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Reindel

[11] **3,839,720**

[45] **Oct. 1, 1974**

[54] **CORPORATE FEED SYSTEM FOR CYLINDRICAL ANTENNA ARRAY**

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

[22] Filed: **June 25, 1973**

[21] Appl. No.: **373,052**

[52] **U.S. Cl.** **343/854,** 333/10
[51] **Int. Cl.** **H01q 3/26**
[58] **Field of Search** 343/853, 854; 333/10

[56] **References Cited**

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2,466,354 4/1949 Bagnall 343/854

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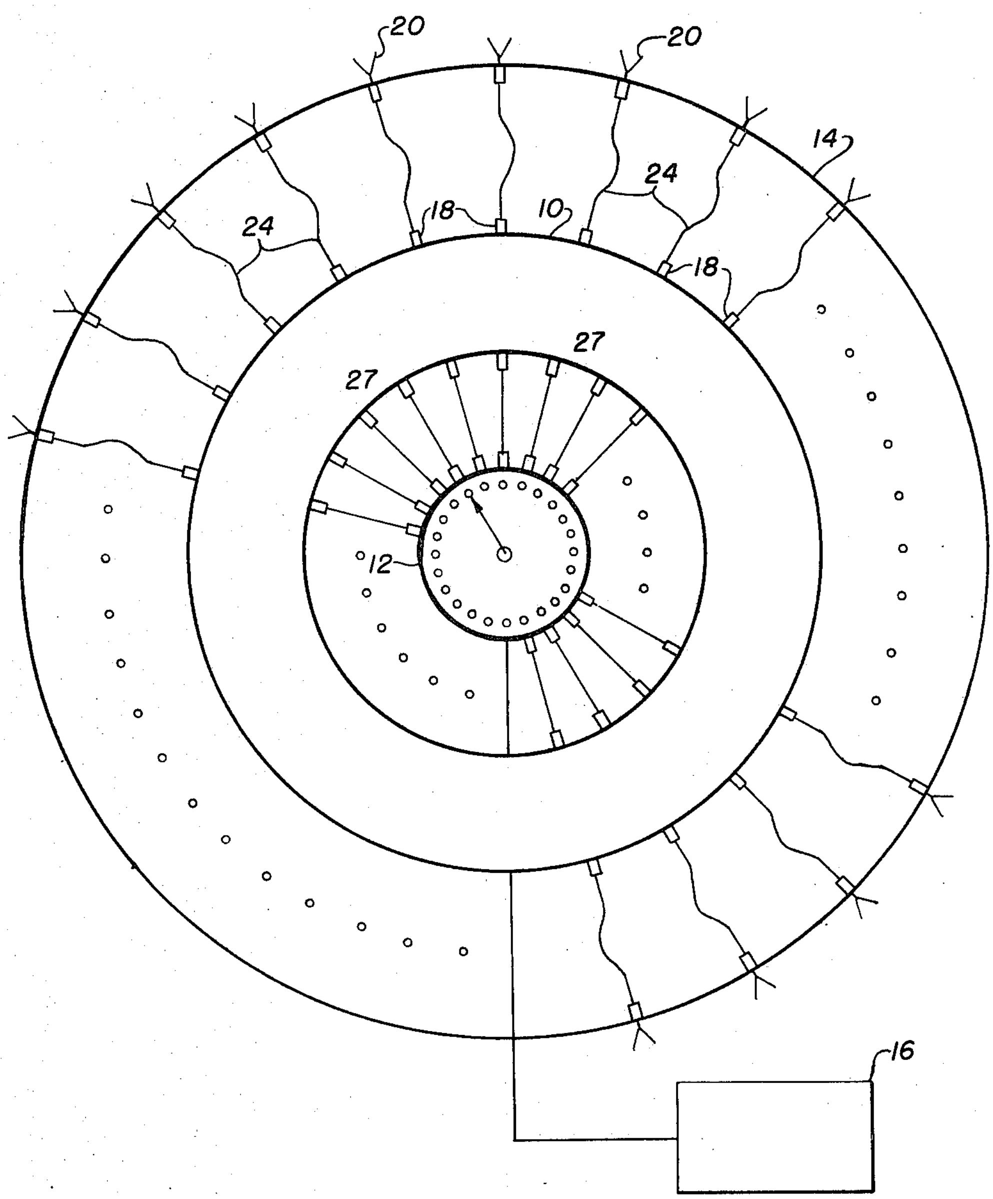
Attorney, Agent, or Firm—R. S. Sciascia; G. J. Rubens

[57] **ABSTRACT**

A reciprocal corporate microwave feed network. A matrix is connected between a selector switch and an antenna ring array. The matrix divides microwave energy from sender apparatus and produces a tapered phase distribution to a selectively predetermined sector of the array. The active or energized array sector forms a highly directive beam which is normal to the array sector. The matrix is circularly symmetric and can feed any sector of the array as selected by an input switch. The beam is step scanned over 360°, with the number of steps being determined by switching and matrix circuitry.

