INTERCOUPLING LINES FOR IMPEDANCE MATCHING OF ARRAY ANTENNAS

Filed Dec. 28, 1962 3 Sheets-Sheet 1

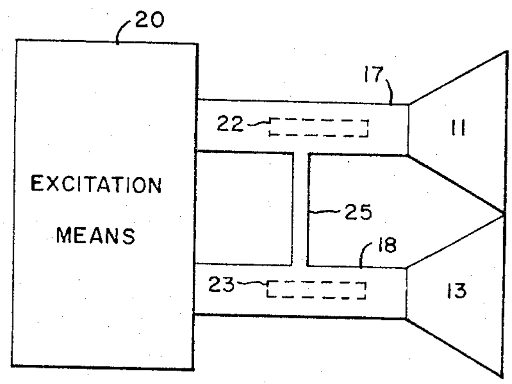

FIG. 1a

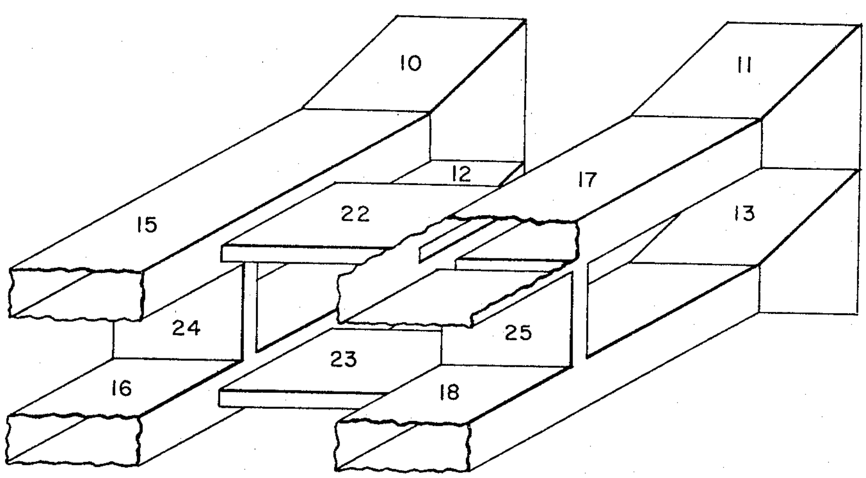

FIG. 1b

Sept. 6, 1966 P. W. HANNAN 3,271,776

INTERCOUPLING LINES FOR IMPEDANCE MATCHING OF ARRAY ANTENNAS

Filed Dec. 28, 1962

3 Sheets-Sheet 2

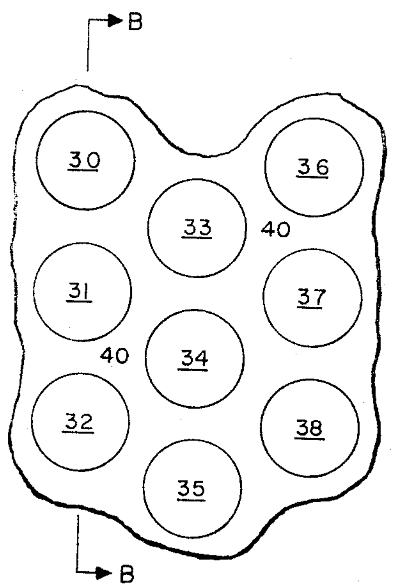

FIG. 2a

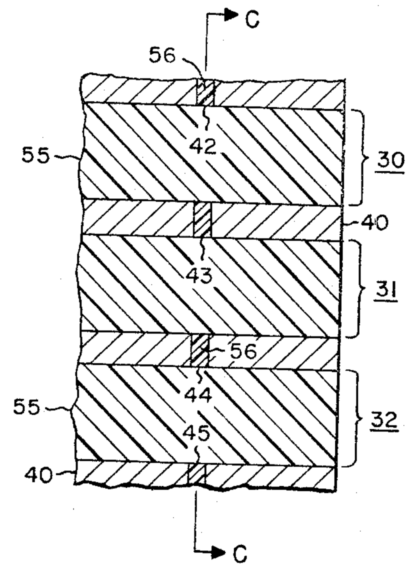

FIG. 2b

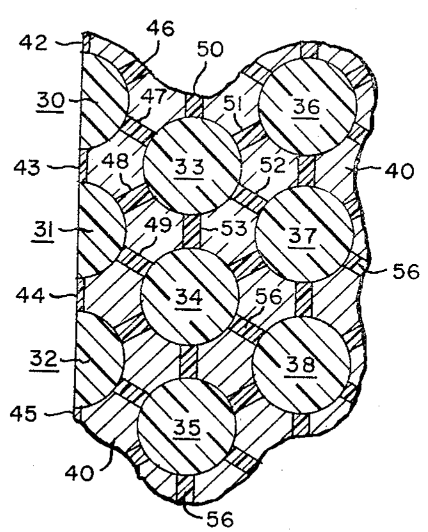

FIG. 2c

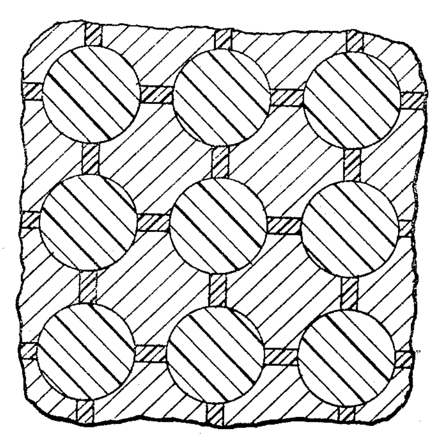

FIG. 3

Sept. 6, 1966 P. W. HANNAN 3,271,776
INTERCOUPLING LINES FOR IMPEDANCE MATCHING OF ARRAY ANTENNAS
Filed Dec. 28, 1962 3 Sheets-Sheet 3

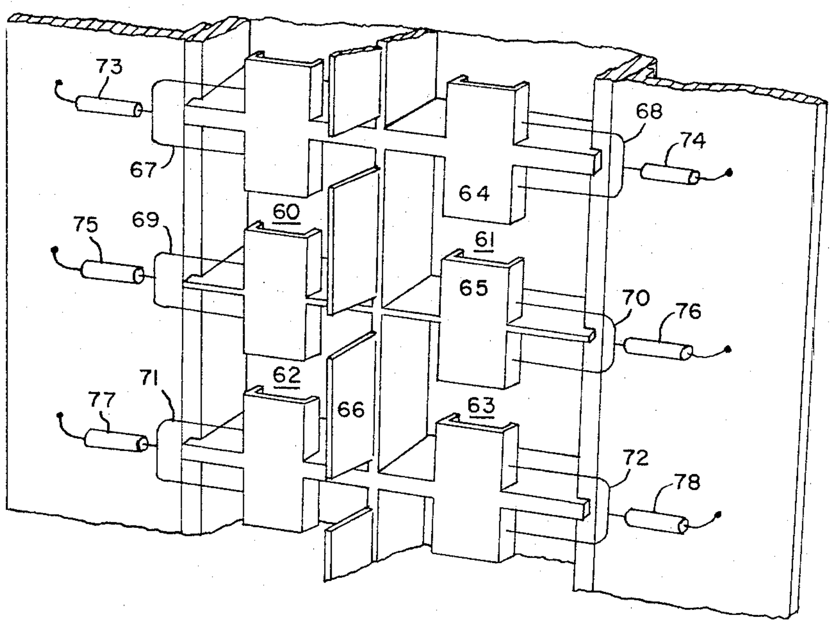

FIG. 4

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INTERCOUPLING LINES FOR IMPEDANCE MATCHING OF ARRAY ANTENNAS

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This invention is directed to impedance matching of array antennas and more particularly to closer impedance matching achieved by intercoupling the transmission lines leading to the radiating elements of an array antenna, so as to provide an intercoupling effect which is dependent on relative excitation differences between radiating elements. The relative excitation differences may take the form of relative phase or amplitude differences between radiating elements.

At the present time a great deal of effort is being directed toward the development of array antennas for use in electronically scanned systems, monopulse systems and other antenna systems. In an array antenna used in an electronically scanned system for example, the configuration and orientation in space of the radiated beam can be controlled by changing the phase or amplitude of the excitation of the radiating elements. Also, in an array for a monopulse antenna, radiation in several configurations and orientations can be obtained simultaneously by exciting the radiating elements in several modes having reversed phase or amplitude of excitation. However, a disadvantage of known systems has been that coupling between the elements of the array causes the antenna impedance to change with changes in excitation. Thus, the impedance match in an electronically scanned antenna varies as a function of scan angle and the impedance match in a monopulse antenna is different for different operating modes.

