

Goddard



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF: GP

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for
Patent Matters

SUBJECT: Announcement of NASA-Owned U. S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code USI, the attached NASA-owned U. S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U. S. Patent No. : 3,569,976

Government or Corporate Employee : U.S. Government

Supplementary Corporate Source (if applicable) : _____

NASA Patent Case No. : GSC-10220-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

Yes No

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

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Enclosure
Copy of Patent cited above

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SHEET 1 OF 3

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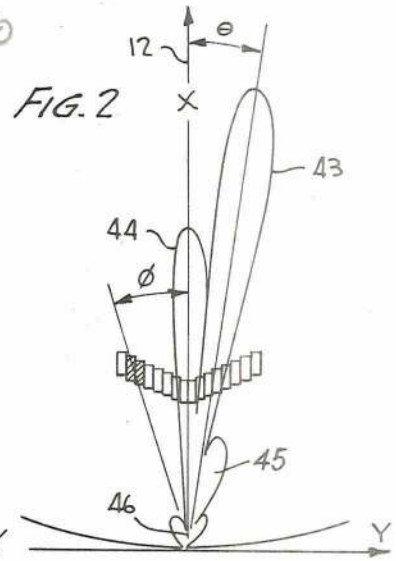
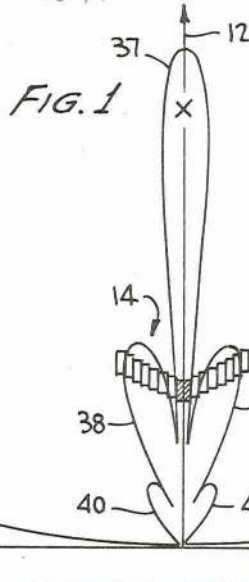


FIG. 3

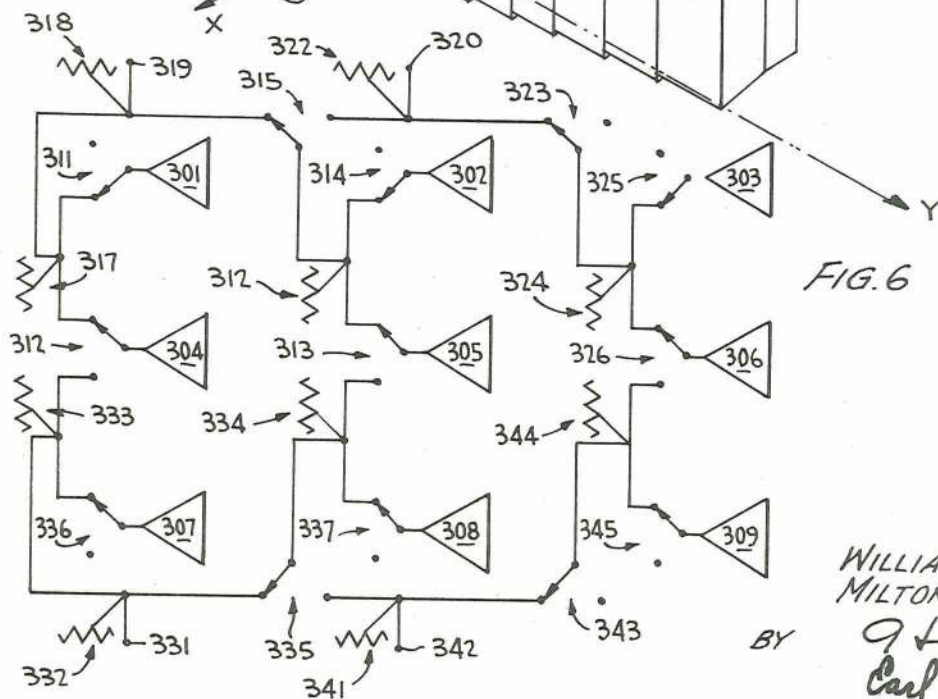
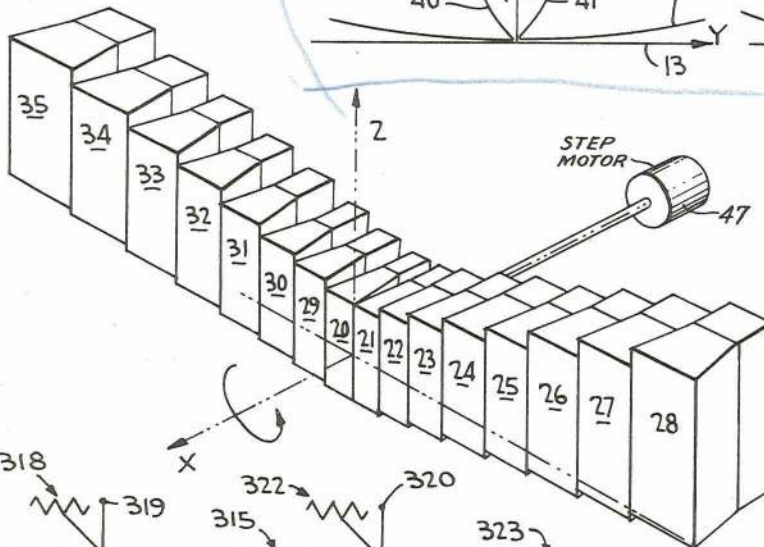


