United States Patent [19]

Hannan et al.

[11] **3,864,679**

[45] **Feb. 4, 1975**

[54] **ANTENNA SYSTEM FOR RADIATING DOPPLER CODED PATTERN USING MULTIPLE BEAM ANTENNA**

[75] Inventors: **Peter W. Hannan; Harold A. Wheeler,** both of Smithtown, N.Y.

[73] Assignee: **Hazeltine Corporation,** Greenland, N.Y.

[22] Filed: **Apr. 3, 1973**

[21] Appl. No.: **347,506**

[52] **U.S. Cl.** .... **343/106 D,** 343/100 SA, 343/113 DE, 343/854

[51] **Int. Cl.** **G01s 1/38**

[58] **Field of Search** ... 343/106 D, 113 DE, 100 SA, 343/854

[56] **References Cited**

UNITED STATES PATENTS

3,460,145 8/1969 Johnson .... 343/100 SA

3,465,337 9/1969 Tanaka et al. .... 343/100 SA

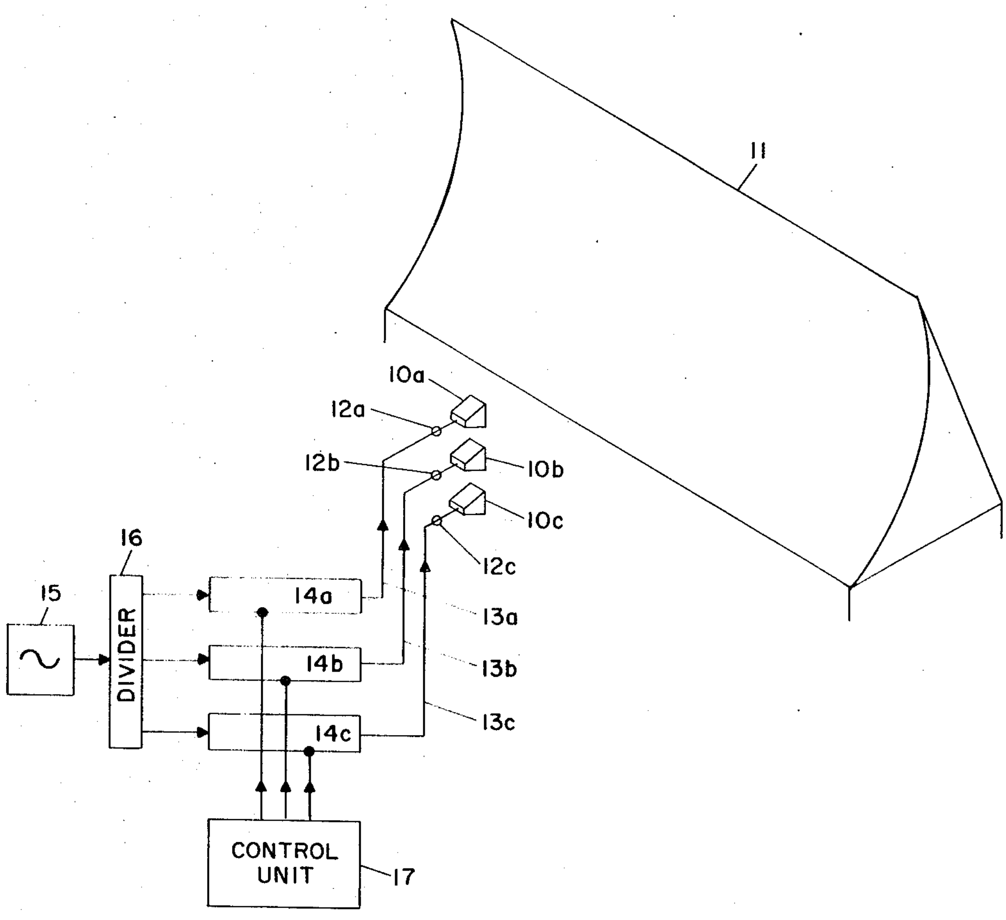
Primary Examiner—Maynard R. Wilbur

Assistant Examiner—Richard E. Berger

[57] **ABSTRACT**

Disclosed is an antenna system for radiating a frequency coded or "Doppler" pattern of wave energy into a region of space using a multiple-beam antenna unit. The system radiates a pattern in which the radiated frequency varies as a function of angular direction from the antenna unit. The system uses an antenna unit capable of radiating simultaneous multiple beams and having a separate input port associated with each beam. The frequency coded pattern is achieved during a time period by simultaneously supplying wave energy signals having a varying phase in relation to each other to the antenna input ports.