Using known methods, an array antenna may be impedance matched for one condition of excitation by matching each individual radiating element. However, for other conditions of excitation the antenna is no longer matched resulting in a loss of efficiency and other deterioration of performance.

The objects of the present invention are to provide new and improved array antennas which avoid one or more disadvantages of the prior art and which have closer impedance matches.

In accordance with the invention an array antenna having closer impedance matching comprises: a plurality of radiating elements, branch transmission lines connecting to the radiating elements, means for exciting the elements through the lines in a plurality of conditions, and means, substantially independent of the function of the exciting means, for intercoupling the branch transmission lines so as to provide an effect on impedance which is dependent on differences of excitation between radiating elements so that closer impedance matching results for at least one condition of excitation.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

Referring to the drawings:

FIGS, 1*a* and 1*b* show, respectively, a top and an isometric view of an array antenna in the form of a monopulse antenna utilizing the invention;

FIGS. 2*a*, 2*b* and 2*c* show, respectively, a face view, a transverse section and a cross section of a portion of an array antenna in accordance with the invention;

FIG. 3 is a view of an array antenna similar to the FIG. 2 antenna, except that FIG. 3 shows a square type array, while FIG. 2 shows a triangular type array, and

FIG. 4 shows another type of monopulse array antenna in accordance with the invention.

FIG. 1.—Array antenna

Referring now more particularly to FIGS. 1*a* and 1*b*, there are shown two views of an array antenna in accordance with the invention. FIG. 1*a* shows a complete antenna and FIG. 1*b* is an isometric view of the right-hand portion of the FIG. 1*a* antenna showing greater detail. As shown, the antenna includes a plurality of radiating elements shown as horns **10**, **11**, **12** and **13**, horn **12** being substantially hidden by other components of the antenna. The antenna also includes branch transmission lines connecting to the radiating elements **10–13**. These branch transmission lines are shown as rectangular waveguides **15**, **16**, **17** and **18** which connect to the horns **10–13**. The antenna further includes means for exciting the elements **10–13** through the lines **15–18**. These means are represented by rectangle **20** and will be described in greater detail below. The antenna finally includes means for intercoupling the branch transmission lines **15–18**, so as to provide an effect on impedance which is dependent upon relative differences of excitation between the radiating elements. These intercoupling means are shown as waveguides **22–25** inclusive.

The antenna of FIGS. 1*a* and 1*b* represents a rectangular array of four horns for a monopulse antenna. As is common in monopulse systems, the four horns are arranged to be excited in three phasing conditions. The three conditions are:

(1) All horns in phase;

(2) 180° phase difference between the left and right pairs of horns; and

(3) 180° phase difference between the upper and lower pairs of horns.

These phasing conditions are often referred to as the:

(1) Sum mode;

(2) Azimuth difference mode;

(3) Elevation difference mode.

The phasing conditions are controlled by a main signal distribution system which includes waveguides **15–18**, excitation means **20**, and components such as the receivers and signal generators used in monopulse systems. Means **20** may include hybrid junctions intercoupling a network of waveguides so as to allow the horns **10–13** to be excited in a plurality of conditions or modes. The construction and operation of complete monopulse systems is well known and need not be discussed in detail. It should be noted that intercoupling lines **22–25** are not part of the main signal distribution system.

If the four-horn array of FIG. 1*b* had been constructed in accordance with the prior art without the intercoupling waveguides **22–25**, impedance would be different for the three phasing conditions. Ordinary matching structures in the horns or waveguides leading to the horns could achieve impedance matching for one of the three conditions. This is because the effect of such impedance matching remains the same under all conditions of phasing. However, with the waveguides **22–25** included in accordance with the present invention a much closer match is achieved for all three conditions.