FIG. 6

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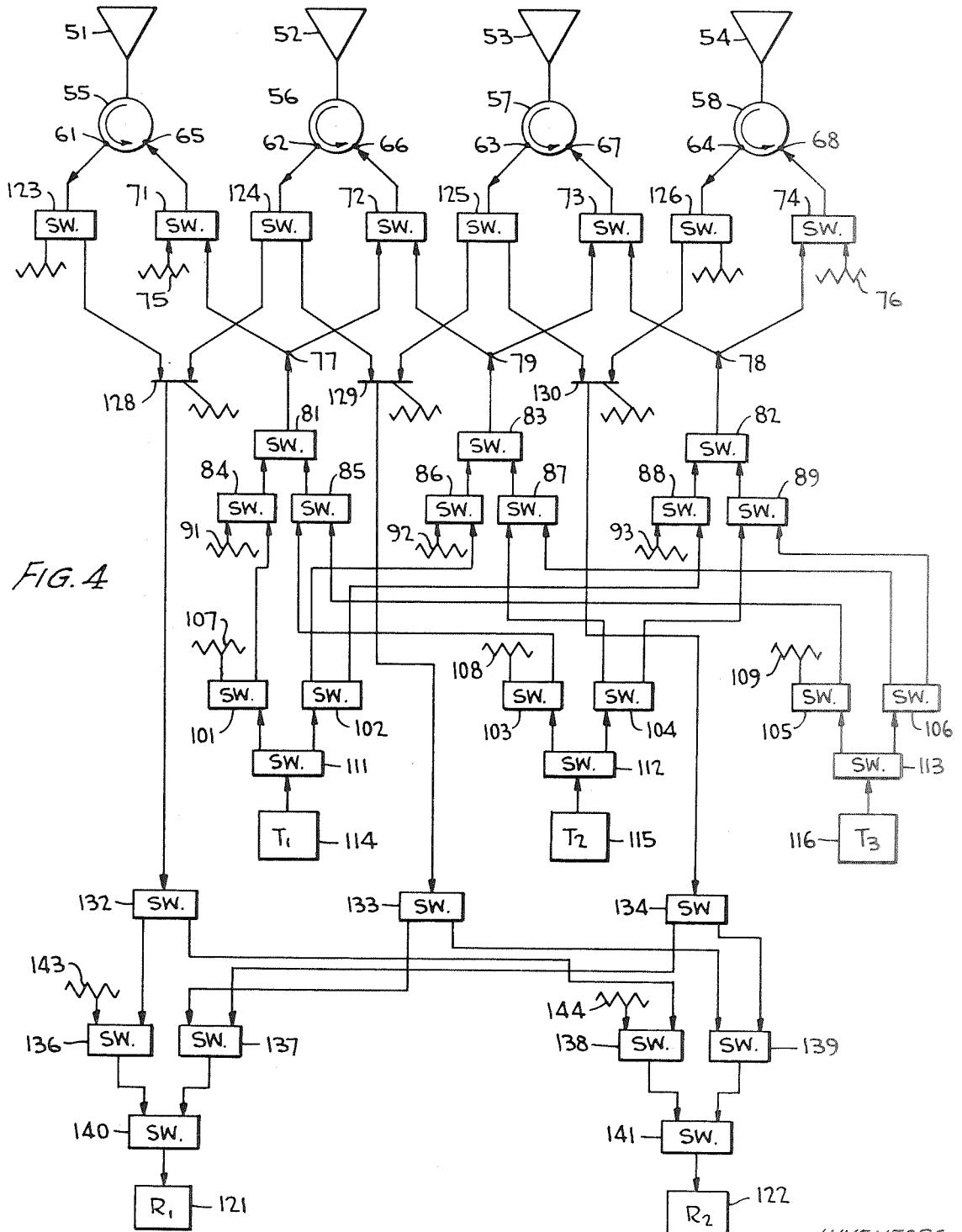


FIG. 4

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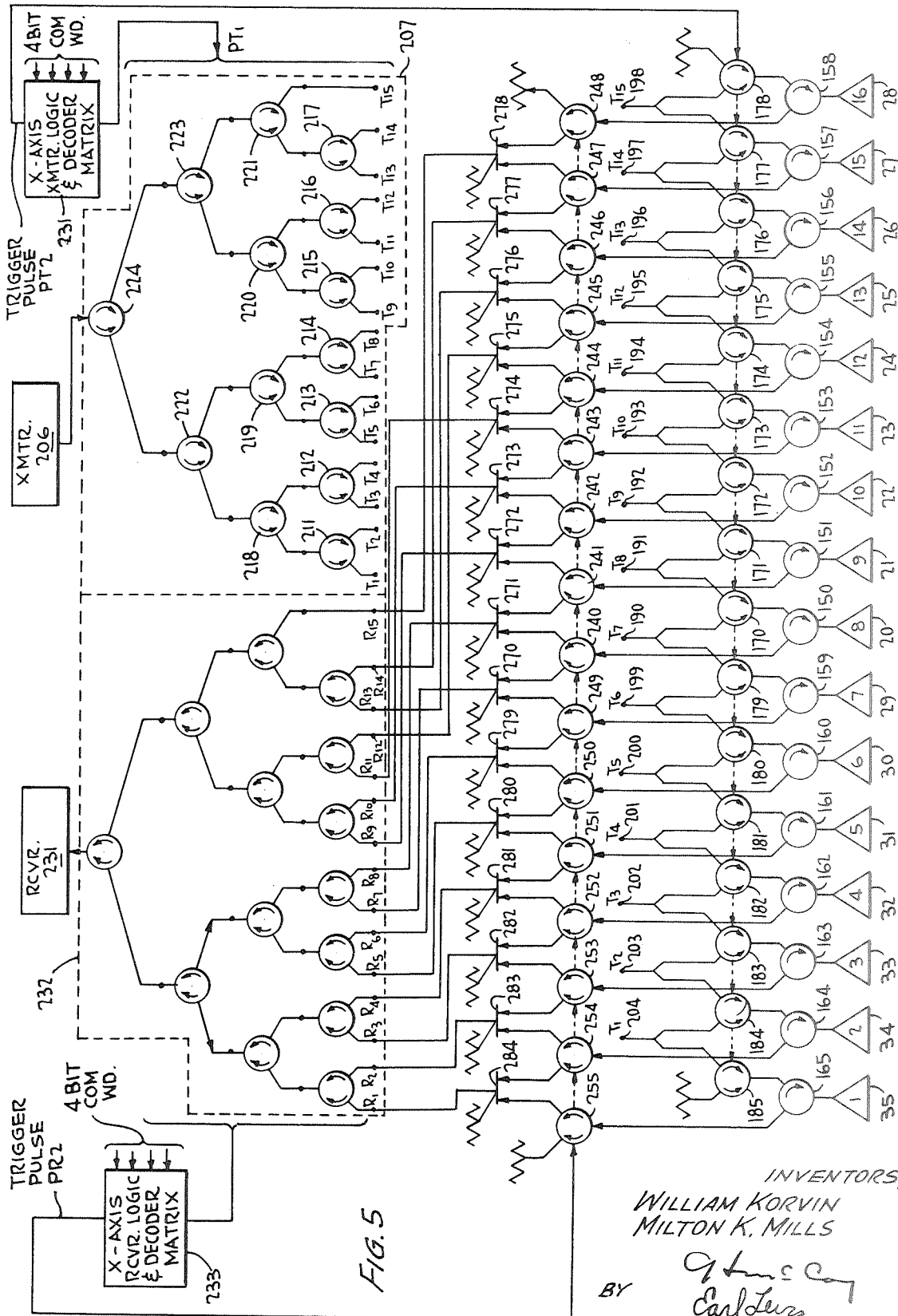


FIG. 5

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 [45] Patented **Mar. 9, 1971**
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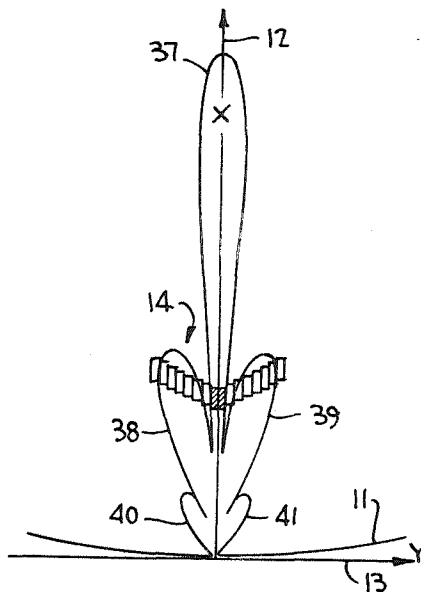
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[54] **ANTENNA ARRAY AT FOCAL PLANE OF REFLECTOR WITH COUPLING NETWORK FOR BEAM SWITCHING**
 26 Claims, 6 Drawing Figs.