16 Claims, 4 Drawing Figures



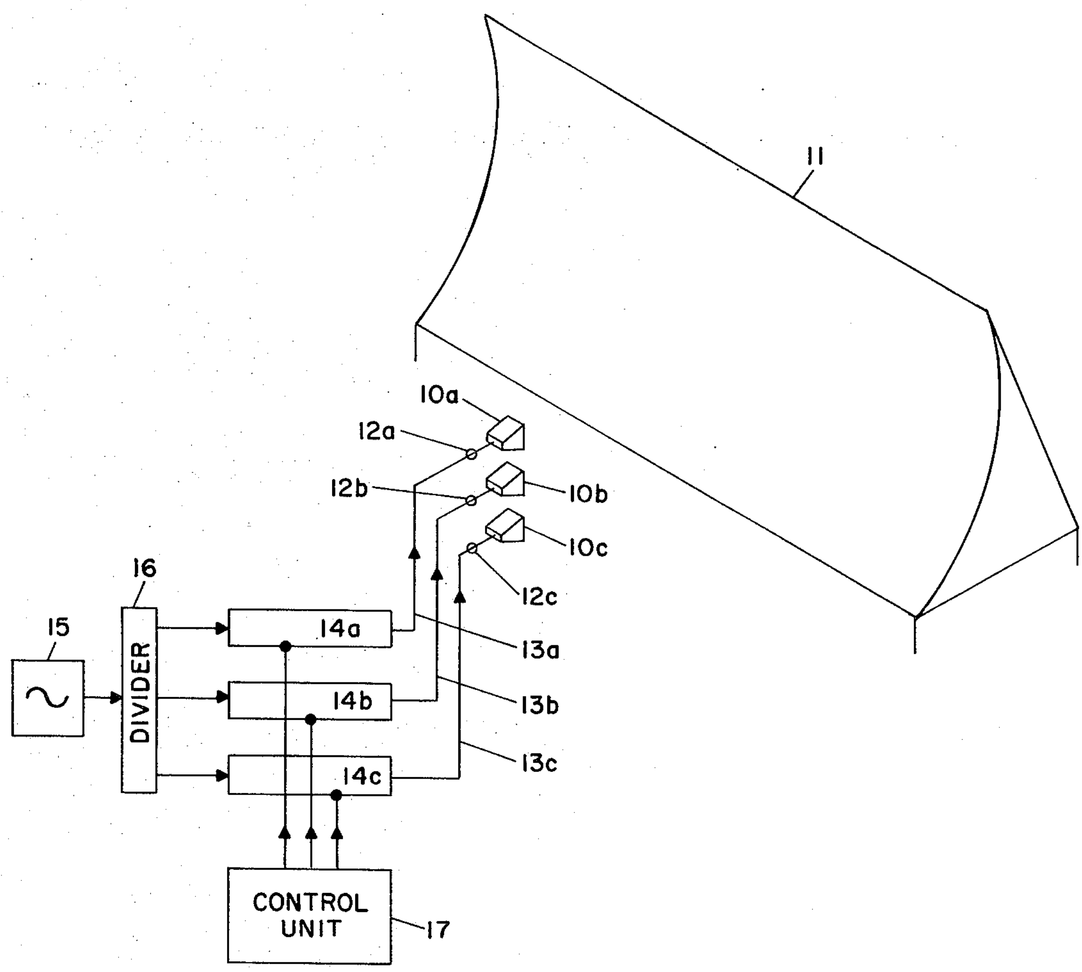

11
10a
12a
12b
10b
10c
12c
16
15
DIVIDER
14a
14b
14c
13a
13b
13c
CONTROL UNIT
17

FIG. 1

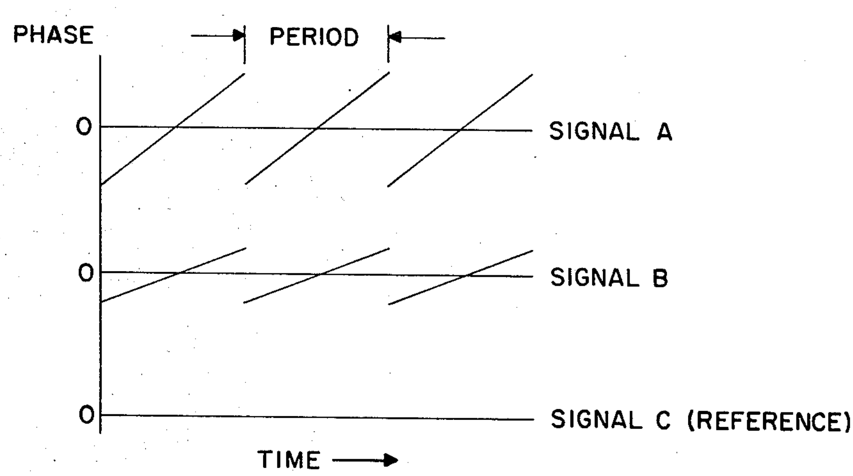

PHASE
PERIOD
0
SIGNAL A
0
SIGNAL B
0
SIGNAL C (REFERENCE)
TIME

FIG. 2

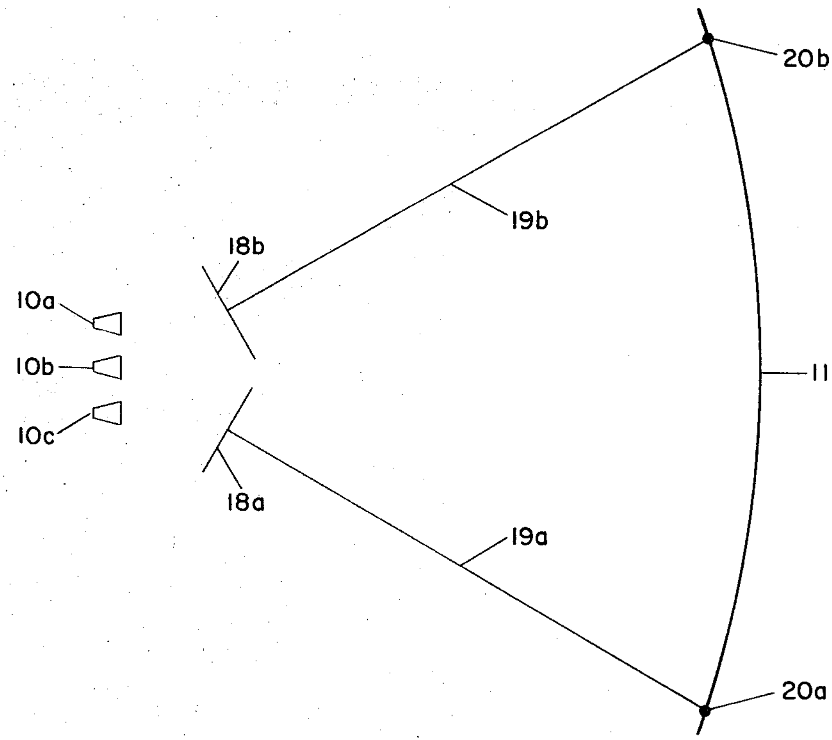

20b
19b
18b
10a
10b
10c
11
18a
19a
20a

FIG. 3

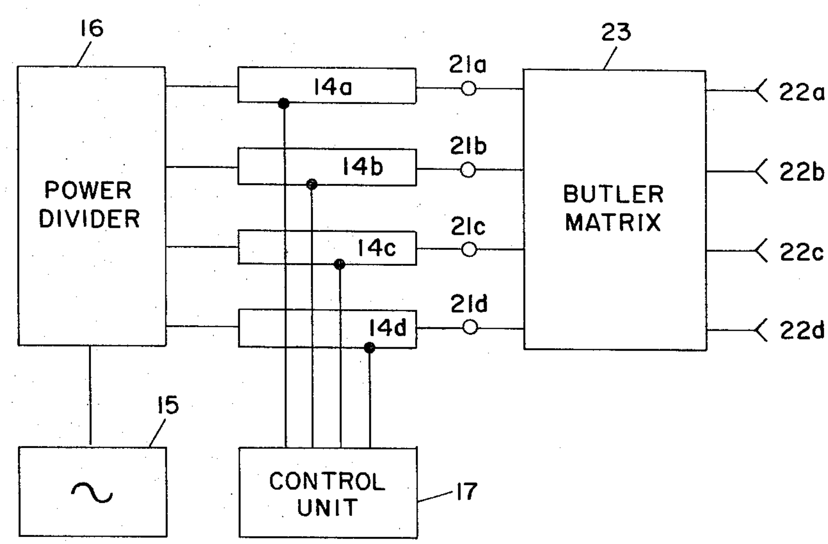

16
POWER DIVIDER
14a
14b
14c
14d
21a
21b
21c
21d
23
BUTLER MATRIX
22a
22b
22c
22d
15
CONTROL UNIT
17

FIG. 4

ANTENNA SYSTEM FOR RADIATING DOPPLER CODED PATTERN USING MULTIPLE BEAM ANTENNA

CROSS REFERENCE TO RELATED APPLICATIONS

The present invention relates to antenna systems radiating Doppler coded patterns using multiple beam antennas, one form of which is described in co-pending U.S. application Ser. No. 347,505, filed Apr. 3, 1973, entitled "Antenna System For Radiating Multiple Planar Beams," which is assigned to the same assignee as the present application.

BACKGROUND OF THE INVENTION

This invention relates to systems for determining the angular position of a target with respect to a reference location. In particular this invention relates to systems which use a frequency coded pattern to perform angle measurement, also known as "Doppler" systems. In a Doppler system an antenna radiates wave energy into a region of space in a pattern wherein the frequency of radiation varies with one of the angular components of direction from the antenna. Frequency coded radiation has in the past been achieved by radiating wave energy sequentially from the individual antenna elements of an array. This causes apparent motion of the radiation source, resulting in a "Doppler" frequency shift which depends on the relative angle of the target with respect to the antenna.