The intercoupling waveguides **22** and **23** connecting between the right pair (**15** and **16**) and the left pair (**17** and **18**) of branch waveguides affect the impedance for the number **2** phasing condition (see above) differently than the impedance for the number **1** and number **3** phasing conditions. Similarly, the waveguides **24** and **25** connecting between the upper (**15** and **17**) and the lower (**16** and **18**) pairs of branch waveguides affect the impedance for the number **3** phasing condition differently than the impedance for the number **1** and number **2** phasing conditions. By providing the four intercoupling transmission lines **22–25** and also providing ordinary matching structures as commonly used with waveguides (such as, inductive irises or capacitive screws) perfect impedance match can be achieved in all three conditions of excitation. A detailed analysis of the design and placement of the intercoupling lines is not required here. Once a worker skilled in the design of prior art array antennas appreciates the basic principle of relying on intercoupling lines which provide an effect on impedance which is dependent on relative phase or amplitude difference between the radiating elements, he can then apply the invention using known antenna design technology. (In an actual antenna the waveguides **15–18** would be placed closer to each other, this and other distortions in the drawings are included to allow clearer pictorial representation.)

For the purposes of this specification, the term "transmission line" is used as a generic term which encompasses waveguides, coaxial lines, and other means for guiding electromagnetic waves from one point to another. Also, in this specification, antennas and components thereof are at times described using terms relating to transmission, rather than reception, however, such usage is relied upon merely for ease of description and it must be understood that reciprocity applies and the principles involved apply equally to reception and transmission.

FIG. 2.—Array antenna

Referring now to FIG. 2, there are shown three views of another type of array antenna in accordance with the invention. FIG. 2*a* is a view looking into the radiating end of a portion of a planar array composed of many circular waveguide radiating elements. Thus, FIG. 2*a* shows nine circular waveguide radiating elements **30–38** inclusive, arranged in what will be called a triangular type array. FIG. 2*b* is a view of the FIG. 2*a* arrangement taken along the BB section indicated in FIG. 2*a*. FIG. 2*c* is a view of the FIG. 2*a* arrangement taken along the CC section indicated in FIG. 2*b*.

The portion of the array shown could be a portion of a steerable beam array antenna (the word "steerable" will be defined to include what are commonly called "scanning array antennas") or of a multi-beam array antenna or of any other type of array antenna which utilizes an array of radiating elements.

It will now be seen that while the external view in FIG. 2*a* resembles a prior art array, the sectional views of FIGS. 2*b* and 2*c* disclose a plurality of intercoupling transmission lines according to the present invention. A representative group of these intercoupling transmission lines are labeled **42–53**, inclusive.

Structurally, the array antenna of FIG. 2 is shown as comprising a metallic block **40** in which circular holes form the waveguides **30–38** and **42–53**. All these waveguides **30–38** and **42–53** are filled with a dielectric material. The waveguides **30–38** are shown as being filled with a dielectric material **55** and waveguides **42–53** are shown as being filled by a dielectric material **56**, which has a higher dielectric constant than material **55**.

In the FIG. 2 arrangement the radiating elements are the ends of the branch waveguides **30–38**. In a complete antenna system of this type, a main signal distribution system such as described with reference to FIG. 1*a* will be included for coupling the radiating elements to one or more generators or receivers or both. This main signal distribution system will include means for exciting the elements in a plurality of conditions. In FIG. 2, branch waveguides **30–38** form part of this main signal distribution system, the remaining portions of which connect to the left-hand ends of waveguides **30–38**. It is not necessary to discuss such additional portions in detail because any one of a number of well known arrangements can be used.

Thus, in the array antenna of FIG. 2 the branch waveguides **30–38** are intercoupled by the circular waveguides **42–53**. It will be seen that in the arrangement shown, the

intercoupling waveguides are used singly, however, more than the single set shown can be used if further improvement in performance is desired.

In operation, an array antenna as shown in FIG. 2 is caused to produce a scanning beam by varying the relative excitation of the radating elements. This can be done by exciting the waveguide radiating elements in a continuous sequence of phasing conditions. Each condition involves a linear progression of phase across the array corresponding to a particular scan angle. In a typical case the radiated beam may be scanned from broadside, to 45° off broadside. So far this description of operation relates equally to prior art antennas and to the present invention. The difference is that in prior art antennas the impedance has varied greatly with scan angle.

Ordinary matching structures in the waveguides can be used to achieve impedance match only for a single scan angle (typically broadside) because the effect of such structures remains the same for all scan angles. This is more or less the crux of the problem; the impedance varies with scan angle, but prior matching arrangements produce an effect which remains constant for all scan angles. Intercoupling waveguides in accordance with the invention (such as **42–53** in FIG. 2) provide an effect on impedance which varies with scan angle. Thus, by the inclusion of intercoupling lines an impedance characteristic can be achieved which is greatly improved as compared to prior types of scanning antennas.