[52] U.S. Cl. 343/777,
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 H01q 13/00
 [50] Field of Search 343/776,
 778; 343/777, 779, 786, 840, 854

ABSTRACT: An antenna system for steering plural beams from a secondary reflector is formed from a primary array of linear feed elements, which can be arranged in either a one- or two-dimensional configuration. By controlling which of the radiators are simultaneously excited with a switching matrix, the position of the primary beam is varied as a function of the axis of the reflector forming the secondary beam.



ANTENNA ARRAY AT FOCAL PLANE OF REFLECTOR WITH COUPLING NETWORK FOR BEAM SWITCHING

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

The present invention relates generally to systems for controlling the position of a secondary radiation beam and, more particularly, to a system of said class including a radiation array for generating a primary radiation pattern and means for switching the array excitation so that a plurality of adjacent elements in the array is simultaneously excited.

One of the frequently utilized approaches of the prior art for controlling the position of a secondary radiation beam has been to mechanically rotate a single feed element about an axis of a reflector utilized for forming the secondary beam. This technique, commonly utilized in the radar field for deriving a scanned pattern, completely obviates the possibility of deriving a plurality of independently steerable secondary beams which can simultaneously excite a plurality of transmitters and/or receivers.

To enable a plurality of steerable beams to be derived, the phased array has been devised. The usual phased array includes a plurality of independent linear or planar feed elements. The feed elements of a typical phased array are simultaneously excited with energy of different phases. To scan the beam pattern, the phase shift for each element excitation is changed. Because the beam position in a phased array is a function of phase shift, it is apparent that the array is frequency dependent. Hence, a phased array system cannot be utilized for broadband applications, a frequent requirement when it is sought to generate a plurality of beams with the same radiator assembly. In addition, transmission lines connecting the radiating or feed elements with a transmitter and/or receiver must be precisely controlled in length to prevent phase errors from being introduced and enable accurate control of beam position to be attained.

In accordance with the present invention, an antenna system capable of simultaneously deriving a plurality of steerable beams is provided by including in combination with a secondary beam-forming reflector a primary radiation source having several, i.e., more than two, feed elements. To form one primary beam a plurality of adjacent feed elements is simultaneously in phase excited to the exclusion of other feed elements through a switching matrix. The feed elements can be simultaneously excited to either the transmit or receive modes with a three-port circulator connected between first and second switching arrays respectively connected to at least one transmitter and receiver. Because the only connections to the transmitters and/or receivers and the radiation elements are through wideband devices such as switches, circulators and hybrids, the frequency dependent problems encountered in phased arrays are obviated and a plurality of steerable beams can be generated over a wide bandwidth.

The secondary beam pattern position can be controlled in two dimensions if either a linear or planar array is utilized. For a linear array, the beam position is controlled in one direction by mechanically scanning the array about a bore sight axis of the reflector forming the secondary beam. The position of the secondary beam can be controlled with a planar array, extending in two orthogonal axes. The center of the primary radiation beam can be derived either directly in the focal plane of the reflector forming the secondary beam or it can be effectively derived in that plane by utilizing well-known Cassegrain techniques. Regardless of whether the primary beam is derived directly or effectively at the focal point of the radiator forming the secondary beam, the array forming the primary pattern can be either planar or linear.

One particular advantage of the present invention is attained when it is utilized for scanning purposes. In the scanning mode, the switching network is activated so that as the beam position is moved, at least one of the feed elements excited while the beam is in a first position remains activated

when the beam is scanned to a second position. Thereby, there are low crossover levels between adjacent beams and the beam appears to be smoothly scanned although, in fact, it is actually stepped.

Another feature of the present invention is that the secondary beam side lobes have a relatively low amplitude relative to the main lobe for virtually all off-axis orientations. This result is achieved by positioning the effective phase centers of the radiation sources along a best fit curve in the real or virtual focal plane of the reflector forming the secondary beam. In other words, the individual elements comprising the radiator beams are not located exactly in a straight line, but are positioned in the best fit focal plane of the secondary reflector.

Another advantage of the present invention is enhanced array efficiency, achieved by minimizing energy spillover so that virtually all of the energy derived from the primary beam impinges against the reflector forming the secondary beam. This result is achieved by employing tapered horns having apertures increasing in size as a function of increasing radius from the antenna system boresight. Tapering the horns to decrease the spillover also reduces the side lobe energy since energy is not reflected from regions behind the reflector.

It is, accordingly, an object of the present invention to provide a new and improved system for controlling the position of a radiating beam.

Another object of the invention is to provide a new and improved steerable radiation beam controlling system capable of deriving a plurality of independent beams which can be utilized for transmission and/or reception purposes.

Another object of the present invention is to provide an antenna system for deriving a scanning beam utilizing a switching array, wherein the effective phase center derived from the antenna system is moved in relatively smooth increments.

Another object of the present invention is to provide a new and improved antenna system wherein a scanned secondary beam is derived with maximum efficiency.

Still an additional object of the present invention is to provide a new and improved system for controlling the position of a radiation beam having a relatively low side lobe.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of several specific embodiments thereof, especially when taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a schematic diagram of the feed and secondary reflector in accordance with the present invention, showing a radiation pattern derived from on-axis, boresight excitation;

FIG. 2 is a further schematic diagram illustrating the same apparatus as is shown by FIG. 1, but showing the pattern derived from off-axis feed element excitation;

FIG. 3 is a perspective view illustrating one embodiment of a linear array for exciting the reflector illustrated by FIGS. 1 and 2;

FIG. 4 is a circuit diagram of one embodiment of the network utilized for exciting the array of FIG. 3;

FIG. 5 is a circuit diagram of another embodiment which can be utilized for exciting the array of FIG. 3; and

FIG. 6 is a circuit diagram, in combination with a schematic diagram of an antenna array, in accordance with yet another embodiment of the invention.