Some deficiencies associated with the sequentially excited array antenna for generating Doppler signals are difficulty in controlling beam shape and complexity in construction. A multiple beam antenna radiating a different frequency on each beam would appear to be an attractive method for radiating a Doppler coded pattern. This method could use a simpler antenna unit and have better control over pattern shape and coding. An attempt to continuously radiate different frequencies on the various beams of a multiple beam antenna would result in random interference between the radiated signals, resulting in widely varying signal amplitude and failure of coding.

SUMMARY OF THE INVENTION

It is an object of this invention, therefore, to provide a new and improved antenna system for radiating a Doppler pattern into a region of space from a multiple beam antenna.

It is a further object of this invention to provide such a system wherein the radiated signal has a substantially constant amplitude versus time characteristic during a time period.

It is a still further object of this invention to provide such a system wherein the radiated pattern can be shaped to coincide with the desired region of space.

In accordance with the invention, there is provided an antenna system for radiating wave energy into a desired region of space in a desired radiation pattern during a selected time period. The desired pattern is one in which the frequency of the radiated energy within the region of space varies with at least one of the components of angular direction from the antenna system. The antenna system includes an antenna unit capable of radiating a plurality of beams in different directions within the region of space from a common aperture, and having a plurality of wave energy input ports, such that each of the ports corresponds to one of the beams. The antenna system additionally includes means for simultaneously supplying a plurality of wave energy signals during the time period, one to each of the ports of the antenna unit, with each of the signals having a phase, measured with respect to the phase of the wave energy signal supplied to the port corresponding to an adjacent antenna beam, which varies during said time period between a predetermined pair of values, the variation being less than 360° and the sense of the variation being alike for pairs of antenna ports corresponding to similarly adjacent beams. When these signals are supplied to the antenna ports, the antenna radiates the desired radiation pattern.

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

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is one embodiment of an antenna system constructed in accordance with the present invention.

FIG. 2 is a diagram illustrating the phase of wave energy signals used in conjunction with the FIG. 1 antenna.

FIG. 3 illustrates the operation of the FIG. 1 antenna.

FIG. 4 is an alternative embodiment of the present invention.

DESCRIPTION AND OPERATION OF THE FIG. 1 ANTENNA SYSTEM

The antenna system of FIG. 1 includes an antenna unit consisting of a plurality of feedhorns **10***a*, *b*, *c* for illuminating a focusing reflector **11**. The feedhorns **10** are located near the focal axis of the parabolic cylindrical reflector **11** and displaced from each other such that wave energy from each feedhorn **10** illuminates the reflector **11** and causes a beam to be radiated at a different angle in space with respect to the antenna system. This type of antenna unit is more fully described and covered by the above referenced co-pending application.