In an array composed of a large number of radiating elements, identical intercoupling lines will provide the desired impedance matching for all radiating elements except those near the edges of the array. Thus, the design considerations are simplified and individual calculations are required only for radiating elements near the edges of the array.

In the FIG. 2 array a simple system of intercoupling lines is used. Dielectric filled circular waveguides are used to intercouple each of the branch waveguides **30–38** to each branch waveguide in the nearest adjacent rank. With respect to branch waveguide **34**, the "nearest adjacent rank" comprises branch waveguides **31, 32, 33, 37, 38** and **35**. (Referring back to the FIG. 1 antenna briefly, it will be seen that the "nearest adjacent rank" to line **15** consists of lines **16** and **17**. According to the degree of matching required, in some applications it may be desired to include additional intercoupling lines, as for example, between waveguides **33** and **38** etc.

It should be appreciated that the invention is not only applicable to triangular type arrays such as shown in FIG. 2. The invention is equally applicable to other arrays such as, for example, the square type array shown in FIG. 3. The square type array of FIG. 3 is illustrated only as an additional example and the actual construction can correspond to the FIG. 2 array as described above.

FIG. 4.—Array antenna

Referring now to FIG. 4 there is shown a portion of an array antenna constructed in accordance with the invention. This array consists of a large number of four-element monopulse antennas stacked in a vertical direction. One of these four element monopulse antennas is illustrated as comprising the four elements **60, 61, 62** and **63**. Each of these elements **60–63** can be considered to be the open end of a ridged waveguide. Thus, the end of the waveguide **61** is defined as the space limited by the ridges **64** and **65** and the remaining metallic walls of the waveguide. The antenna also includes metallic fins such as **66** whose function is not related to the present invention. In operation, signals are supplied to the ridges (such as **64** and **65**) which then act as radiating elements. Thus, the ridges are the terminal ends of the branch lines and also the radiating elements.

As stated, this is a portion of a monopulse system and as such it is intended to operate in the three modes described in connection with the antenna of FIG. 1. Originally, the impedance of this antenna of FIG. 4 was well matched when the antennas were excited in phase but was poorly matched when an upper pair of elements such as **60** and **61** were excited 180° from the phase of a corresponding lower pair such as **62** and **63**. To correct this situation, an intercoupling line was attached between each element and its immediate neighbor above and below. Each of the intercoupling lines **67–72** appears as a three-sided loop and is attached to the ridge at the aperture of each radiating element. At the midpoint of each of the connecting lines is a resistor (**73–78**) going to the ground plane formed by the metallic side portions of the antenna. The principal function of these resistors is to widen the frequency band of operation of the antenna.

Each of loops **67–72** is approximately ¼ wavelength deep at the operating wave length so it has almost no effect on the in-phase condition, but has a large effect on the 180° phasing condition. The result is a well matched antenna system for both phasing conditions over a wide frequency band. Although the intercoupling lines of the FIG. 4 antenna are unshielded and are located at the radiating aperture, the resulting radiation from these lines is sufficiently weak so as to give substantially the same performance as intercoupling lines which are shielded from the radiating antenna as in the previously described examples.

The principle of the use of intercoupling lines enables the impedance of an array of radiating elements to be greatly improved over all the various conditions of excitation.

Intercoupling lines do not necessitate any change in the radiating portion of the antenna which may therefore be designed to satisfy other requirements such as polarization, bandwidth ruggedness for ease of construction.

In the embodiments of the invention shown in FIGS. 1, 2 and 3, the intercoupling means are in the form of "lossless" transmission lines. In the FIG. 4 arrangement, the intercoupling means incorporate resistors connecting to ground and the result is not lossless. Lossless arrangements are preferred because of the degradation of overall efficiency caused by the inclusion of resistance elements.

While there has been described what are at present considered to be the preferred embodiments of this invention it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and it is, therefore, aimed to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- branch transmission lines connecting to said radiating elements;
- means for exciting said elements through said lines in a plurality of conditions;
- and means, substantially independent of the function of said exciting means, for intercoupling said branch transmission lines so as to provide an effect on impedance which is dependent on differences of excitation between radiating elements so that closer impedance matching results for at least one condition of excitation.