3 Claims, 6 Drawing Figures



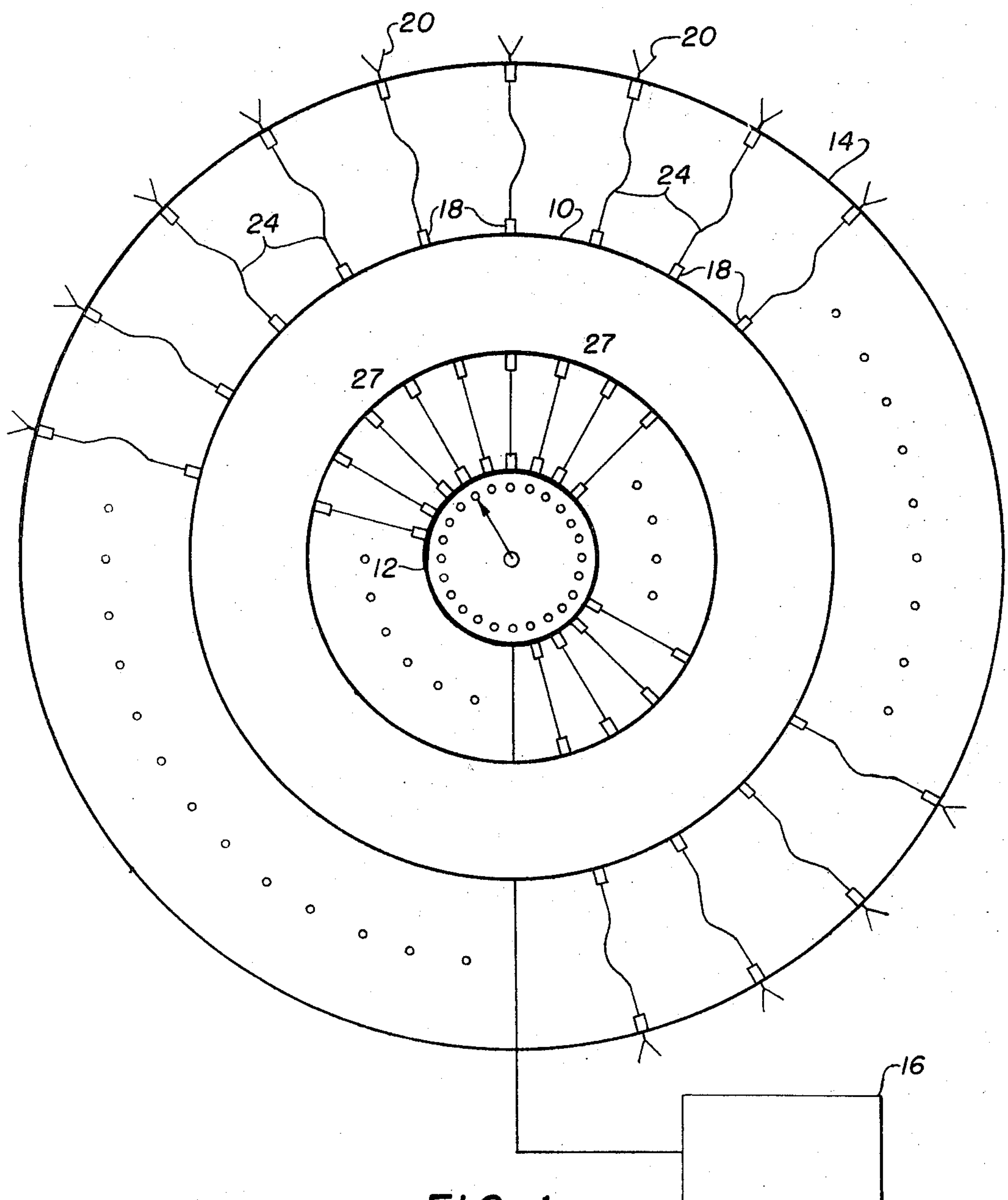


FIG. 1

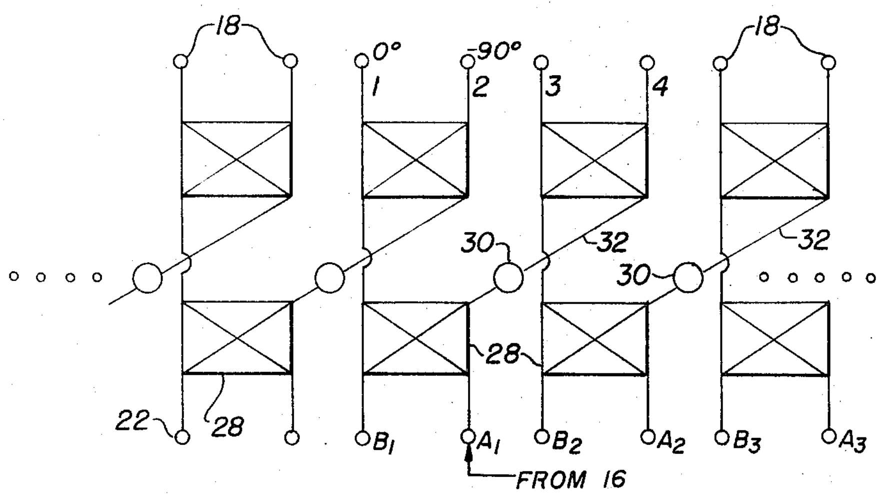

18
0°
-90°
1
2
3
4
18
30
32
30
32
28
22
28
B1
A1
B2
A2
B3
A3
FROM 16

FIG. 2

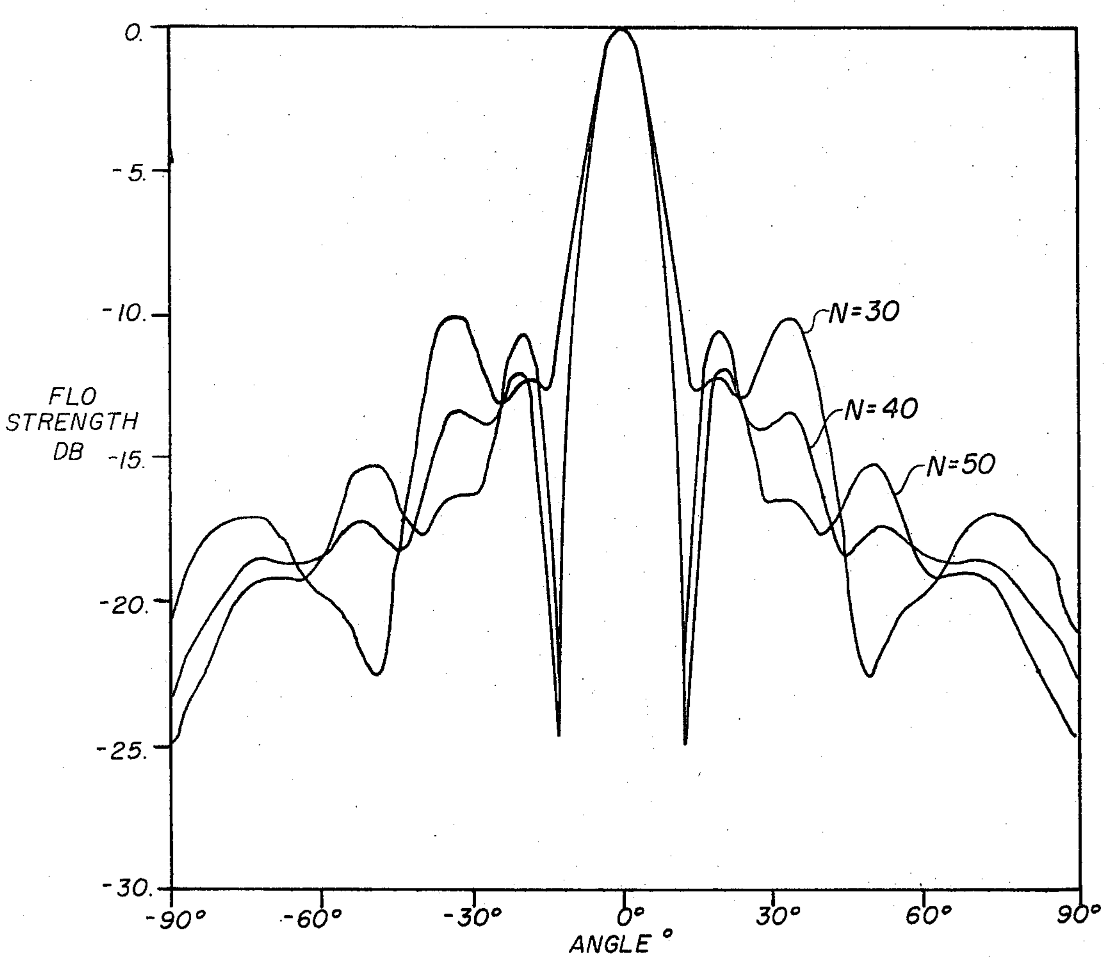

0.
-5.
-10.
-15.
-20.
-25.
-30.
FLO
STRENGTH
DB
N=30
N=40
N=50
-90°
-60°
-30°
0°
30°
60°
90°
ANGLE °

FIG. 4

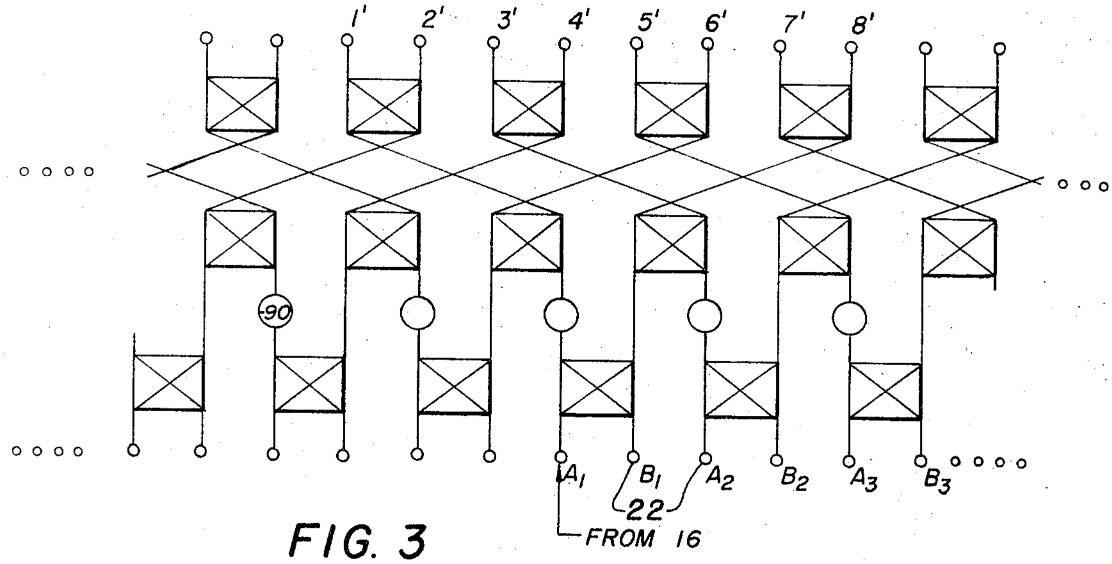

1'
2'
3'
4'
5'
6'
7'
8'
-90
A1
B1
A2
B2
A3
B3
22
FROM 16

FIG. 3

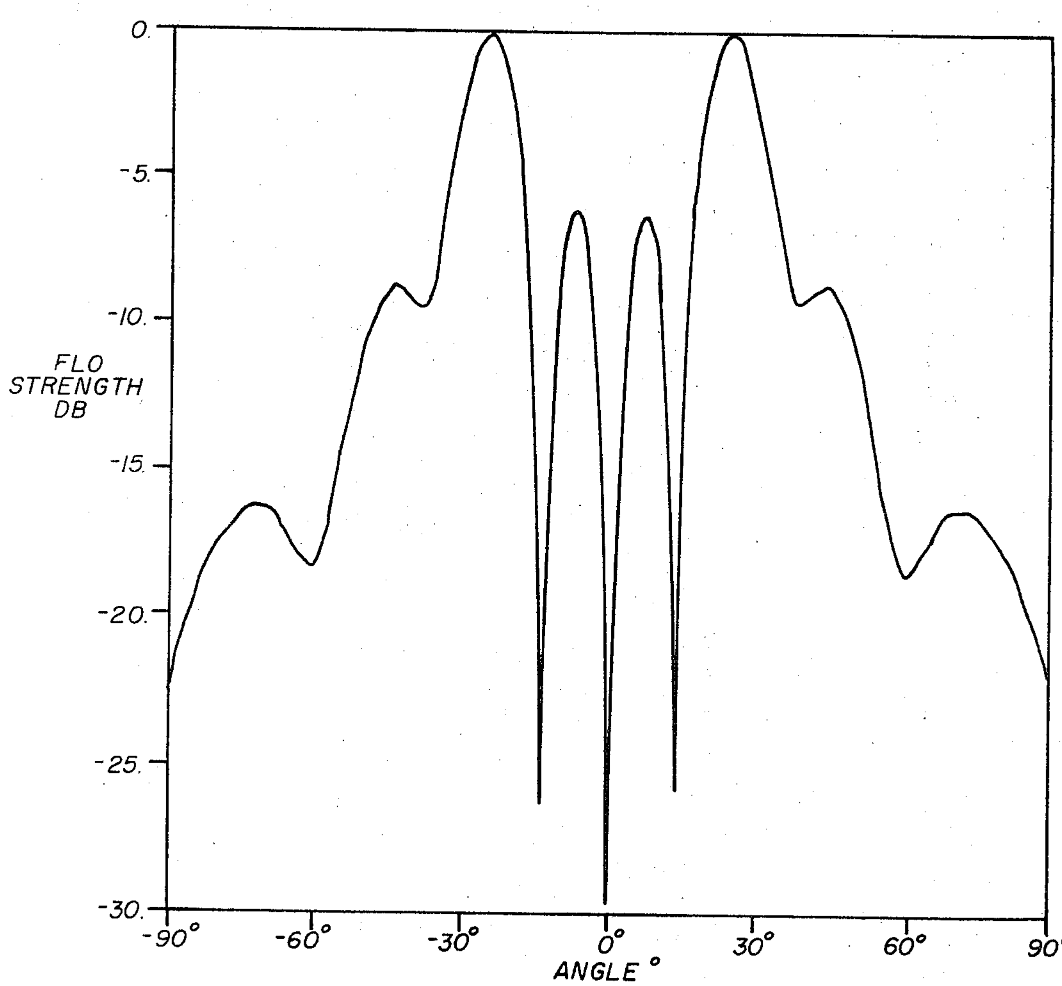

0.
-5.
-10.
-15.
-20.
-25.
-30.
FLO STRENGTH DB
-90°
-60°
-30°
0°
30°
60°
90°
ANGLE °

FIG. 5

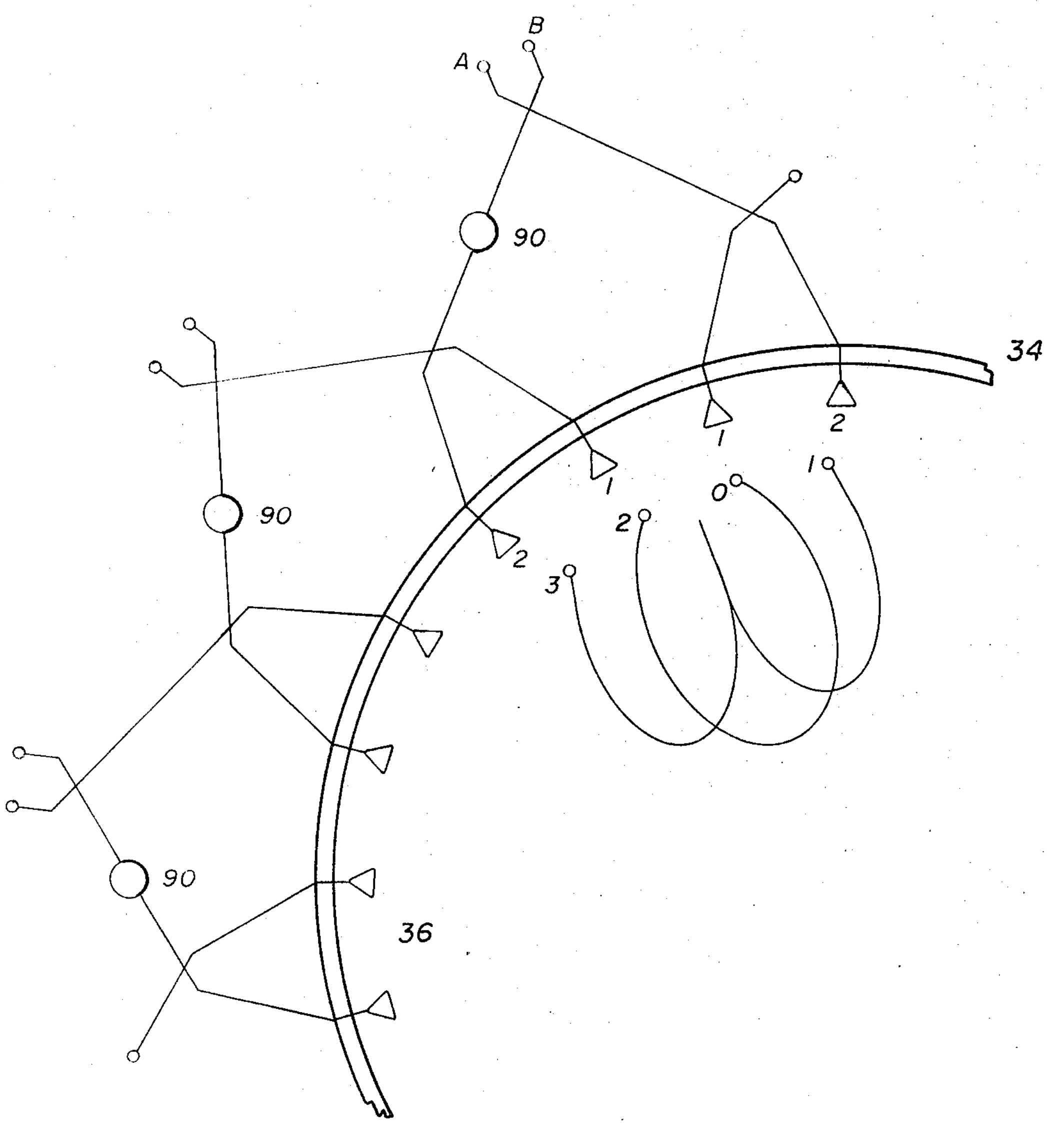


FIG. 6

CORPORATE FEED SYSTEM FOR CYLINDRICAL ANTENNA ARRAY

