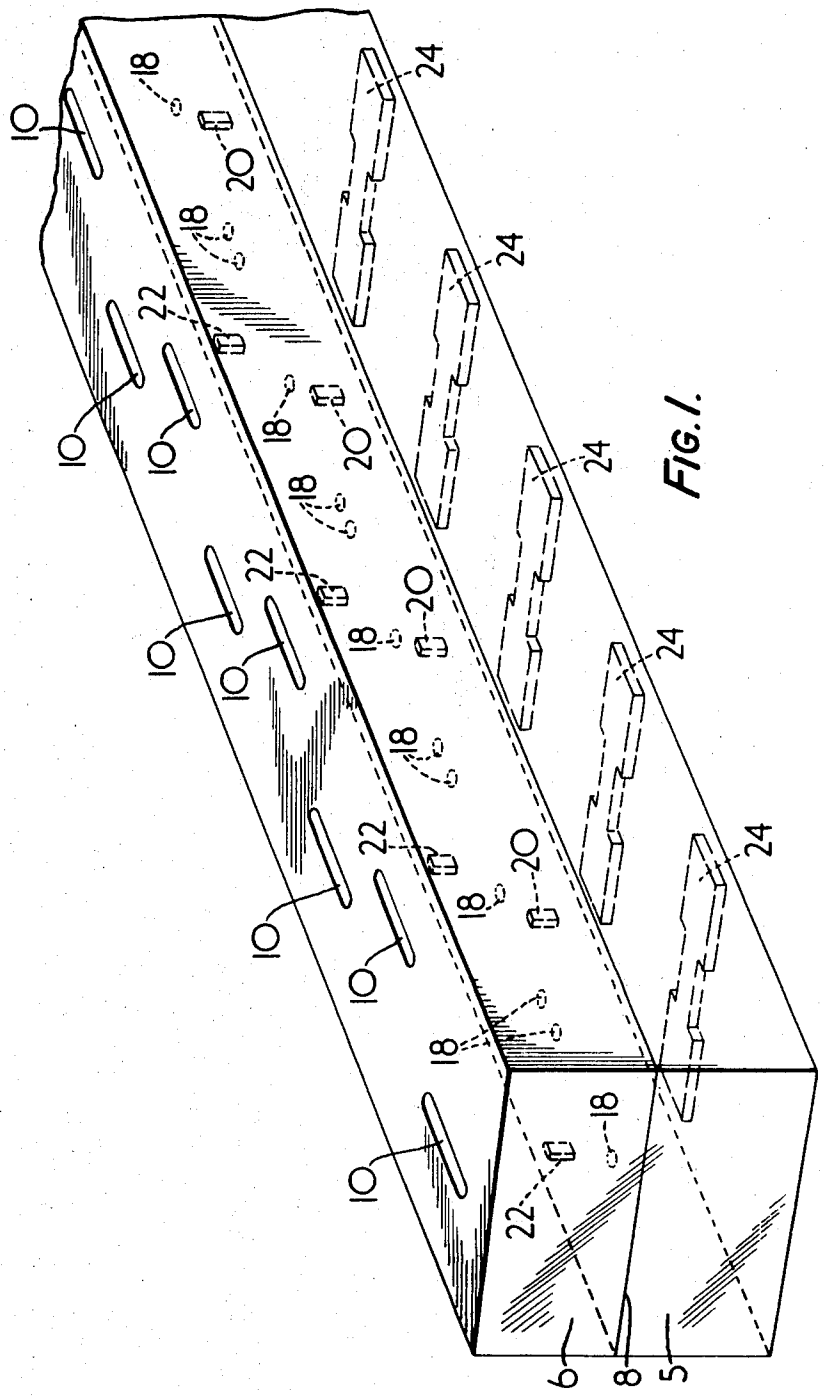


FIG. 1.