Associated with each of the feedhorns **10** are corresponding wave energy input ports **12***a*, *b*, *c*. Each of these input ports **12** are connected to a corresponding one of the phase shifters **14***a*, *b*, *c* by suitable transmission lines **13***a*, *b*, *c*. An oscillator **15** supplies wave energy signals to a power divider **16.** The wave energy signals from the outputs of the power divider **16** are supplied to the phase shifters **14.** Varying phase control signals are generated by control unit **17** and supplied to control inputs of the phase shifters **14.** Thus, the wave energy signals supplied to the phase shifters **14** have their phase shifted in relation to each other in accordance with the phase control signals such that signals with varying phase in relation to each other are supplied by transmission lines **13** to the input ports **12** of the feedhorns **10.**

The oscillator **15,** power divider **16,** phase shifters **14,** transmission lines **13** and control unit **17** together comprise means for simultaneously supplying a plurality of wave energy signals, one to each of the ports **12** of the antenna unit, with each of the wave energy signals having a predetermined varying phase in relation to any other of said signals.

Each of the feedhorns **10** in FIG. **1** is designed to illuminate the reflector **11**, which forms a common aperture. The antenna unit radiates a beam for each of the feedhorns **10** in a direction which is unique to each of the feedhorns by reason of the displacement of the feedhorns **10** from each other as explained more fully in the aforementioned copending application. Each of the input ports **12** of the feedhorns **10** is therefore associated with an antenna beam.

Those skilled in the art will recognize that other types of multiple beam antennas may be substituted for the antenna unit shown in FIG. **1**. The antenna must be capable of radiating a plurality of beams in different directions within a desired region of space from a common aperture, and have a plurality of wave energy input ports such that each of the ports corresponds to one of the beams. Antennas of this type may be conveniently referred to as "Beamport" antennas.

The transmission lines **13** may be any type appropriate for use at the operating frequency chosen for the antenna system. It is important, however, in the FIG. **1** embodiment that these transmission lines have a phase length in relation to each other which is appropriate for supplying the wave energy signals to the ports **12** with the required varying phase in relation to each other.

The phase shifters **14** may be any type which is appropriate for the frequency of the wave energy signals. Example of suitable phase shifters are ferrite phase shifters and diode phase shifters, both of which use phase control signals to vary their apparent electrical length and thereby phase shift the wave energy signals. The phase control signals supplied by the control unit **17** should be signals appropriate for controlling the phase shifters **14** selected for use in the antenna system. These signals may be digital logic signals or analog signals according to the type of phase shifters selected.

The oscillator **15** may be any suitable generator of wave energy signals at the chosen operating frequency. The power divider may be any of the commonly used types, well known in the art, such as couplers, "T" junctions or reactive dividers.

It will be evident that other means may be used to supply the necessary wave energy signals with a varying phase in relation to each other. For example, phase control may be performed at a different frequency than the radiated frequency and using frequency converting devices, or by performing a digital or analog frequency synthesis to generate the required signals. Phase control may also be achieved by using mixing devices rather than phase shifters.

FIG. 2 illustrates typical varying phase of the signals supplied to the input ports **12** of the FIG. **1** antenna. Phase is shown in relation to the phase of signal "C," which would be supplied to the input port **12***c*, for example. As is evident from the diagram, the phase of the signals "A" and "B," which would be supplied to input ports **12***a* and **12***b*, respectively, have a varying phase in relation to the phase of the signal "C" and in relation to each other. As shown in FIG. **2**, the sense of phase variation for the signals supplied to each port with respect to an adjacent port is alike for pairs of antenna ports corresponding to similarly adjacent beams. Consequently, signal "A," supplied to port **10***a* has a positive phase variation with respect to signal "b" supplied to port **10***b*. Likewise, signal "B" has a positive phase variation with respect to signal "C" supplied to port **10***c*. The phase of the signals during a period nominally varies linearly from a first predetermined phase point for each of the signals to a second predetermined point for each of the signals. The phase variation may depart from a linear variation to account for particular characteristics of various antennas such as defocusing or nonequal spacing of the feedhorns, etc. The phase variation period may be continuously repeated as shown in FIG. **2** to produce a substantially continuous frequency coding.