FIG. 1 is a side sectional, schematic view of a parabolic reflector 11, described as a surface of revolution about boresight axis 12 and having its apex located at the intersection of axes 12 and 13, the latter being at right angles with the former. Positioned in the focal plane of parabolic reflector 11 is linear array 14 which includes an even number, 16, of individual feed elements 20—35. Elements 20—35 are symmetrically located about axis 12 so that the intersection between the two elements 20, 21 in the center of the array is coincident with the boresight axis. A primary radiation pattern, formed by exciting the elements of array 14, is converted into a secondary beam by reflection from reflector 11. The primary radia-

tion pattern forming array 14 can be replaced, however, with a subreflector which is excited by an array positioned in the vicinity of the apex of reflector 11, in accordance with the well-known Cassegrain assembly.

In accordance with one embodiment of the invention, illustrated specifically in FIG. 3, each of the 16 elements comprising array 14 is a horn having a rectangular aperture. Adjacent ones of the elements 20—35 forming array 14 have abutting juxtapositioned walls to comprise a linear array, that is, one located along a straight line. The horn elements 20—35 of the array deviate from a straight line in the plane at right angles to axis 12, however, to enable a best fit for the array to be derived. In particular, the positions of the horns 20—35 are arranged so that the center of each horn is in the best fit focal plane for parabola 11, i.e., a surface which approximates a parabola having a focal length equal to one-half the focal length of reflector 11 and an axis coincident with the axis of reflector 11. Thereby, regardless of which of the horns in array 14 that is excited, the energy thereof is directed to the surface of reflector 11.

To derive a beam directly along boresight axis 12 and symmetrical therewith, the two center horns 20 and 21 of array 14 are simultaneously excited with in phase energy. In response to excitation of horns 20 and 21 with in phase energy, a beam having a narrow main lobe 37 and side lobes 38—41 is derived. It is noted that the amplitude of main lobe 37 is considerably in excess of the amplitudes of side lobes 38—41. For one particular arrangement actually constructed utilizing S-band horn feeds and a parabolic reflector having a 30 foot diameter main lobe 37 of the secondary beam derived from reflector 11 in response to excitation of elements 20 and 21 was 17.6 db greater than the amplitude of the first side lobes 38 and 39.

To translate the position of the secondary beam derived from reflector 11 to an off-axis location, a pair of adjacent horns in array 14 located remote from axis 12 are simultaneously excited with in phase energy. In FIG. 2, for example, off-axis horns 33 and 34 are simultaneously excited to derive a primary pattern that results in a secondary beam from reflector 11 which includes a large amplitude main beam 43, displaced from axis 12 by an angle Θ , and a plurality of lower amplitude side beams 44, 45 and 46. It is noted that the displacement angle of beam 43 from axis 12 is less than the angle which defines the phase center of the primary radiation derived by simultaneously exciting horns 33 and 34. In addition, the amplitude of side lobe 44 relative to main beam 43 is considerably in excess of the relative amplitudes of the side lobes and main lobes of FIG. 1, although the side lobe in FIG. 2 is not large enough to cause deleterious results.

To rotate beam 43 of FIG. 2 about axis 12, the entire array 14 can be rotated by a step motor, or the like, utilizing conventional techniques. The angle Θ between main beam 43 and axis 12, however, is varied by simultaneously exciting a different pair of adjacent horns in array 14 which produces a primary radiation phase center at the intersection of the two excited horns. For example, the angle Θ in FIG. 2 defining the phase center of the primary excitation for the secondary pattern having the main beam 43, is on a line between the apex of reflector 11 and the intersection of horns 33 and 34. With a linear array including N elements, where N is an even integer, the simultaneous in phase excitation of adjacent element pairs enable N-1 different primary beams to be derived.

It has been found advisable to taper the apertures of the horns comprising feed array 14, in at least the direction parallel to axis 13, to minimize the side lobes for the off-axis excitation. In addition, it has been found that the increased E- and H-plane apertures of the horns removed from axis 12 minimize spillover, i.e., cause most of the energy in the primary beam derived from the horns at the extremity of array 14 to be directed at reflector 11, rather than at areas outside of the reflector. Containing the primary feed excitation to reflector 11, rather than areas outside of the reflector, increases the efficiency of the antenna system, as well as decreasing side lobes.

To these ends, the E- and H-plane dimensions of horns 20—35 increase as a function of distance from boresight axis 12. In particular, the transverse dimensions of horns 20 and 21 are equal and relatively short along a line parallel to axis 13, while the lengths of horns 28 and 35 along a line parallel to axis 13 are relatively large, to effect the E-plane variations. Similarly, in the H-plane, at right angles to the E-plane, the heights of horns 20 and 21 are considerably less than those of horns 28 and 35. While the tapers of the horn apertures increase in the E- and H-planes as a function of increasing distance from axis 12, the tapers increase in different manners in the two planes. The tapers in the two directions are different because parabolic reflector 11 is defined as a surface of revolution about axis 12 whereby the reflector has different geometries in planes at right angles to and intersecting axis 12.

A network for exciting an array including four horn elements of the type illustrated in FIG. 3, in response to energy coupled to three transmitters and two receivers is shown by FIG. 4. While the system of FIG. 4 is shown specifically in conjunction with an array including four feed elements, three transmitters and two receivers, it is to be understood that the principles are expandable to include any number of feed elements, transmitters and/or receivers and that the system specifically shown is for illustrative purposes only. The important consideration in the system of FIG. 4 is that at least a pair of feed elements is always simultaneously in phase excited via a broadband network including only switches, circulators, hybrids and power dividers.

In FIG. 4, each of four driven feed or radiation elements, horn antennas 51—54, is separately driven by one of three port circulators 55—58, respectively. Each of circulators 55—58 couples energy between elements 51—54 and one part of a pair of matrices separately controlled for transmission and reception. In particular, the left ports 61—64 of each of circulators 55—58 couple energy from antennas 51—54 into a receiving matrix, while each of right ports 65—68 feeds energy from a transmitting matrix into the circulators.

The transmitting matrix-feeding ports 65—68 includes single-pole, double-throw microwave switches 71—74, each having a pair of terminals selectively connected through a contact to one of the circulators. One terminal of each of switches 71 and 74 (the outside element switches) is connected to matched loads 75 and 76, respectively, for temperature compensation if necessary, while the remaining terminals of switches 71—74 are connected to different branches of three db power dividers 77—79. Each of power dividers 77—79 includes a pair of output arms for feeding in phase equal amplitude energy to the two-switch terminals with which it is coupled.