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PLURAL BEAM COUPLED WAVEGUIDE ANTENNA

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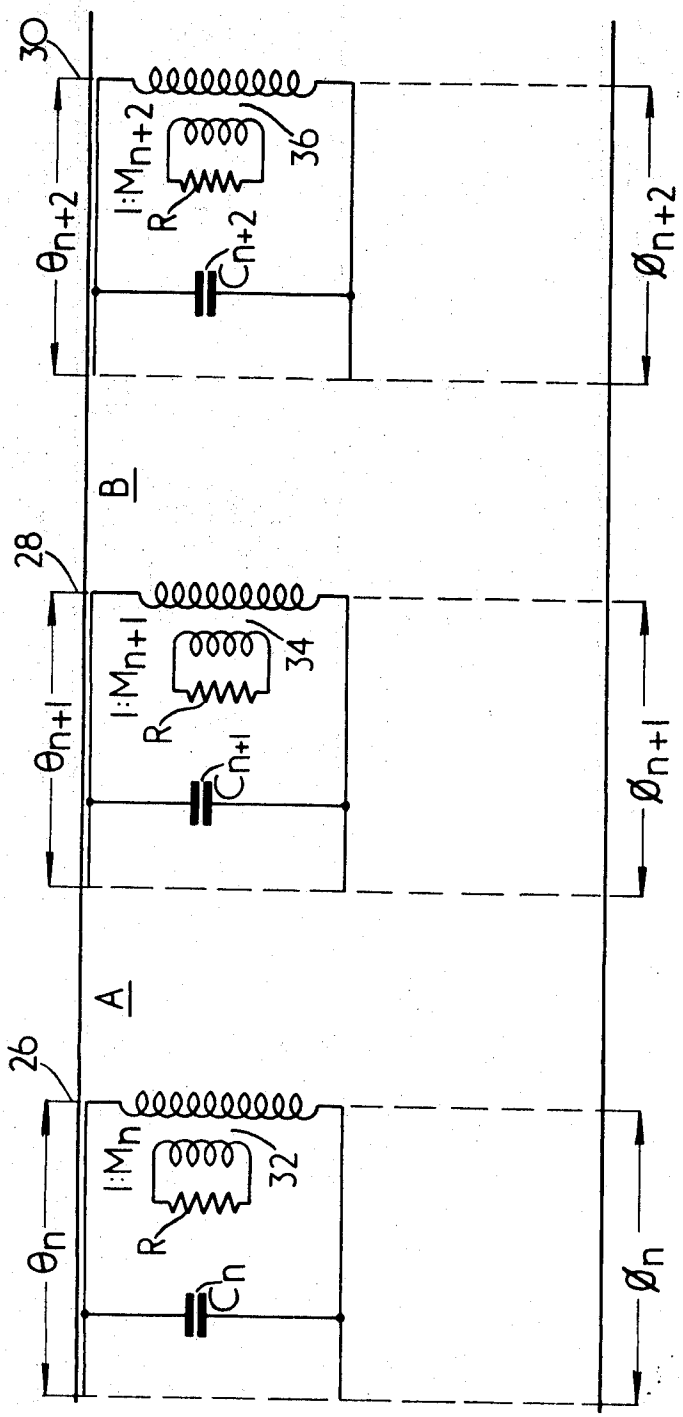


FIG. 2.

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PLURAL BEAM COUPLED WAVEGUIDE ANTENNA