It should be noted that during any particular period the effect of the linear phase variation is to cause a frequency change in the corresponding wave energy signal. However, it is not effective to continuously supply wave energy signals of different frequency to the input ports of the antenna to cause the desired radiation pattern, because the phase relation necessary to prevent interference of the signals in the various beams is only present during a particular period. To prevent interference between adjacent beams it is necessary that the phase between the signals supplied to ports corresponding to adjacent beams never be such that the adjacent beams are 180° out of phase. Consequently, the total phase variation between adjacent ports can never exceed 360° and is usually much less than 360°.

Doppler frequency coding is most often associated with an antenna which radiates energy from a moving radiation source. FIG. **3** illustrates a sectional view of the antenna unit used in the FIG. **1** antenna system. At the beginning of a period the phase of the wave energy signals supplied to the feedhorns **10** combine when radiated from the feedhorns to form a radiation phase front **18***a* which proceeds in the direction **19***a*, to illuminate an area around the point **20***a* on the reflector **11**. During the period the phase of the wave energy supplied to the feedhorns **10** varies, as shown in FIG. **2**, causing the illuminated area to move vertically across the reflector. At the end of the period the phase of the wave energy signals supplied to the feedhorns **10** form the phase front **18***b*, which proceeds in a direction **19***b*, to illuminate an area around point **20***b* on the reflector. This process may be repeated for several periods, causing the illuminated area on the reflector **11** to repeatedly move from the vicinity around the point **20***a* to the vicinity around the point **20***b*. Points **20***a* and **20***b* are shown by way of example in FIG. **3**. The illuminated area may center around any points on the section of the reflector. This motion of the illuminated area on the reflector causes the antenna system to radiate a pattern similar to a sequentially excited array wherein the frequency of radiation varies with one of the angular components of direction from the antenna.

The group of feedhorns **10** may be considered to be a phased array for illuminating the reflector **11** and array design principles are therefore applicable. The spacing between the feedhorns should be chosen such that there will be no "grating lobes" on the reflector when the feedhorns are excited by any of the phase relations associated with a period. The number of feedhorns required is a function of the angular region of space within which it is desired to radiate the frequency coded pattern. A larger number of feedhorns would cause a narrower illuminated area and hence a larger angular region in which the frequency coded pattern would be radiated. Other tradeoffs will be evident to those skilled in the art. For example, the time duration of the phase variation period is dependent on the amount of frequency shift desired in the radiated pattern. The shape and size of the reflector **11** and feedhorns **10** are dependent on the region of coverage and beamshape desired. The use of other feed elements in place of feedhorns and other means for focusing wave energy in place of a parabolic reflector will be evident to those skilled in the art.

DESCRIPTION AND OPERATIONS OF THE FIG. 4 ANTENNA SYSTEM

FIG. **4** illustrates another embodiment of an antenna system constructed in accordance with the present invention. In the FIG. **4** system, wave energy signals are supplied to the antenna ports **21***a, b, c, d* by similar devices **14–17** as in the FIG. **1** antenna. The principal difference is that the antenna unit in the FIG. **4** embodiment comprises an array of antenna elements **22** which are coupled to the antenna ports **21** by a Bulter Matrix **23.** The properties of a Butler Matrix are well known in the art. Basically, each of the input ports **21** is coupled to the antenna elements **22** by the Bulter Matrix **23** such that wave energy signals supplied to each of the ports **21** will be radiated by the elements **22** in a beam which is in a direction unique to that port. Thus, the antenna unit in the FIG. **4** embodiment has the same general characteristics as the antenna unit in the FIG. **1** embodiment, that is, they are both "Beamport" antennas, although different in form.

Wave energy signals having varying phase in relation to each other, when simultaneously supplied to the antenna ports **21** in FIG. **4,** will cause wave energy signals to be sequentially supplied to the elements **22** of the aperture in a manner resulting in an apparent motion of the radiation source. This operation is evident because of the nature of the transformation performed by the Bulter Matrix **23.**

Other variations in antenna systems which embody the present invention will be evident to those skilled in the art. Other matrices can be used to provide the necessary multiple-beam, multiple-port antenna function, including those which operate at a different frequency than the desired frequency of radiation in conjunction with devices for frequency conversion. Also, devices which are not matrices of themselves, such as enclosed lenses, but have the same properties by reason of transmission characteristics can be used in an antenna system constructed in accordance with the present invention.