Power dividers 77—79 are respectively driven by the contact of single-pole, frequency or phase selective double-throw, R.F. switches 81—83, each of which includes a pair of terminals driven by the contact of a different one of single-pole, frequency or phase selective double-throw switches 84—89. One terminal of each of switches 84, 86 and 88 is respectively connected to temperature-compensating, load-matching loads 91—93, while the remaining terminals of switches 84—89 are driven by the contact of single-pole, frequency or phase selective double-throw switches 101—106. Loads 91—93 can be replaced by suitable transmitters. One terminal of each of switches 101, 103 and 105 is respectively connected to matching temperature compensating loads 107—109, while the remaining terminals of switches 101—106 are connected to different input of switches 84—89. The contacts of switches 101—106 are selectively driven in pairs by signals derived from the terminals single-pole, double-throw switches 111—113, each of which has a contact connected to a different microwave transmitter 114—116. It should be noted as an example that the switching network comprised of elements 101, 102 and 111 is a multiplexer when the switches take a specific position.

In operation, any one of transmitters 114—116 is selectively connected to any one of power dividers 77—79, which in turn feed energy through switches 71—74 to input ports 65—68 of

circulators 55—58. The selective connections through the four banks of switches between transmitters 114—116 and power dividers 77—79 are such that a unique path exists between each of them, whereby any one of the power dividers can be simultaneously excited by any or all of the transmitters. Simultaneously with the establishment of the path through the four switch banks, switches 71—74 are selectively activated so that from each of power dividers 77—79 a pair of paths simultaneously subsists to a pair of adjacent ones of circulators 55—58, whereby a pair of adjacent feed elements in the array comprised of antennae 51—54 is simultaneously in phase excited with equal amplitude energy. The simultaneous coupling of energy from transmitters 114—116 to power dividers 77—79 results from the frequency or phase selective properties of the five banks of single-pole, double-throw switches connected between them. In particular, each of the switches connected between the power dividers and transmitters is capable of simultaneously feeding diverse frequencies or phases from its contact to its terminals or vice versa. For example, the contact of switch 81 can be simultaneously responsive to energy at two different carrier frequencies f_1 and f_2 , as derived from transmitters 114 and 115 and coupled to the terminals of switch 81 via the contacts of switches 84 and 85. Switches capable of this operation are well known in the art and generally include filter networks in combination with diode switching elements.

To describe more fully the operation of the matrix of FIG. 4, consider the path between transmitter 114 and feed elements 51 and 52. Under these circumstances, the path between transmitter 114 and power divider 77 is established by activating switches 81, 84, 101 and 111 so that energy is coupled from transmitter 114 through switch 111 to the contact of switch 101, and from the right output port or terminal of switch 101 into the left terminal of switch 81 through switch 84. While energy is being coupled into power divider 77 from switch 81, switches 71 and 72 are activated so that the contacts thereof are respectively connected to the right and left input ports or terminals thereof. The energy from transmitter 114 is thereby supplied with the same phase to ports 65 and 66 of circulators 55 and 56 which in turn drive feed or radiating elements 51 and 52 with in phase equal amplitude energy to derive a beam having a phase center equidistant between the two elements.

If now it should be desired to switch the position of the transmitter 114 to primary radiation beam so that it lies on the centerline between radiators 52 and 53, the path coupling energy to power divider 77 from transmitter 114 is replaced with a path between the transmitter and power divider 79. Simultaneously, the path between the right outlet port of power divider 77 to inlet port 66 of circulator 56 is replaced by activating switch 72 to that there subsists a path between the left output port of power divider 79 and inlet port 66, while the right output port of divider 79 is coupled to terminal 67 of circulator 57 via the left terminal of switch 73. To establish an energy-coupling relationship between the inlet port of power divider 79 and transmitter 114, switches 83, 86, 102 and 111 are activated so that the contact of switch 102 is driven by the output of transmitter 114 through the contact and right outlet port of switch 111; the left terminal of switch 102 drives the left terminal of switch 83 through a connection established by the contact of switch 86. The energy coupled into power divider 79 is fed equally and in phase through switches 72 and 73 to inlet ports 66 and 67 of circulators 56 and 57, which in turn drive feed elements 52 and 53 with in phase, equal amplitude energy.

If it should now be desired to drive feed elements 53 and 54 from transmitter 114, a path is established between the transmitter and power divider 78 through switches 82, 88, 102 and 111 in a manner similar to that described supra with regard to the connections between the coupling of power from transmitter 114 to power dividers 77 and 79.

Circulators 55—58, in addition to being capable of feeding energy from several of transmitters 114—116 to the several

feed elements, can also function simultaneously with any one or both of receivers 121 or 122. The matrix for driving receivers 121 and 122 from the outlet ports 61—64 of circulators 55—58 in response to the outputs of transmitters 114—116 is substantially a duplicate of the array coupling transmitters 114—116 with circulators. The only material differences between the arrays are the substitution of hybrids for power dividers, both of which have the same function and the connections resulting from exciting two, rather than three, devices. In particular, outlet ports 61—64 of circulators 55—58 drive the contacts of single-pole, double-throw switches 123—126, respectively, which in turn have contacts for selectively driving hybrids 128—130. The left and right input arms of hybrids 128 and 130 are respectively driven by the left and right terminals of frequency or phase selective switches 123, 124 and 126, 127, while the left and right arms of hybrid 129 are respectively driven by the right and left terminals of switches 124 and 126. The left and right terminals of switches 123 and 126 are respectively connected to matching resistors. One arm of each of hybrids 128—130 is connected to a matching resistor, while the other arm is connected to drive the contact or pole of single-pole, double-throw frequency or phase selective switches 132—134, respectively.

The six output ports or terminals of switches 132—134 are selectively connected through a matrix tree which may be frequency or phase selective comprising switches 136—141 to receivers 121 and 122. The terminals of switches 137 and 139 are responsive to the signals derived at the terminals of switches 133 and 134, while one terminal of each of switches 136 and 138 is driven by a different terminal of switch 132. The remaining terminals of switches 136 and 138 are connected to matching resistances 143 and 144, respectively. The output signals selectively coupled through switches 136 and 137 are paired to the input ports of switch 140, while the terminals of switch 141 are responsive to the signals fed through switches 138 and 139. The contacts of switches 140 and 141 individually drive receivers 121 and 122, respectively. If the matrix tree comprising switches 136—141 is frequency or phase selective, isolated paths subsist to receivers 121 and 122. In particular, switches 136, 137 and 140 can be considered as a frequency or phase multiplexer for energy having a first frequency or phase relationship while switches 138, 139 and 141 are a multiplexer for energy having a second frequency or phase relationship.