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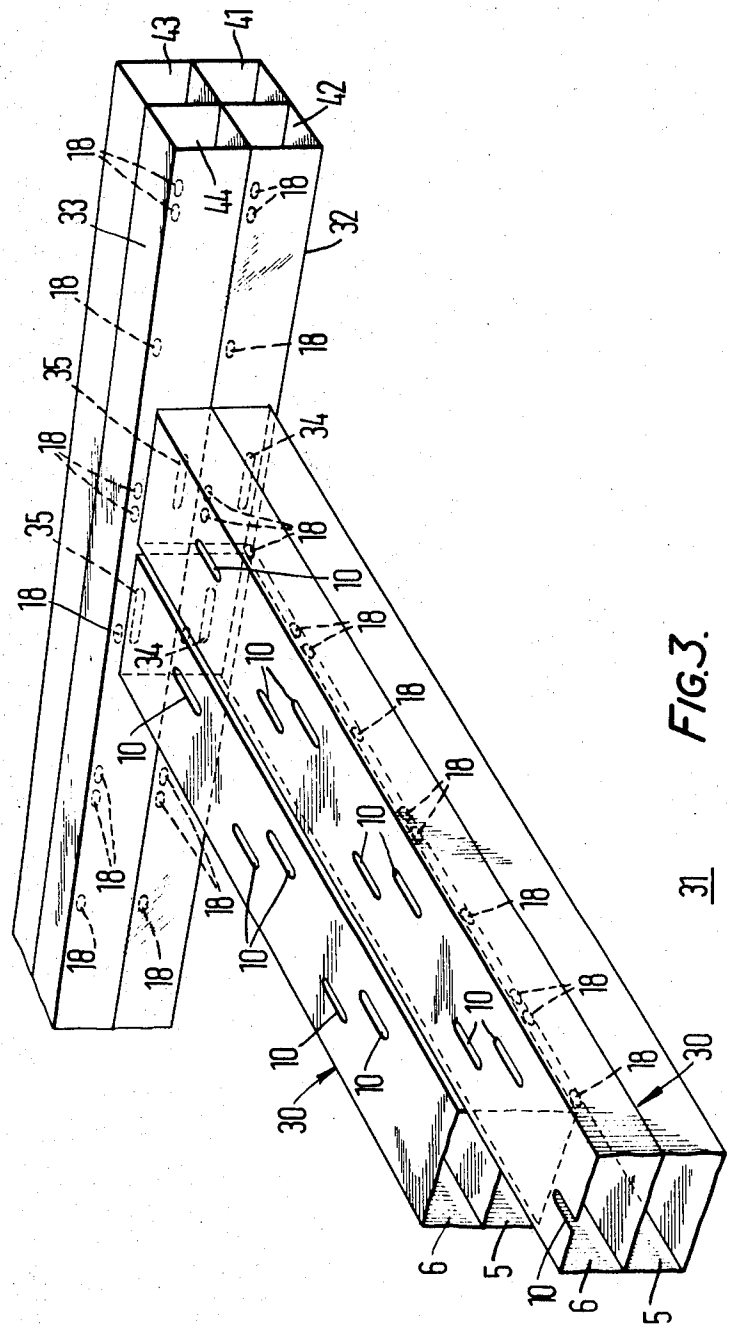


FIG. 3.

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3,570,007

PLURAL BEAM COUPLED WAVEGUIDE ANTENNA

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Int. Cl. H01q 13/10
U.S. Cl. 343—771 4 Claims

ABSTRACT OF THE DISCLOSURE

The elements of a linear aerial array are fed by one of a pair of transmission lines coupled together by directional couplers. By feeding a respective transmission line different radiation patterns are produced. A planar array, formed by mounting the linear arrays adjacently, can be fed by two pairs of feeder transmission lines each pair coupled together by directional couplers and one feeder line of each pair feeding a respective array line. Supplying any one of the four feeder lines produces a respective one of four radiation patterns.

This invention relates to aerials and aerial arrays.

According to the invention, there is provided an aerial comprising a radio frequency transmission line having integral therewith energy radiating and/or receiving means, the arrangement being selectively operable whereby the energy radiating and/or receiving means can radiate or receive energy in at least one of two or more different patterns.

Advantageously, a further transmission line is mounted adjacent the first mentioned transmission line and the two transmission lines are coupled together by coupling means, the energy to be radiated or to be received in one said pattern being fed into or from one said transmission line and the energy to be radiated or received in the other said pattern being fed into or from the other said transmission line.