In describing the various embodiments above, reference has been made to transmitting antenna systems, but it will be recognized by those skilled in the art that the principles of the present invention can also be applied to receiving antenna systems. Accordingly, the appended claims shall be construed as covering both transmitting and receiving antenna systems regardless of the descriptive terms actually used therein.

While there have 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 antenna system for radiating wave energy into a desired region of space during a selected time period in a desired radiation pattern, wherein the frequency of said radiated energy within said region of space varies with at least one of the components of angular direction from said antenna system comprising:

an antenna unit capable of radiating a plurality of beams in different directions within said region of space from a common aperture, and having a plurality of wave energy input ports such that each of said ports corresponds to one of said beams;

and means for simultaneously supplying a plurality of wave energy signals during said time period, one to each of said ports of said antenna unit, each of said wave energy signals having a phase, measured with respect to the phase of the wave energy signal supplied to the port corresponding to an adjacent antenna beam, which varies during said time period between a predetermined pair of values, said variation being less than 360° and the sense of said variation being alike for pairs of antenna ports corresponding to similarly adjacent beams;

whereby when said signals are supplied to said antenna ports, said antenna radiates said desired radiation pattern.

2. An antenna system for radiating wave energy into a desired region of space during a selected time period in a desired radiation pattern, wherein the frequency of said radiated energy within said region of space varies with at least one of the components of angular direction from said antenna system comprising:

an antenna unit capable of radiating a plurality of beams in different directions within said region of space from a common aperture, and having a plurality of wave energy input ports such that each of said ports corresponds to one of said beams;

means for individually controlling the phase of wave energy signals supplied to each of the ports of said antenna unit such that each of said wave energy signals has a phase, measured with respect to the phase of the wave energy signal supplied to the port corresponding to an adjacent antenna beam, which varies during said time period between a predetermined pair of values, said variation being less than 360° and the sense of said variation being alike for pairs of antenna ports corresponding to similarly adjacent beams;

and means for simultaneously supplying wave energy signals during said time period to said antenna ports via said phase control means;

whereby when said wave energy signals are controlled by said phase control means and supplied to said antenna ports, said antenna radiates said desired radiation pattern.

3. An antenna system as specified in claim **2** wherein each of said wave energy signals is controlled to have a phase which varies linearly with time between said predetermined pair of values.

4. An antenna system as specified in claim **2** wherein said wave energy signals are supplied to the ports of said antenna during a succession of said periods.

5. An antenna system as specified in claim **2** wherein said means for controlling the phase of the supplied wave energy signals comprises a plurality of phase shifters and means for controlling said phase shifters.

6. An antenna system for radiating wave energy into a desired region of space during a selected time period in a desired radiation pattern wherein the frequency of said radiated energy within said region of space varies with at least one of the components of angular direction from said antenna system, comprising:

an antenna unit capable of radiating a plurality of beams in different directions within said region of space from a common aperture and comprising means for focusing incident wave energy and a plurality of feed elements, each having a wave energy input port, for illuminating said focusing means with wave energy patterns such that each of said feed elements corresponds to one of said beams;

means for individually controlling the phase of wave energy signals supplied to each of the ports of said antenna unit such that each of said wave energy signals has a phase, measured with respect to the phase of the wave energy signal supplied to the port corresponding to an adjacent antenna beam, which varies during said time period between a predetermined pair of values, said variation being less than 360° and the sense of said variation being alike for pairs of antenna ports corresponding to similarly adjacent beams;

and means for simultaneously supplying wave energy signals during said time period to said ports via said phase control means;

whereby when said wave energy signals are controlled by said phase control means and supplied to said ports, said antenna unit radiates said desired radiation pattern.

7. An antenna system for radiating wave energy into a desired region of space during a selected time period in a radiation pattern wherein the frequency of said radiated energy within said region of space varies with at least one of the components of angular direction from said antenna system comprising:

an antenna unit capable of radiating a plurality of beams in different directions within said region of space from a common aperture and comprising a parabolic cylindrical reflector for focusing incident wave energy and a plurality of feed elements, each having a wave energy input port, for illuminating said reflector with wave energy patterns such that each of said feed elements corresponds to one of said beams;

a number of phase shifters equal to the number of said feed elements for individuallly controlling the phase of wave energy signals supplied to each of the ports of said antenna unit;

means for controlling said phase shifters such that the phase of wave energy signals supplied to each of said phase shifters is shifted to a phase, measured with respect to the phase of the wave energy signal supplied to the port corresponding to an adjacent antenna beam, which varies during said time period between a predetermined pair of values, said variation being less than 360° and the sense of said variation being alike for pairs of antenna ports corresponding to similarly adjacent beams;

and means for simultaneously supplying wave energy signals during said time period to said ports via said phase shifters;

whereby when said wave energy signals are controlled by said phase shifters and supplied to said ports, said antenna unit radiates said desired radiation pattern.