CROSS-REFERENCES TO RELATED APPLICATIONS

The novel concept disclosed herein is closely related to the subject matter of U.S. Pats. Nos. 3,568,207 (Reindel et al); 3,729,742 (Jerry Boyns); and 3,655,997 (Jerry Boyns).

BACKGROUND OF THE INVENTION

It is well known in the art that microwave feed systems can electronically switch antenna arrays to shape and direct radiation beams. For example, a class of arrays is fed by beam-forming Butler matrices which consist of directional couplers and fixed lengths of transmission lines which interconnect the couplers in a passive, corporate branching network. The Butler matrix has N-input and N-output ports, where N can have the value of $2n$, where n is any interger greater than two. An N-port array fed by a Butler matrix forms N independent overlapping beams which are controlled electronically by switching the desired input port, or a combination of ports to either a receiver or a transmitter. Four such linear arrays are needed to scan through 360°.

The following disadvantages are associated with the four linear arrays. The gain and pattern shape change with the position of the beam; the matrices are complex and difficult to make when a large number of ports are needed; and, the number of ports is restricted to powers of 2 (4, 8, 16, 32, 64, etc.)

A circular array can be fed by a Butler matrix, but a set of N 3-bit phase shifters, an N-port power divider, and a system for controlling the power distribution as the beam is scanned would be required. Consequently, the Butler technique is not viable due to its inherent complexity.

SUMMARY OF THE INVENTION

A microwave energy feed system for a cylindrical antenna array is disclosed. The apparatus comprises a matrix consisting of a reciprocal, corporate microwave network which is connected between a selector switch and an antenna ring array. The matrix comprises directional couplers and fixed lengths of transmission lines which divide and control input energy to provide a tapered phase distribution which can be fed to a selectively predetermined sector of the array. The active or energized array sector forms a highly directive beam which is normal to the array sector. The matrix is circularly symmetric and feeds any sector of the array as selected by an input switch. The resulting beam is step-scanned over 360° with a number of steps being determined by switching and matrix circuitry.

STATEMENT OF THE OBJECTS OF THE INVENTION

It is the general object of the present invention to provide a microwave energy feed system for a cylindrical antenna array and which is simple in structure and whose structure can be made repetitive.

It is a specific object to disclose a matrix feed system which is symmetrical whereby identical beam shape is achieved as it is step-scanned around the array.