The connections between outlet ports 61—64 and the input terminals of receivers 121 and 122 are substantially duplicated by the connections between transmitters 114—116 and inlet ports 65—68 of circulators 55—58. Because of reciprocity, it should thereby be obvious as to how the receivers are driven by energy illuminating adjacent pairs of feed elements 51—54. For either transmission or reception, the positions of secondary beams derived from an array including elements 51—54 are derived by locating the effective phase centers of the primary beam in the best fit focal plane of a secondary beam forming reflector as described supra with regard to FIGS. 1—3.

Reference is now made to FIG. 5 of the drawings wherein there is illustrated a specific embodiment of the present invention specifically designed for scanning a secondary radiation beam derived from reflector 11, FIG. 1. The stepping action is achieved with minimum crossover by activating a pair of feed elements simultaneously and transferring the excitation so that one of the previously activated elements remains activated, while one of the previously excited elements is deactivated and an element adjacent the remaining activated element becomes excited. The matrix of FIG. 5 is generally similar to that of FIG. 4 but replaces the single-pole, double-throw switches of the previously described embodiment with three port-latching circulators, i.e., circulators which are energized in response to a bipolarity control signal so that energy is selectively fed between adjacent ports thereof in clockwise and counterclockwise directions. In the embodiment of FIG. 5, the 16-horn array of FIG. 3, including elements 20—35 is specifically excited.

Each of horns 20—35 of the 16-element array is driven by one port of a different one of fixed three-port circulators 151—165. Another of the ports of each of circulators 151—165 is driven by the output port of latching circulators 170—185, respectively. The remaining ports of circulators 170—185 are connected so that adjacent ports of adjacent circulators are connected together, with the exception of the left and right-hand ports of circulators 178 and 185 which are connected to temperature-compensating matching loads. Latching circulators 170—185 are connected so that energy fed thereto from the left and right ports thereof is invariably coupled to an input port of circulators 150—165. The ports of circulators 170—185 are connected to 15, 3-db power dividers 190—204, which in turn are connected to transmitter 206 through a switching matrix 207 including four orders of latching circulators. Fourteen of the power dividers 190—197 and 199—204 are connected via seven latching circulators 211—217 to four latching circulators 218—221, thence to a pair of latching circulators 222 and 223 to a single latching circulator 224. The outlet port of latching circulator 224 is connected directly to transmitter 206. The remaining power divider 198 is connected directly to latching circulator 221. The latching circulators in matrix 207, as well as the latching circulators 170—185 are arranged whereby energy is always coupled from transmitter 206 in the direction of horn feed elements 20—35.

The circulators in matrix 207 are selectively activated in response to a four-bit command word supplied to decoder matrix 231. In response to the four-bit command word, decoder matrix 231 simultaneously derives four bipolarity output signals controlling the direction of energy flow in the four different levels of the latching circulators in matrix 207, so that all of the circulators in any particular row of the matrix propagate energy in the same direction. Thereby control of power into one of the 15 power dividers 190—204 is achieved. Simultaneously with energization of the latching circulators in matrix 207, decoder matrix 231 derives a bipolarity trigger pulse which simultaneously activates all of latching circulators 170—185 so that adjacent ones of these circulators propagate energy in opposite directions.

To consider the operation of the array including horns 20—35 as driven by transmitter 206 through matrix 207, initially assume that decoder matrix 231 activates matrix 207 so that energy flows clockwise in each row of the latching circulators, while simultaneously activating latching circulators 170—185 so that energy is transmitted clockwise in the odd numbered of these circulators and counterclockwise in the even numbered circulators. Under these conditions, power is supplied to the right-hand port of each of circulators 224, 223 and 221, and thence to the input terminal of power divider 198 from where it is fed through the left- and right-hand input ports of latching circulators 177 and 178 to the left and right input terminals of fixed circulators 157 and 158. Exciting the right input ports of circulators 157 and 158 results in energy being coupled from the circulators to horn antennas 27 and 28. The energy fed to the horn antennas 27 and 28 is in phase and of equal amplitude since equal attenuation and phase shift exist between the input port of power divider 198 and the input terminals of horn antennas 27 and 28. Thereby, a radiation beam is derived having a phase center approximately on the intersecting line between horn antennas 27 and 28.

To scan the radiation beam derived from the array so that it is transferred from the intersection of antennas 27 and 28 to approximately the intersection of antennas 26 and 27, matrix 207 is energized so that power is fed into 3-db power divider 197. To this end, a path is established in matrix 207 from transmitter 206 through circulators 224, 223, 221 and the right-hand output port of circulator 207 by activating all of the circulators in the rows containing circulators 224, 223 and 217 so that energy is transmitted clockwise and energizing all of the circulators in the row containing circulator 211 so that energy propagates counterclockwise. In response to the establishment of the aforementioned path under the control of the output of matrix 231, circulators 170—185 are energized

by the output of the decoder so that the odd numbered of them couple energy in the counterclockwise direction, while the even numbered ones of circulators 170—185 transfer energy in the clockwise direction. Thereby, power fed into 3-db divider 197 is applied to the right input ports of fixed circulators 156 and 157 through circulators 176 and 177. In response to the energy transmitted through circulators 156 and 157 horns 26 and 27 are in phase excited with energy of the same amplitude to step the beam position from the intersection of horns 27 and 28 to the intersection of horns 26 and 27.

Because horn 27 remains excited and the phase and amplitude of the energy applied thereto does not change even through the beam position changes, the crossover level in switching the beam position is minimized. Thereby, the phase angle of the beam derived from array 14 relative to axis 12 of reflector 11 undergoes a relatively smooth transition. In contrast, if the array were activated so that all of the elements previously excited were deactivated, the crossover level would be relatively high in switching between the different beams forming the primary pattern illuminating reflector 11.

From the foregoing description, it is believed obvious as to the manner in which the position of the primary beam is translated so that a plurality of horns is always simultaneously excited with in phase equal amplitude energy. In switching, the beam is always translated so that one of the horns previously excited remains excited. While excitation for a beam derived from a pair of horns has been described, it is to be understood that the principles are applicable, with lower crossovers, if more than two feed elements or radiators are simultaneously excited. If more than two adjacent feed elements are simultaneously excited, the criterion that one of the previously excited feed elements must remain excited after the beam pattern has been switched is maintained.

