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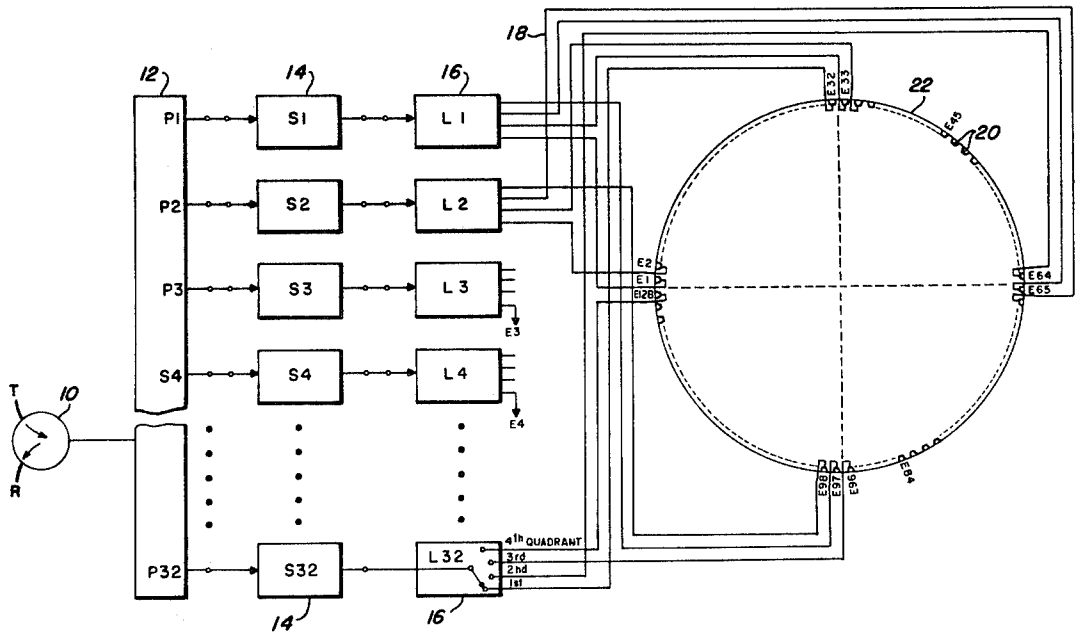
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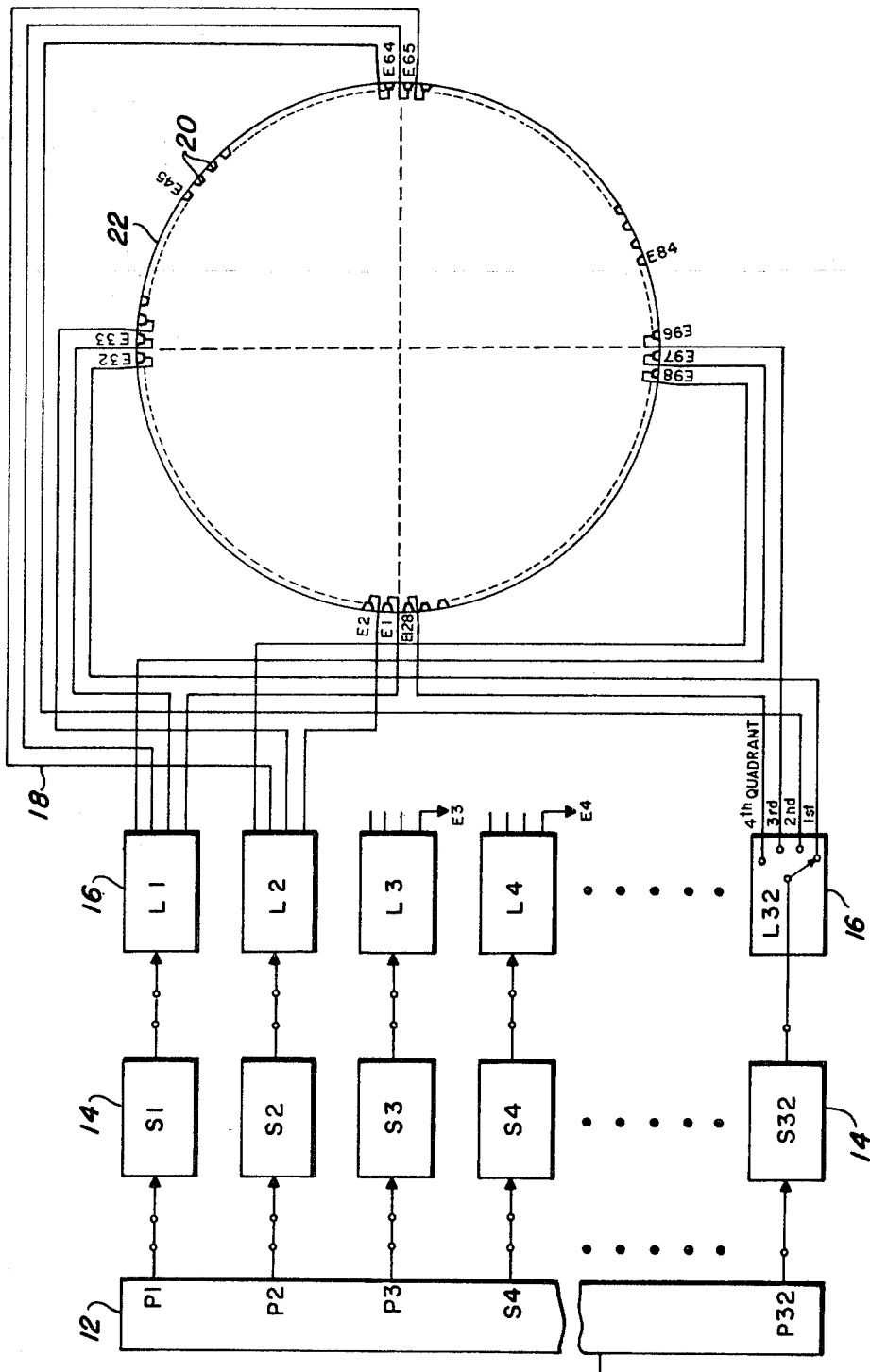
[54] **VECTOR TRANSFER FEED SYSTEM FOR A CIRCULAR ARRAY ANTENNA**
2 Claims, 1 Drawing Fig.