It is a further specific object to describe a feed system which transmits only over an arc of 60° to 90°.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified electrical schematic of the feed system to be disclosed herein for energizing a cylindrical antenna array;

FIG. **2** illustrates a matrix having two rows of directional couplers;

FIG. **3** illustrates a matrix having three rows of directional couplers;

FIG. **4** graphically illustrates beam patterns for a cylindrical array fed by a three-row cylindrical matrix;

FIG. **5** graphically illustrates difference beam patterns for a forty-eight element array fed by a three-row matrix without switches; and

FIG. **6** illustrates a concave aperture array fed by a matrix as dislosed herein.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. **1**, which is a simplified schematic of the corporate feed system to be disclosed herein, a matrix **10**, comprising a reciprocal corporate microwave network, is shown connected between a centrally located selector switch **12** and a ring **14** of a cylindrical array. The ring **14** comprises a plurality of radiating elements **20**.

As stated above, the matrix **10** divides and controls the phase of the input power from the reciprocal sender apparatus **16**. The matrix provides a tapered phase distribution to a selectively predetermined sector of the ring array **14**. The active or energized array sector thereby provided with the tapered phase distribution forms a highly directive beam which is normal to the array sector.

The matrix **10** is circularly symmetric with respect to the switch **12** and the ring **14** and can feed any sector of the array as selected by the switch apparatus **12**. The resultant beam from the array sector is step-scanned over 360°, with the number of steps being determined by the switching and matrix circuitry.

The feed matrix **10** comprises, for example, 3db-directional couplers and fixed lengths of transmission lines which function to provide a tapered phase distribution at the output ports **18**, which distribution is suitable for energization of a sector of a cylindrical array **14**. The matrix is reciprocal in nature and thus may be used for both transmission and reception of microwave energy from the apparatus **16**.

The matrix is shown connected at each of its input ports **22** to a different position of the switch **12**. Each output port **18** of the matrix is connected by an equal length cable to a different one of the radiating elements **20**. Obviously, the selector switch **12** connects the input power from the sender apparatus **16** to the desired input port on the matrix **10**.

As stated previously, the matrix divides the incoming power and feeds a sector of the array with a tapered phase distribution such that the array sector forms a cophasal wave which is tangent to the active sector, and it also forms a beam which is normal to the active sector. The beam is step-scanned by switching the input power to a new input port **22** of the matrix **10.**

The cylindrical matrix **10** can comprise two or more concentric and symmetrical rows of directional couplers in combination with lengths of transmission line as shown in FIG. **2.** The interconnections as shown are symmetrical, periodic, and closed in an end-to-end manner in the ring **10.** The ring can have any number of links and an even number of output ports, typically from 20 to 80. Since the array has cylindrical symmetry, the shape of the beam formed is the same at all positions.

The input power which is applied to an input port **22** of a directional coupler **28** of the matrix **10** is divided evenly twice, three times, or four times, depending on the number of concentric rows of couplers utilized. For example, the two-row matrix of FIG. **2** has four active outputs, **1, 2, 3,** and **4,** and consequently energizes four antenna radiating elements for each input port **22** energized. Each output port provides one-fourth of the input power for the circuit of FIG. **2.**

Fixed, phase shifters **30** are connected as shown between the couplers **28** in the matrix and can comprise, in its simplest form, a length of line equal to one-quarter wavelength at the operating frequency. The couplers are interconnected with the fixed delay lines **32** such that the phases of the center active elements are retarded symmetrically. That is, if a 90° delay is given a logic value of 1, the relative phases for the two-row matrix are: 0, 1, 1, 0; for the three-row matrix, they are: 0, 1, 2, 2, 1, 1, 0.

Since the array elements **20** are connected to the matrix **10** by means of equal-length transmission lines **24,** the phase relation is transferred substantially intact to the array elements. Due to the curvature of the array and to the retardation of the center elements, the resultant wavefront of the ring array becomes nearly cophasal.

FIG. **3** illustrates a three-row matrix which as can be seen can feed eight output ports, **1′, 2′, 3′, 4′, 5′, 6′, 7′,** and **8′.** It can be seen that the interconnections are substantially like FIG. **2.**

The matrices disclosed in FIGS. **1, 2,** and **3** offer distinct advantages over existing microwave feed systems for cylindrical arrays. First, the system disclosed is relatively simple to construct because it is symmetrical and thus can be made repetitive. That is, a 16-port matrix can be built with four identical circuits, and a 64-port can be built with 16 identical circuits, etc. Secondly, the transmission losses are smaller because the signal only traverses through two or three directional couplers. Thirdly, since the matrix is symmetrical, it provides identical beam shape as it is step-scanned around the array. Fourthly, the array can have any even number of elements between approximately twenty and eighty, subject to changes in side lobe levels, which in general is about the same as that of the uniformly-fed Butler matrix. Fifth, the system does not require phase switching components such as in a multimode, cylindrical, matrix-fed array. And finally, the system transmits only over an arc of about 60° to 90°, and it is therefore more effective than the multimode array which feeds all elements at all times.