2. An array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- branch transmission lines connecting to said radiating elements;
- means for exciting said elements through said lines in a plurality of phase relations;
- and means, substantially independent of the function of said exciting means, for intercoupling said branch transmission lines so as to provide an effect on impedance which is dependent on phase differences between radiating elements so that closer impedance matching results in at least one phase relation.

3. An array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- branch transmission lines connecting to said radiating elements;
- means for exciting said elements through said lines in a plurality of conditions;
- and means, substantially independent of the function of said exciting means, for intercoupling said branch transmission lines to branch transmission lines in the nearest adjacent rank to cause partial intercoupling of said signals between said branch lines so that closer impedance matching results for at least one condition of excitation.

4. An array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- a main signal distribution system including a branch transmission line connecting to each radiating element and means for exciting said elements through said lines in a plurality of conditions;
- and means, substantially independent of the function of said main signal distribution system, for intercoupling said branch transmission lines so as to provide an effect on impedance which is dependent on differences of excitation between radiating elements so that closer impedance matching results for at least one condition of excitation.

5. An array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- a plurality of branch transmission lines, one connecting to each radiating element;
- means for exciting said elements through said lines in a plurality of conditions;
- and a plurality of transmission lines, substantially independent of the function of said exciting means, intercoupling said branch transmission lines so as to provide an effect on impedance which is dependent on differences of excitation between radiating elements to cause partial intercoupling of said signals between said branch lines so that closer impedance matching results for at least one condition of excitation.

6. An array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- a plurality of branch transmission lines, one connecting to each radiating element;
- means for exciting said elements through said lines in a plurality of phase relations;
- and a plurality of transmission lines, substantially independent of the function of said exciting means, intercoupling said branch transmission lines so as to provide an effect on impedance which is dependent on phase differences between radiating elements so that closer impedance matching results for at least one phase relation.

7. An array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- a main signal distribution system including branch transmission lines connecting to each of said radiating elements and means for exciting said elements through said lines in a plurality of conditions;
- and a plurality of transmission lines, substantially independent of the function of said main signal distribution system, intercoupling each of said branch transmission lines to each branch transmission line in the nearest adjacent rank to cause partial intercoupling of said signals between said branch lines so that closer impedance matching results for at least one condition of excitation.

8. A monopulse array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- a plurality of branch transmission lines, one connecting to each radiating element;
- means for exciting said elements through said lines in a plurality of modes;
- and means, substantially independent of the function of said exciting means, for intercoupling said branch transmission lines so as to provide an effect on impedance which is dependent on the particular monopulse mode involved, so that closer impedance matching results for at least one mode.

9. A monopulse array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- a main signal distribution system including a branch transmission line connecting to each radiating element and means for exciting said elements through said lines in a plurality of modes;
- and a network of transmission lines, substantially independent of the function of said main signal distribution system, intercoupling said branch transmission lines to cause partial intercoupling of said signals between said branch lines so that a closer impedance match results in at least one monopulse mode.

10. A steerable beam array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- a plurality of branch transmission lines, one connecting to each radiating element;
- means for exciting said elements through said lines so as to produce a steerable beam;
- and means, substantially independent of the function of said exciting means, for intercoupling said branch transmission lines so as to provide an effect on impedance dependent on differences of excitation, to cause partial intercoupling of said signals between said branch lines so that closer impedance matching results for at least one condition of beam steering.

11. A multibeam array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- a plurality of branch transmission lines, one connecting to each radiating element;
- means for exciting said elements through said lines so as to produce a plurality of beams;
- and means, substantially independent of the function of said exciting means, for intercoupling said branch transmission lines so as to provide an effect on impedance which provides closer impedance matching for at least one beam.

12. A steerable beam array antenna having closer impedance matching, comprising:
- a plurality of radiating elements;
- a main signal distribution system including a branch transmission line connecting to each radiating element and means for exciting said elements through said lines so as to produce a steerable beam;
- and a network of transmission lines, substantially independent of the function of said main signal distribution system, intercoupling said branch transmission lines so that a closer impedance match results under certain steering conditions.

References Cited by the Examiner

UNITED STATES PATENTS

2,227,563	1/1941	Werndl	343—854
2,624,002	12/1952	Bouix	343—778
2,727,233	12/1955	Eyges	343—785
2,925,595	2/1960	Thourel	343—778
3,071,769	1/1963	Randall et al.	343—779

FOREIGN PATENTS

1,188,206	9/1959	France.

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