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343/778, 854

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ABSTRACT: A feed system for a circular array antenna which is steerable through 360° in a predetermined number of discrete steps is disclosed. A beam forming network consisting of diode phase and amplitude switches is used to select the phase and amplitude (vector) of the energy distribution which is applied to the active array radiating elements. The radiated beam is scanned by transferring the vectors to a new set of active array elements selected by multithrow switches. The scanning technique is called a vector transfer.





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VECTOR TRANSFER FEED SYSTEM FOR A CIRCULAR ARRAY ANTENNA

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

A circular array antenna configuration has several desirable characteristics. Mechanically, such a configuration offers savings in weight and space. Electronically, the configuration provides stability in beam position with wideband signals. Furthermore, the circular symmetry yields identical beams for every azimuth position.

One existing feed system for a circular array antenna consists of an R-2R or Luneberg lens and a complex network of multithrow switches to provide 360° scanning. The phase and amplitude distributions which are applied to the radiating elements are formed optically in the lens. The beam is scanned by means of transfer switches which will transmit and route the signals to selected parts of the lens and from the lens to the radiating elements. The phase and amplitude distribution of the lens-feed system are accurately determined by means of the R-2R parallel plate lens.

The lens-fed ring array yields radiation patterns which agree with computer-predicted radiation patterns. Furthermore, the ease of implementing the lens-feed ring array combination makes it an attractive tool for the investigation of ring-array and arc-array characteristics. However, for many applications, especially where high power requirements are present, this method has several disadvantages because the power-handling capability is limited by the lens input ports and the diode transfer switches. Furthermore, the lens does not lend itself to compact packaging, and the diode switching circuitry which is required to give 360° coverage and azimuth is complicated.