According to a feature of the invention there is provided an aerial comprising an array of energy radiating and/or receiving means, a first radio frequency transmission line coupled to said means, a second radio frequency transmission line mounted adjacent to said first transmission line, and coupling means coupling said first and second transmission lines together, the arrangement being such that either one of two special response patterns of the said array can be employed by feeding a signal to or from a respective one of said first and second transmission lines.

Optionally, the said energy radiating and/or receiving means comprises slots in the first mentioned transmission line, and the transmission lines are waveguides.

According to a further feature of the invention there is provided an aerial array comprising two adjacent waveguides coupled together by directional coupling means, and a plurality of energy radiating and/or receiving means the energy radiating and/or receiving means and the directional coupling means being arranged whereby energy radiated by the radiating and/or receiving means is radiated in a particular beam pattern according to the particular one of the two waveguides into which the energy to be radiated is fed, and whereby the energy radiating and/or receiving means has a particular one of two response patterns to received energy according to the particular one of the two waveguides from which the received energy is fed.

Perferably, the energy radiating and/or receiving means are situated in or on one face of one said waveguide.

The energy radiating and/or receiving means can comprise slots in the said one face of the said one waveguide.

Advantageously, the said directional coupling means comprises aperture means in a face of the said one waveguide and arranged in alignment with aperture means in an adjacent face of the other said waveguide.

Each aperture means may comprise a plurality of holes to form a directional coupler. Instead, each aperture means may comprise a longitudinal slot.

Means may be provided for impedance-matching the slots.

In an embodiment of the invention, phase shifting means may be incorporated in the said other waveguide.

According to a further feature of the invention, there is provided a planar aerial array comprising a plurality of aerials or aerial arrays as disclosed in the preceding paragraphs and arranged side by side.

These and other novel features of the invention will be apparent from the following description, by way of example, of a linear aerial array embodying the invention which is shown in the accompanying drawings in which:

FIG. 1 is a diagrammatic perspective view of the linear aerial array showing internal parts;

FIG. 2 is a circuit diagram of part of the equivalent circuit of the aerial array of FIG. 1; and

FIG. 3 is a diagrammatic perspective view of part of a planar aerial array made up of adjacent linear arrays as shown in FIG. 1.

The linear array (FIG. 1) comprises two adjacent waveguides **5** and **6** (or other form of transmission line) which have a mutual face **8**. The upper face of the waveguide **6** is provided with energy radiating or receiving slots **10**, the slots **10** being arranged longitudinally at positions on each side of the centre line of the upper face. In a manner to be described in more detail below, the slots **10** couple with the energy in the waveguide **6** and radiate the energy outwardly or pick up energy outside the waveguide **6** and couple it into the waveguide. The positions of the slots **10** determines the effectiveness of the coupling between the slots and the waveguide **6**; the coupling is increased as the slots are moved outwardly so as to be closer to an edge of the top face of the waveguide **6**, and the coupling is reduced as the slots are moved closer to the centre line of the top face.

Adjacent slots **10** are spaced apart by a distance of approximately half the wavelength of the energy in the waveguide **6**.

The slots **10** could be replaced by a continuous slot in the top face of the waveguide **6**, this continuous slot being sinuous so as to extend first towards one edge of the top face and then towards the other parallel edge.

The slots **10** may be replaced by other energy radiating and/or receiving elements such as dipoles.

The two waveguides **5** and **6** are coupled through the mutual face **8** by means of a series of slots or holes **18** which form a directional coupler; instead a single continuous coupling aperture such as a longitudinal slot in the face **8** could be used.

For impedance matching purposes, as will be explained in more detail below, matching elements such as capacitive posts **20**, **22** may be provided on, for example, the mutual face **8** between the waveguides **5** and **6**. These capacitive posts are positioned accordingly to interact with the incident energy.

In order to control the phase and amplitude of the energy radiated by the slots **10**, phase shifting elements may be provided in either or both of the waveguides. In FIG. 1, they are shown for example in the lower waveguide **5**. Such phase shifting elements may comprise in-

serts **24** of plastics material, for example, as shown; instead of using phase shifting elements, the actual width of the waveguides may be varied.