Horn elements 20—35 are selectively connected to receiver 231 through matrix 232 that is substantially identical with matrix 207 but has the circulators thereof reversed. The excitation of the circulators in array 232 is in response to binary signals derived from decoder matrix 233 which is driven by a four-bit command word. Simultaneously with the derivation of a control signal from decoder matrix 233, the matrix generates a trigger pulse utilized for activating the latching circulators 240—255 in the same manner that circulators 170—185 are energized. Circulators 240—255 selectively connect the left ports of fixed circulators 150—165 with the inputs of hybrids 270—285. Hybrids 270—285 function in approximately the same manner as power dividers 190—204, but instead of feeding energy from a switching matrix, the hybrids couple power from the horns into switching matrix 232. In response to the binary signals applied to the latching circulators in matrix 232, a path is provided through the matrix from only one of the hybrids to receiver 231. Simultaneously, a pair of paths is established through an adjacent pair of circulators 240—258 to an adjacent pair of fixed circulators whereby a pair of adjacent feeds 20—35 in array 14 is simultaneously excited with in phase energy of the same amplitude. To scan the beam, switching between the feeds is such that one of them remains excited while a feed adjacent thereto is deactivated simultaneously with the excitation of the other adjacent feed.

To obviate the requirement for mechanically rotating the linear array 14 comprising feed elements 20—35, the planar array of FIG. 6 may be effectively located in the best fit focal plane of reflector 11. While the planar array obviates the requirement of mechanically rotating the linear array about the reflector boresight axis, it has the disadvantage of occupying a considerably larger space than is required by the linear array. The array disclosed in FIG. 6 is exemplified as a 3×3 planar array including feed or radiator elements 301—309, and for purposes of simplicity is shown only in the receive mode. It is to be understood, however, that the array can be excited in both the receive and transmit modes and that a plurality of transmitters and/or receivers can be employed by utilizing the switching techniques described supra in conjunction with FIGS. 4 and 5.

In the planar array of FIG. 6, four adjacent ones of the nine elements are simultaneously excited with equal amplitude and in phase energy. Excitation of the four elements always occurs at approximately the corners of a square whereby the apparent phase center of the energy derived from the four elements is at the geometric center between the four excited elements, assuming equal separation between the centers of each of the radiation elements.

In FIG. 6, the nine radiating elements 301—309 are arranged in three columns, each having three rows, and are preferably horn antennas, as in the previously discussed embodiments. The sides of adjacent ones of the horns abut and are approximately of equal length so that the same distance exists between each of the adjacent radiating elements. The diagram of FIG. 6 is schematic and for purposes of simplicity it does not show the abutting relationship of horns 301—309.

The excitation network driving horns 301—309 includes ten hybrid networks, which effectively function as power dividers, as well as 13 single-pole, double-throw switches. The hybrids and switches are connected with each other so that four different beams can be derived, with the first beam having a phase center defined by the intersection of feed elements 301, 302, 304 and 305; the second beam having a phase center at the intersection of feed elements 302, 303, 305 and 306; the third beam having a phase center at the intersection of elements 304, 305, 307 and 308; and the fourth beam having a phase center at the intersection of elements 305, 306, 308 and 309.

To establish the connections for beam one, having a phase center at the intersection of feed elements 301, 302, 304 and 305, the outputs of these four radiator elements are connected via single-pole, double-throw switches 311—315 and hybrids 316—318 to terminal 319. In particular, switches, 311 and 312 connect radiator elements 301 and 304 to a pair of arms in hybrid 317, having an additional arm connected to a matching resistor and still a further arm connected to one arm of hybrid 318. Another arm of hybrid 318 is connected via switch 315 to a first arm of hybrid 316, the latter hybrid having a second pair of arms which are connected to switches 313 and 314. The remaining arm of hybrid 316 is connected to a matching resistor. The transmission paths between terminal 319 and feed elements 301, 302, 304 and 305 are identical and have the same insertion loss, whereby each of radiator elements 301, 302, 304 and 305 is excited with in phase energy having the same amplitude.

Beam two, derived at terminal 320, is formed by activating switch 315 so that the arm of hybrid 316 formerly connected to one of the arms of hybrid 318 is, instead, connected to an arm of hybrid 322. The arm of hybrid 322 opposite from the arm connected to switch 315 is connected via single-pole, double-throw switch 323 and hybrid 324 to single-pole, double-throw switches 325 and 325 which respectively are connected to feed elements 303 and 306.

Beam three, formed by combining the in phase and equal amplitude energy fed to radiators 304, 305, 307 and 308, is derived at terminal 331 in response to energy fed to hybrid 332. The arms of hybrid 332 are connected to hybrids 333 and 334, with the latter connection being via single-pole, double-throw R.F. switch 335. Hybrid 333 is selectively connected to radiators 304 and 307 via a pair of opposed output arms thereof through single-pole, double-throw switches 312 and 336, respectively. Hybrid 334 couples energy selectively to terminal 331 from elements 305 and 308 via single-pole, double-throw switches 313 and 337.

Beam four, derived at terminal 342, is formed by activating single-pole, double-throw switch 335 so that it is connected with one arm of hybrid 341. The arm of hybrid 341 opposite to that connected to switch 335 is connected to radiator elements 306 and 309 via single-pole, double-throw switch 343, which in turn is connected to hybrid 344, having opposed arms connected to single-pole, double-throw switches 326 and 345. The latter switches are connected for exciting elements 306 and 309.

In scanning the beam derived from the array comprising elements 301—309 in either of the two orthogonal axes along which the elements lie to prevent minimum crossover, two of the radiator elements remain activated during the stepping operation. For example, assume that beam one is derived and that it is desired to translate the beam position in the horizontal direction so that beam two becomes activated. With beam one excited, single-pole, double-throw switches 311, 312, 313, 314 and 315 are in the position illustrated, whereby elements 301, 302, 304 and 305 are excited. To scan the beam so that it is translated from a phase center intersecting elements 301, 302, 304 and 305 to the position of beam two having a center at the intersection of elements 302, 303, 305 and 306, switch 315 is activated so that the armature thereof is connected to one arm of hybrid 322 and the remaining switches in the array do not change position. Thereby, elements 302 and 305 remain excited and are supplied with energy having the same phase and amplitude as was previously fed thereto, as are elements 303 and 306. Elements 301 and 304, however, are decoupled from elements 302 and 305 and do not contribute to the formation of the beam now being derived from elements 302 and 305.

If, now, it should be desired vertically to shift the beam from a phase center at the intersection of elements 302, 303, 305 and 306 to a radiation center defined by the intersection of elements 305, 306, 308 and 309, switches 313, 326 and 335 are activated so that they engage the open-circuited terminals illustrated in FIG. 6. Thereby, radiation is still derived from elements 305 and 306, to the exclusion of elements 302 and 303; however, feed elements 308 and 309 are now excited simultaneously with elements 305 and 306 with energy of in phase and equal amplitude characteristics.