SUMMARY OF THE INVENTION

A feed system for a circular array antenna which is steerable through 360° in a predetermined number of discrete steps is disclosed. Microwave energy radiated from sending apparatus is divided into a predetermined number of signals having approximately equal phase and amplitude characteristics. The resulting signals are applied to a beam-forming network. The network functions to provide a beam-cophasal, tapered-amplitude energy distribution. The resulting energy distribution is selectively transferred by means of multithrow switches to active radiating elements.

The radiated beam is scanned by transferring the energy distributions, i.e., vectors, to a different set of active array elements selected by multithrow switches. The beam-forming network is reciprocal and can thus be used for both transmission and reception.

STATEMENT OF THE OBJECTS OF THE INVENTION

An object of the present invention is to provide apparatus for feeding a circular array antenna in a manner that produces antenna beams having minimal side-lobe patterns.

Another object of the present invention is to provide apparatus for feeding a circular array antenna in a manner that produces antenna beams having bearing agility independent of frequency.

Another object of the present invention is to provide apparatus for feeding a circular array antenna in a manner that produces an antenna beam which can be steered through 360° in a predetermined number of discrete steps.

Another object of the present invention is to provide apparatus having a high-power-handling capability for feeding a circular array antenna.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same become

better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

The figure is a schematic diagram of the vector transfer feed system for a circular array antenna of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the FIGURE, a sending apparatus 10, which can be either transmitting or receiving means, is shown connected to the input of a power divider 12. In the preferred embodiment, the power divider 12 is shown as having 32 output ports which are designated as P1, P2, etc. Each output port is connected to a vector switch 14. The vector switches are designated as S1, S2, etc. The output terminal of each vector switch 14 is connected to a multithrow switch 16. In the preferred embodiment, the switches 16 are single-pole four-throw switches which are designated L1, L2, etc.

Each SP4T switch 16 is connected by means of equal-length electrical cables 18 to a radiating element 20 in the first, second, third, and fourth quadrants of the circular array 22. For example, switch L32 is shown connected to radiating element E32 in the first quadrant, element E64 in the second quadrant, element E96 in the third quadrant, and element E128 in the fourth quadrant. It should be noted that the four elements 20 which are connected to each switch 16 are physically located 90° apart from each other. Although the switches 16 are shown as being SP4T switches, other multithrow switches may be used. For example, if single-pole three-throw switches are used, each switch would be connected to three radiating elements 120° apart. Likewise, if single-pole six-throw switches were used, each switch would be connected to six radiating elements 60° apart.

The cables 18 are all of equal length so that the signal phase relationships that exist at the output ports of vector switches 14 will be transferred (by cables 18) intact to the radiating elements 20.

The circular array antenna 22 consists of 128 radiating elements equispaced at a distance of approximately $\lambda/2$ from each other, where λ is the wavelength of the center frequency, and embedded in a smooth-walled cylinder having a radius of approximately 13λ at the center frequency. Usually, a plurality of such circular arrays, or rings, are "stacked" upon each other within a cylinder to constitute a cylindrical array.

The radiating elements 20 can be sectoral horns of the type described in a copending application Ser. No. 795,512, filed Jan. 31, 1969 in the name of Jerry E. Boyns, and entitled Coaxial-Line to Waveguide Transition for Antenna Arrays. The sectoral horns are end fed by means of a miniature connector which is connected to the end of a rectangular waveguide opposite the open end of the waveguide. The vector transfer feed system of the present invention, however, is not restricted to the use of radiating elements of the type described herein and in said copending application.