As an alternative to the concept disclosed, monopulses tracking could be achieved with the matrix disclosed. As is well known, monopulse techniques are based on the theory of obtaining complete angle-error

information from a single pulse by comparing the amplitudes of signals received from two separate feeds. A hybrid combining circuit generates simultaneously a sum and a difference signal of two-array patterns.

The matrix input ports labeled A in FIGS. **2** and **3** produce the sum patterns, whereas the ports labeled B provide the difference patterns. The relative circuit phase delay of the two-row matrix feeding a B port is: 0, 1, 3, and 2, where each unit represents 90°. The ports labeled B of the three-row matrix do not provide the desired difference pattern directly. The phase delays are: 2, 3, 1, 2, 4, 3, 1, 0.

If the output ports **3′, 4′, 5′,** and **6′** are interchanged by means of two double-pole, double-throw switches, the phases change to: 2, 3, 4, 3, 1, 2, 1, 0, which now provides the desired difference patterns as shown in FIG. **5.** The effect of the interchange does not change the relative phases of the sum pattern since it is symmetrical about the center of the active array.

As another alternative, the matrix can be used to feed a concave cylindrical microwave energy as shown in FIG. **6** by reversing the order of the connections to the output ports. The relative output phases in this case are: **−1,** 0, 0, **−1;** that is, the signals at the center ports are advanced relative to the outside ports. A cophasal beam is generated due to the curvature of the array elements.

Thus it can be seen that a microwave energy feed for use with cylindrical antenna arrays has been disclosed. The matrix accepts, in a reciprocal manner, input power and provides a tapered phase distribution which can be used to energize array sectors to form a highly directive beam which is normal to the array sector. The matrix is circularly symmetric and thus can feed any sector of the array as selected by switching circuitry. The resultant beam is step-scanned over 360° with the numbers of steps being determined by the switch matrix circuitry.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A microwave energy feed system for a cylindrical phased-array antenna array comprising:

a plurality of radiating elements equi-spaced and positioned about a ring of said array;

reciprocal, microwave energy sending apparatus;

switch means connected at its input to the output of said sender means;

cylindrical and symmetrical, microwave energy feed matrix means having an equal number of input ports and output ports, and comprising two or more concentric and symmetrical rows of directional couplers connected at the input to said output ports of said switch means and further being connected, with respect to each other in a periodic, closed end-to-end manner by means of transmission lines and further including phase shifters connected between said directional couplers and said transmission lines such that the phases of the center radiating elements of said sector are retarded symmetrically;

said switch means having a like number of output ports, a different one of which is connected to one of said input ports of said matrix means by means of an equal-lenght transmission line for coupling energy from said sending means to selectively predetermined ones of said input ports of said matrix to provide at the corresponding output ports thereof a tapered phase distribution;

each of said output ports of said matrix means being connected by means of an equal-length transmission line with respect to each other, to a different one of said radiating elements, whereby said tapered phase distribution can be fed to a selectively predetermined sector of said ring to produce a cophasal wave which is tangential with respect to said sector and to form a beam which is normal with respect to said dector; and,

said switch means further comprising means for step-scanning said beam over 360°.

2. Microwave beam-forming apparatus for a phased-array antenna system and comprising a plurality of radiating elements equi-spaced and positioned about a ring of said array; reciprocal, corporate matrix means having an equal number of input ports and output ports connected between microwave energy sending means and said antenna system for dividing said energy to provide a tapered phase distribution to a selectively predetermined sector of said phased array and including a plurality of symmetrical and parallel disposed rows of directional couplers, each of said couplers in said rows being connected by means of transmission line to a selectively predetermined coupler in an adjacent row, whereby said rows are connected to each other in a repetitive, closed, end-to-end manner, one of said rows being selectively connected at the inputs of said couplers to said energy sending means and another one of said rows being connected at the outputs of said couplers to said phased array, and said matrix further including phase shifters connected between said couplers connected to each other.

3. The apparatus of claim **2** further including switch means connected between said energy sending means and said matrix means for coupling energy to selectively predetermined ones of said inputs of said couplers.

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