In a similar manner, the phase center can be shifted from beam four, defined by the intersection of elements 305, 306, 308 and 309 to a phase center coincident with the intersection of elements 304, 305, 307 and 308, whereby the elements 305 and 308 remain excited during the energy transfer to minimize crossover.

While there have been described and illustrated several specific embodiments of the invention, it will be clear that variations in the details of the embodiments specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims. For example, the horn feeds can be replaced by spirals to derive circularly polarized energy. To reverse the polarization of the energy derived from the spirals, it is merely necessary to reverse the phase of the energy applied thereto. In addition, to apply the principle illustrated in FIG. 6 for use with a plurality of transmitters and/or receivers, fixed circulator frequency selective switches can be connected between the switching networks and radiating elements as illustrated in FIG. 4.

We claim:

1. A system for controlling the position of a secondary radiation beam derived by reflection from a parabolic reflector having a bore sight axis comprising an array including several radiating elements arranged in the best fit focal plane of the reflector, means for simultaneously in phase exciting a plurality of adjacent ones of said elements so that the axis of the pattern is substantially at the center of the excited elements, said exciting means including means for maintaining said plurality of elements excited in phase throughout the interval while the pattern axis is at the center of the excited elements, said plurality being less than said several, said exciting means including switch means for selectively switching the excitation of different ones of said several elements to translate the pattern axis to a plurality of positions.

2. The system of claim 1 wherein said exciting means includes N-terminals, one for each of the pattern positions, N-power dividers, each of said dividers equally coupling power between a different one of said N-terminals and a plurality of ports, and means for connecting the plurality of ports of each divider in power-coupling relationship to adjacent ones of said

elements, said switching means including means for connecting a load or source to each of said N-terminals.

3. The system of claim 1 wherein the elements are arranged in a single direction.

4. The system of claim 3 further including means for mechanically scanning said array about the center of the elements and on the boresight axis of a reflector forming the secondary beam.

5. The system of claim 3 wherein the switching means includes means for energizing only a pair of said elements simultaneously.

6. The system of claim 1 wherein each of said elements comprises a horn, said horns having increasing tapers as the separation thereof from the boresight axis of a reflector forming the secondary beam increases.

7. The system of claim 6 wherein said horns have increasing tapers along and at right angles to a longitudinal axis of the array.

8. The system of claim 6 wherein said horns have increasing tapers along a longitudinal axis of the array.

9. A system for controlling the position of a secondary radiation beam derived by reflection from a parabolic reflector having a boresight axis comprising an array including several radiating elements arranged to illuminate the reflector, means for simultaneously in phase exciting a plurality of adjacent ones of said elements so that the axis of the pattern is substantially at the center of the excited elements, said exciting means including means for maintaining said plurality of elements excited in phase throughout the interval while the pattern axis is at the center of the excited elements, said plurality being less than said several, said exciting means including switch means for selectively switching the excitation of different ones of said several elements to translate the pattern axis to a plurality of positions, said exciting means including several circulators, a different one of said circulators coupling energy with a different one of each of said elements via a first port of the circulator, each of said circulators including a plurality of other ports in energy exchange relationship with the respective elements via the first port, first and second networks, each of said networks including N-terminals, one for each of the pattern positions, N-power dividers, each of said dividers equally coupling power between a different one of said N-terminals and a plurality of ports; means for connecting the plurality of ports of each divider of the first network in power-coupling relationship to one of the other ports of adjacent ones of said circulators, means for connecting the plurality of ports of each divider of the second network in power-coupling relationship to another of the other ports of adjacent ones of said circulators, said switching means including a first switching matrix for coupling power between a load and each of the N-terminals of the first network and a second switching matrix for coupling power between a source and each of the N-terminals of the second network.

10. The system of claim 9 wherein said first matrix includes means for coupling power between a plurality of loads and each of the N-terminals of the first network, and said second matrix includes means for coupling power between a plurality of sources and each of the N-terminals of the second network.

11. The system of claim 9 wherein said first matrix includes means for coupling power between a plurality of loads and each of the N-terminals of the first network.

12. The system of claim 9 wherein said second matrix includes means for coupling power between a plurality of sources and each of the N-terminals of the second network.

13. The system of claim 9 wherein each of said matrices includes a plurality of ordered single-pole, double-throw switches, different orders of said switches being connected in series to provide a unique path to each of said terminals from the source and load.

14. The system of claim 9 wherein each of said second connecting means includes a single-pole, double-throw switch between a pair of said power dividers and one port of circulators coupling energy to adjacent pairs of said elements.

15. The system of claim 9 wherein the elements are arranged in a pair of directions at right angles to each other, and said means for exciting includes means for simultaneously exciting said elements in both said directions.

16. The system of claim 15 wherein said elements are approximately equispaced in N-columns of M-rows, where N and M are integers.

17. The system of claim 13 wherein said switches are frequency selective for coupling different frequencies between different ones of said sources and loads with said circulator ports.

18. The system of claim 13 wherein said switches are phase selective for coupling different phases between different ones of said sources and loads with said circulator ports.

19. The system of claim 9 wherein said first matrix includes means for coupling power between a plurality of loads and each of the N-terminals of the first network simultaneously with said second matrix coupling power between a plurality of sources and each of the N-terminals of the second network.

20. A system for electrically scanning a secondary radiation beam derived by reflection from a parabolic reflector having a boresight axis comprising an array including several radiating elements arranged in the best fit focal plane of the reflector, means for simultaneously in phase exciting a plurality of adjacent ones of said elements so that the axis of the pattern is substantially at the center of the excited elements, said exciting means including means for maintaining said plurality of elements excited in phase throughout the interval while the pattern axis is at the center of the excited elements, said exciting means including means for translating the pattern axis, said translating means including switch means for switching the excitation of said elements so that at least one element of said plurality remains excited while at least another element of said plurality is deactivated and at least one previously deactivated element is excited, said at least one previously deactivated element being adjacent to an element remaining excited.

21. The system of claim 20 wherein the elements are arranged in a single direction.

22. The system of claim 21 further including means for mechanically scanning said array about the center of the arranged elements and on the boresight axis of a reflector forming the secondary beam.

23. The system of claim 21 wherein the switching means includes means for energizing only a pair of said elements simultaneously.

24. The system of claim 20 wherein each of said elements comprise a horn, said horns having increasing tapers as the separation thereof from the boresight axis of a reflector forming the secondary beam increases.

25. The system of claim 24 wherein said horns have increasing tapers along and at right angles to a longitudinal axis of the array.

26. The system of claim 24 wherein said horns have increasing tapers along a longitudinal axis of the array.