THEORY AND OPERATION

To obtain the characteristics of broad-spectrum signal capability, antenna beams with minimal side lobes, and bearing agility independent of frequency, a unique feed system having certain characteristics is required to overcome inherent difficulties in the application of the cylindrical array. First, to utilize the symmetry of the cylinder, the directional pattern must be rotatable, i.e., steerable, by electronic means, and, in general, the methods which can be used to accomplish this are more complicated than the simple phasing of a linear array. Second, the amplitude taper must also be rotated. Since the individual element pattern is a function of array radius and elevation angle, deterioration of the azimuth beam results when the radiation angle departs from the normal. The difference in amplitude and phase from most elements of the array and the variation of these differences around the array

presents stringent requirements for control of amplitude and phase distribution for adequate limitation of the side-lobe level over a wide frequency band.

The circular array, or ring, in a cylindrical array antenna will provide the desired radiation pattern characteristics if a Tchebycheff distribution is applied to all of the radiating elements of a circular array and if the interior spacing is properly chosen, as is well known to those skilled in the art. For some configurations, however, the allowable interelement spacing exceeds the limits imposed by the Tchebycheff formulation.

However, the application of a beam cophasal distribution and a tapered amplitude distribution to a sector of the array will produce approximately the same results. If a maximum of 90° on either side of the center of the feed system providing a beam cophasal distribution is used, satisfactory agreement between the cophasal and Tchebycheff band for this region can be obtained.

One method which has been found satisfactory for providing a beam-cophasal, tapered-amplitude distribution to a circular array antenna is to use the vector transfer feed system of the present invention.

In operation, input power consisting of electromagnetic energy from sending apparatus 10 is divided by power divider 12 into, for example, 32 signals having approximately equal phase and amplitude characteristics. Each of the 32 signals thus derived is fed to a separate vector switch 14 which consists of a phasor board and an amplitude attenuation board. The vector switches function in a manner well known to those skilled in the art to adjust the phases and amplitudes of the 32 signals as needed to form the desired array beam-cophasal, tapered-amplitude energy distribution.

The resulting signals from each of the vector switches are selectively transferred to 32 selected adjacent radiating elements of the 128 radiating-element array by means of the SP4T switches 16.

The beam which is formed in the beam-forming network consisting of the power divider 12, vector switches 14 and switches 16, can be selectively positioned around the circumference of the circular array 22 by transferring the vectors to a different set of radiators.

For example, assume that all the SP4T switches 16 are in the position as shown for switch L32. In this position, the energy signals from the vector switches 14 are applied to the first quadrant of the circular array 22 which comprises the radiating elements E1 through E32. In this condition, the radiating elements E1 through E32 will be radiating energy. Radiating elements E16, E17 (not shown) will be in the center of the beam, and thus the phase and amplitude of the input signals will be tapered by means of the vector switches 14 to produce a cophasal, tapered-amplitude distribution and a stepped decreasing amplitude toward the outside radiating elements.

To move the beam one step clockwise, for example, the radiating elements E2 through E33 must be energized. This is accomplished by simultaneously switching the vector switches 14 such that the control signal for the vector switch S1 is transferred to the vector switch S2, the control signal for the vector switch S2 is transferred to the vector switch S3, etc., and the control signal for the vector switch S32 is transferred to the vector switch S1.

Simultaneously, the switch L1 is positioned such that the energy signal from the vector switch S1 is transferred from the radiating element E1 to E33. The remaining 31 SP4T switches remain in the first position so that the energy signals from their respective vector switches are still applied to the elements E2 through E32 in the first quadrant. Thus, the overall effect of the above-described switching is to transfer the cophasal distribution from the elements E1 through E32 to the elements E2 through E33 and thus move the beam one step clockwise.

The transfer of the vector signals is easily accomplished by means of a conventional 32-word, six-bit shift register. Likewise, the SP4T switches can be controlled with a 128-word, one-bit shift register. When, for example, the two shift registers are moved n places, the beam is fed to the n th beam position relative to the origin.

Power divider 12 can be a corporate reactive-tuned stripline circuit. In such a circuit the power usually varies less than ½ db. between the output arms, and the phase varies less than 10 percent. Typically, VSWR as seen in the input arm, is approximately 1.3:1 or less over the bandwidth. The power-handling capability is limited by input miniature connectors to about 20 kw. peak; however, the power-handling capability can be increased to 100 kw. by using a standard type N connector.