In operation, energy may be fed into either the waveguide **5** or the waveguide **6**. The coupling between the waveguides **5** and **6**, the sizes of the slots **10**, and the phase length between adjacent slots **10** are all so arranged, in a manner to be further explained, that when energy is fed into the waveguide **5** the slots **10** radiate energy having one predetermined beam pattern and when energy is fed into the waveguide **6** the slots **10** radiate energy of a different predetermined beam pattern. Similarly, the aerial array may be used to receive energy; the aerial array will have a predetermined response pattern for energy received by the slots **10** and extracted from the waveguide **5** and will have a different response pattern for energy received by the slots **10** and extracted from the waveguide **6**.

The approximate equivalent circuit of part of the arrangement of FIG. 1 is shown in FIG. 2. The equivalent circuit of FIG. 2 considers only the nth, the $(n+1)$th and $(n+2)$th slots which are assumed to be positioned at cross-sections **26, 28** and **30**. The phase lengths along the upper face of the waveguide **6** between adjacent slot-intersecting cross-sections are given as θ_n, θ_{n+1}, θ_{n+2} . . ., and the equivalent phase lengths between the same cross-sections along the waveguides **5** are given by ϕ_n, ϕ_{n+1}, ϕ_{n+2} . . . . In FIG. 2, portions of the waveguides between adjacent slot-intersecting cross-sections are shown, for diagrammatic purposes, as being separated by regions A and B in order to illustrate the effect of the directional coupling provided by the slots or holes **18**. Thus, energy flowing along the waveguide **5** to the region A will be partially coupled into the waveguide **6** by the appropriate slots or holes **18**, the remaining energy continuing to flow along the waveguide **5** towards the region B. It will be assumed that the coupling at the region A is such that the amplitude of the energy flowing along the waveguide **5** away from the region A is equal to the amplitude of the energy flowing along the waveguide **5** into the region A multiplied by a direct coupling coefficient cos α_n, while the amplitude of the energy flowing along the waveguide **6** away from the region A is equal to the amplitude of the energy flowing along the waveguide **5** towards the region A multiplied by a cross-coupling coefficient $j.\sin\ \alpha_n$. The equivalent coupling coefficients for the region B are cos α_{n+1} and $j.\sin\ \alpha_{n+1}$; it will be seen that the directional coupler provides a 90° phase shift in coupling energy from one waveguide to the other. Although the coupling coefficients have been explained with reference to energy fed into the waveguide **5**, it will be appreciated that the same coefficients apply when energy is fed into the waveguide **6**; thus, for example, the amplitude of the energy flowing along the waveguide **6** away from the region A will be equal to the amplitude of the energy flowing along the waveguide **6** towards the region A multiplied by the direct coupling coefficient cos α_n while the amplitude of the energy flowing along the waveguide **5** away from the region A will be equal to the amplitude of the energy flowing along the waveguide **6** towards the region A multiplied by the cross-coupling coefficient $j.\sin\ \alpha_n$.

Each slot **10** is assumed to be tuned in resonance and has an effective resistance R. In FIG. 2, the coupling between each slot **10** and the waveguide **6** is represented by a transformer **32, 34, 36** their respective transformer ratios $1:M_n$, $1:M_{n+1}$, and $1:M_{n+2}$ being dependent on the closeness of the respective slot **10** to the edge of the waveguide **6**. The numerical value of M will be greater as the slot **10** is moved towards the centre of the top surface of the waveguide **6**.

The capacitances provided by the capacitive posts **20, 22** and C_n, C_{n+1}, C_{n+2} . . ., and are such that each slot containing region of the waveguide **6** is matched to the next slot-containing region for energy travelling in the forward direction; the matching provided by the capacitive posts **20, 22** simplifies the design.