8. An antenna system for radiating wave energy into a desired region of space during a selected time period in a desired radiation pattern wherein the frequency of

said radiated energy within said region of space varies with at least one of the components of angular direction from said antenna system, comprising:

an antenna unit capable of radiating a plurality of beams in different directions within said region of space from a common aperture and comprising an array of antenna elements, a plurality of wave energy input ports and means for coupling each of said ports to said elements such that each of said ports corresponds to one of said beams;

means for individually controlling the phase of wave energy signals supplied to each of said antenna ports such that each of said wave energy signals has a phase, measured with respect to the phase of the wave energy signal supplied to the port corresponding to an adjacent antenna beam, which varies during said time period between a predetermined pair of values, said variation being less than 360° and the sense of said variation being alike for pairs of antenna ports corresponding to similarly adjacent beams;

means for simultaneously supplying wave energy signals during said time period to said antenna ports via said phase control means;

whereby when said wave energy signals are controlled by said phase control means and supplied to said antenna ports, said antenna unit radiates said desired radiation pattern.

9. An antenna system, as specified in claim **8** wherein the means for coupling said antenna ports to said elements comprises a matrix of transmission lines and couplers.

10. An antenna system for radiating wave energy into a desired region of space during a selected time period in a desired radiation pattern, wherein the frequency of said radiated wave energy within said region of space varies with at least one of the components of angular direction from said antenna system, comprising:

an antenna unit capable of radiating a plurality of beams in different directions within said region of space from a common aperture and comprising a linear array of antenna elements, spaced from each other by substantially equal distances, a number of wave energy input ports, equal to the number of antenna elements, and a Bulter Matrix for coupling each of said ports to all of said elements, such that each of said ports corresponds to one of said beams;

a number of phase shifters, equal to the number of said ports for individually controlling the phase of wave energy signals supplied to each of the ports of said antenna unit;

means for controlling said phase shifters such that the phase of wave energy signals supplied to each of said phase shifters is shifted to a phase, measured with respect to the phase of the wave energy signal supplied to the port corresponding to an adjacent antenna beam, which varies during said time period between a predetermined pair of values, said variation being less than 360° and the sense of said variation being alike for pairs of antenna ports corresponding to similarly adjacent beams;

and means for simultaneously supplying wave energy signals during said time period to said ports via said phase shifters;

whereby when said wave energy signals are controlled by said phase shifters and supplied to said ports, said antenna unit radiates said desired radiation pattern.

11. An antenna system as specified in claim 6 wherein said predetermined pair of values for the phase of the wave energy supplied to each of said ports comprises a first phase value selected to cause the wave energy radiated by all of said feed elements to form a phase front for illuminating a first selected area on said focusing means and a second phase value selected to cause the wave energy radiated by all of said feed elements to form a phase front for illuminating a second selected area on said focusing means.

12. An antenna system as specified in claim 11 wherein each of said wave energy signals is controlled to have a phase which varies linearly with time between said predetermined pair of values.

13. An antenna system as specified in claim 7 wherein said predetermined pair of values for the phase of wave energy supplied to each of said ports comprises a first phase value selected to cause the wave energy radiated by all of said feed elements to form a phase front for illuminating a first selected area on said reflector and a second phase value selected to cause the wave energy radiated by all of said feed elements to form a phase front for illuminating a second selected area on said reflector.

14. An antenna system as specified in claim 13 wherein said first and second selected areas on said reflector are displaced from each other in a direction which is perpendicular to the focal axis of said reflector.

15. An antenna system as specified in claim 14 wherein each of said wave energy signals is controlled to have a phase which varies linearly with time between said predetermined pair of values.

16. An antenna system as specified in claim 7 wherein said wave energy signals are supplied to the ports of said antenna during a succession of said periods.

* * * * *