The vector switches 14 can consist of a three-bit phasor switch and an amplitude attenuator switch which are controlled by a three-bit logic driver. The stripline circuit board has four cascaded hybrid couplers to which are connected four pairs of matched switches. Three pairs of the matched switches are used for the phase switch and one pair is used for the attenuator switch.

The phasor circuit has been called the hybrid coupled transformed phase shifter. It is widely used and has been fully described. It is preferred over other circuits because it requires only two diodes per bit, has a high-power-handling capability, and has a low loss (about 2 db).

The attenuator switch consists of a hybrid coupler that is terminated in a parallel circuit consisting of a 50-ohm resistor and a diode switch. At low diode currents the attenuation is high (15 to 20 db.) over the frequency band. The attenuation decreases as the diode current is increased in steps by a logic drive circuit. It is possible to eliminate the microwave resistor from the circuit and have PIN diodes absorb the power. However, it is more difficult to tune the resulting circuit over the frequency band without the resistor.

The microwave SP4T transfer switches 16 can be built with shunt mounted PIN diodes on stripline circuits. Typically, these switches are capable of handling up to 5 kw. of peak power and 50 watts of average power. These circuits can have the form of a corporate divider with shunt diodes placed at the junctions. The forward-biased diodes prevent transmission, and the reverse-biased diodes permit transmission. Typically, a switch has a loss of 0.8 db. and a VSWR of 1.2:1 over a 20 percent frequency band.

Thus, it can be seen that a new and novel method for feeding and scanning a circular array has been presented. The system involves a beam-forming network consisting of a vector switch which includes phase and amplitude attenuation switches. In the transmit mode of operation, power is equally divided into 32 signals and each signal is fed to a vector switch. The output of each vector switch is connected by means of an SP4T switch and four equal-length cables to four radiating elements which are physically located 90° apart from each other on the circular array. Any 32 adjacent elements can be fed at the same time since no two elements of a 90° (32 elements) sector of the ring array are connected to the same vector switch.

Obviously many modifications and variations of the present invention are possible in the light of its teachings and it is therefore to be understood that within the scope of the disclosed concept the invention may be practiced otherwise than as specifically described.

I claim:

1. A microwave energy feed system for a circular array antenna having a plurality of radiating elements equispaced about the circumference of the array comprising:
 - a. reciprocal microwave energy sending apparatus;
 - b. a power divider network for dividing the energy of said sending means into a plurality of discrete signals having equal phase and amplitude characteristics;
 - c. a reciprocal beam-forming network for adjusting in a selectively predetermined manner the phase and amplitude characteristics of each of said discrete signals whereby a beam-cophasal, tapered-amplitude energy distribution is provided at the output thereof;
 - d. said beam-forming network consisting of a plurality of vector switch means, each of said vector switch means including a phase-shifter circuit and an amplitude-attenuation circuit;

- e. a reciprocal beam-transferring network for transferring said beam-cophasal, tapered-amplitude energy distribution in a selectively predetermined manner to said radiating elements; and
- f. said beam-transferring network consisting of a plurality of single-pole N -throw switch means where $N=2, 3, 4, 5, 6, \dots$, and where each of said switch means is operably connected by means of equal-length conductor means to N radiating elements spaced $360^\circ/N$ apart with respect to each other about said circumference.
2. A microwave energy feed system for a circular array antenna having 128 radiating elements equispaced substantially about the circumference of the antenna comprising:

- a. reciprocal microwave energy sending apparatus;
- b. power-divider means connected to said sending apparatus, said power-divide means having 32 output ports;
- c. phasor switch means and attenuator switch means connected to each of said output ports;
- d. single-pole four-throw switch means connected to the output of each of said switch means; and
- e. equal-length electrical cables connected between the output of each of said single-pole four-throw switch means and four radiating elements spaced 90° apart with respect to each other.

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