Now, if V_n, V_{n+1}, V_{n+2} . . . are the relative voltages required across the slots **20** when energy is fed into one waveguide and

$$\hat{V}_n,\ \hat{V}_{n+1},\ \hat{V}_{n+2}\ \ldots$$

are the relative voltages required across the slots when energy is fed into the other waveguide, and

$$W_n,\ W_{n+1},\ W_{n+2}\ \ldots \text{ and } \hat{W}_n,\ \hat{W}_{n+1},\ \hat{W}_{n+2}\ \ldots$$

are the corresponding relative voltages in the waveguide **5**, then it can be shown that:

$$M_nV_n=\cos\ \alpha_n e^{j\theta_n}\frac{\sqrt{1+M^2_{n+1}\cdot R}\,(2M_{n+1}\sqrt{R\cdot(1M^2_{n+1}\cdot R)}+j)V_{n+1}}{(1+2M^2_{n+1}R)\sqrt{R}}-j\ \sin\ \alpha_n e^{j\phi_n}W_{n+1}$$

and

$$W_n=-j\ \sin\ \alpha_n\cdot e^{j\theta}\frac{\sqrt{1+M^2_{n+1}\cdot R}\,(2M_{n+1}\sqrt{R(1+M^2_{n+1}\cdot R)}+j)V_{n+1}}{(1+2M^2_{n+1}\cdot R)\sqrt{R}}+\cos\ \alpha_n e^{j\phi_n}W_{n+1}$$

These equations may be solved to give the required values of ϕ_n, θ_n, α_n and M_n as follows:

$$e^{j(\phi_n-\theta_n)}\cdot\tan\ \alpha_n=\frac{-j\sqrt{1+M^2_{n+1}\cdot R}\,(2M_{n+1}\sqrt{R(1+M^2_{n+1}\cdot R)}+j)}{(1+2M^2_{n+1}\cdot R)\sqrt{R}}\cdot M_{n+1}\frac{V_n\hat{V}_{n+1}-\hat{V}_nV_{n+1}}{V_n\hat{W}_{n+1}-\hat{V}_nW_{n+1}}$$

and

$$M_ne^{-j\phi_n}=-j\ \sin\ \alpha_n\frac{V_{n+1}\hat{W}_{n+1}-\hat{V}_{n+1}W_{n+1}}{V_{n+1}\hat{V}_n-\hat{V}_{n+1}V_n}$$

From these equations, once the terminal conditions are decided, the required slot sizes, coupling coefficients and phase lengths can be determined. The terminal conditions where the waveguides will be terminated in matched loads in this example, are to some extent arbitrary, so long as

$$V_n.\ \hat{W}_n=W_n;\hat{V}_n$$

The choice of terminating conditions may have to be determined, at least in part, by trial and error.

Thus, by means of these equations, the array can be arranged to radiate different beam patterns according as to whether energy is fed into the array through the waveguide **5** or through the waveguide **6**. It will be seen that, if energy is fed into the array through the waveguide **5**, the amount of energy initially coupled into the waveguide **6** will be substantially zero and there will be little or no energy available to be radiated from the first slots **10**; as the energy flows along the waveguide **5**, however, an increasing amount of it will couple into the waveguide **6** so increasing the amount of energy radiated by the slots **10** until eventually the energy coupled in to waveguide **6** will reach a maximum whence it will decrease as it is coupled back into the waveguide **5**. Therefore, a particular pattern of energy is radiated by the slots **10**. If, on the other hand, energy is fed into the array through the waveguide **6**, then, initially, there will be a maximum amount of energy available for radiation through the first slots **10**; however, as the energy flows along the waveguide **6**, increasing amounts will be coupled into the waveguide **5** until the position is reached at which the energy in the waveguide **6** is substantially zero whereafter energy in the waveguide **5** will be coupled back into the waveguide **6**. Thus a different pattern of energy is now radiated by the slots **10**. Similar considerations apply when the arrangement is used for receiving energy.

In order to form a planar aerial array, two or more of the linear arrays illustrated in FIG. 1 may be placed side by side as illustrated at **30** in FIG. 3 so as to produce a planar array **31** arranged to radiate or receive two different beams of energy according as to whether the lower waveguides **5** (corresponding to the waveguide **5**, FIG. 1) of all the linear arrays **30** are energised or whether the upper waveguides **6** (corresponding to the waveguides **6**, FIG. 1) of all the linear arrays **30** are energised. Energy can be fed into or out of the linear arrays forming the planar array in any suitable way. The energy may be fed as shown, for example in FIG. 3, through two feeding guides **32, 33** each in the form of a linear array as shown in FIG. 1. In such an arrangement, the slots **10** of one of these two feeding guides **32** would be replaced by coupling elements **34** coupling into the lower waveguides **5** (corresponding to the waveguides **5**, FIG. 1) of the planar aerial while the slots **10** of the other of the feeding guides **33** would be replaced by coupling elements **35** coupling into the upper waveguides **6** (corresponding to waveguide **6**, FIG. 1) of the planar array **31**, and the arrangement would therefore enable the planar array to be arranged to radiate energy in four different beam patterns according to which of the four inputs **41, 42, 43** or **44** of the two feeding guides was energised (and, similarly, the arrangement would have four different responses to received energy).

A linear array of the type shown in FIG. 1 may be used to feed a set of linear arrays of conventional type by substituting coupling elements for the slots **10**.

The aerial arrays described radiate or receive two different beams of energy. The linear array shown in FIG. 1 may therefore be placed at the focus of a cylindrical parabolic reflector, or some other device, so as to focus the beams, and is thus advantageous in this respect as compared with an arrangement in which the two beams have to be respectively produced by two conventional linear arrays placed adjacent to each other and which cannot therefore both be placed at the focus of the parabolic reflector.

The linear array shown in FIG. 1 can also easily be combined with other similar arrays to form a planar array as described above and is thus advantageous as compared to an arrangement in which, for example, a planar array is formed by interleaving conventional linear arrays fed from different inputs in which arrangement the close coupling between adjacent arrays makes the design and development difficult.

I claim:

1. In an antenna,

a first waveguide having a face defining a plurality of energy radiating and receiving slots along the length thereof,

a second waveguide adjacent to the first waveguide along the length thereof,

first energy feeding and receiving means connected to one end of the first waveguide and,

second energy feeding and receiving means connected to the adjacent end of the second waveguide, and

directional coupling means coupling together said waveguides along the length thereof, the directional coupling means comprising a plurality of directional coupling apertures defined in a face of the first waveguide and aligned with corresponding apertures defined in a face of the second waveguide, whereby to cause said array to function in one of two predetermined beam patterns under control of one said feeding and receiving means and to cause said array to function in the other of the two predetermined beam patterns under control of the other feeding and receiving means.

2. An antenna according to claim **1**, wherein means are provided for matching the impedance of said slots.

3. An antenna according to claim **1**, wherein phase shifting means are incorporated in at least one waveguide.

4. In a planar array antenna,

a plurality of adjacently disposed linear arrays of radiating elements,

a plurality of transmission lines, the radiating elements of each said linear array being integral with a respective one of said transmission lines,

a plurality of further transmission lines each adjacent a respective one of said plurality of transmission lines,

directional coupling means coupling together each said first mentioned transmission line and a respective one of said further transmission lines,

two feeder means, each said feeder means comprising, a pair of adjacent feeder transmission lines, directional coupling means coupling said pairs of feeder transmission lines together,

further coupling means disposed at intervals along one of said feeder transmission lines in each of said feeder means, each coupling means in one feeder means coupling with one of the transmission lines associated with a respective array of linear radiating elements and each coupling means in the other feeder means coupling the respective other transmission line, and

selective input feeding means feeding a selected feeder transmission line to cause said planar array to function in a selected one of four response patterns.

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U.S. Cl. X.R.

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