TRACKING ANTENNA SYSTEM

Filed May 1, 1969 3 Sheets-Sheet 3

FIG.5

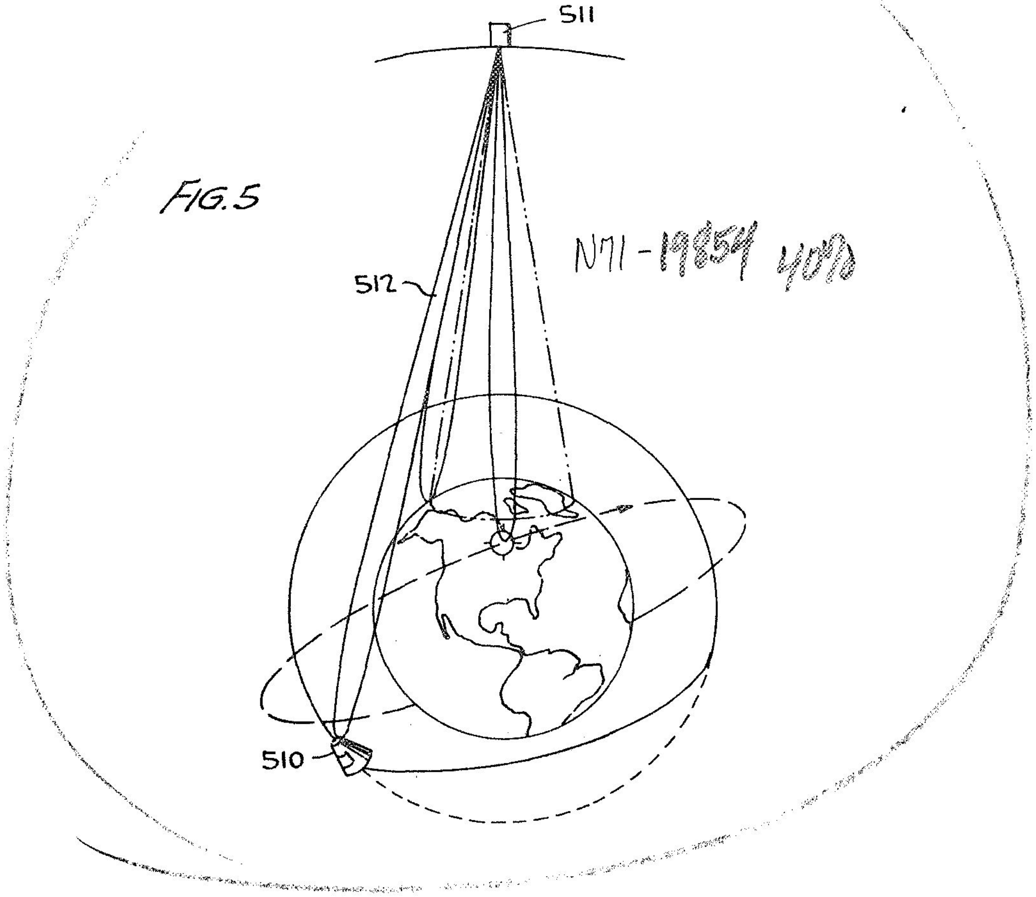
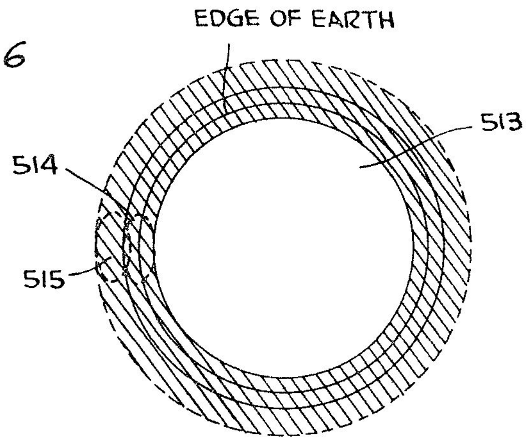


FIG.6



INVENTORS,
WILLIAM KORVIN
MILTON K. MILLS
BY
ATTORNEYS

1152

FIG. 1

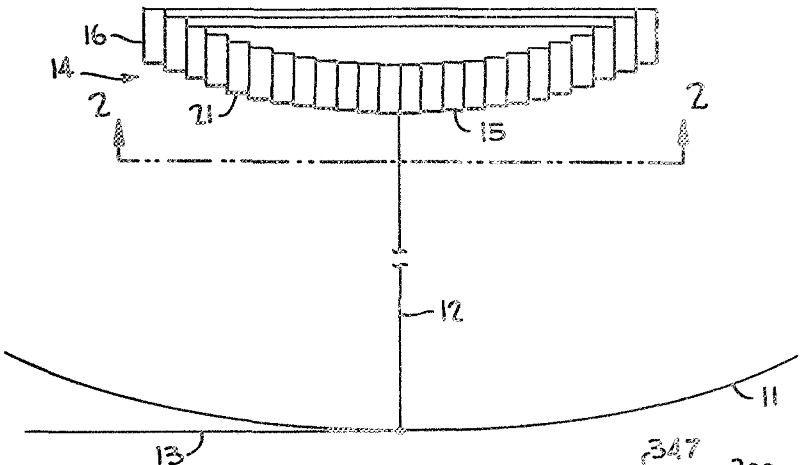


FIG. 2

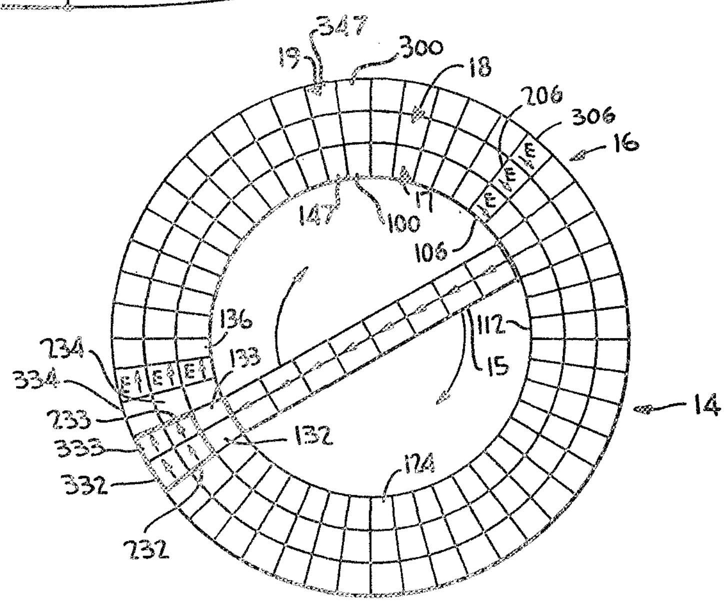
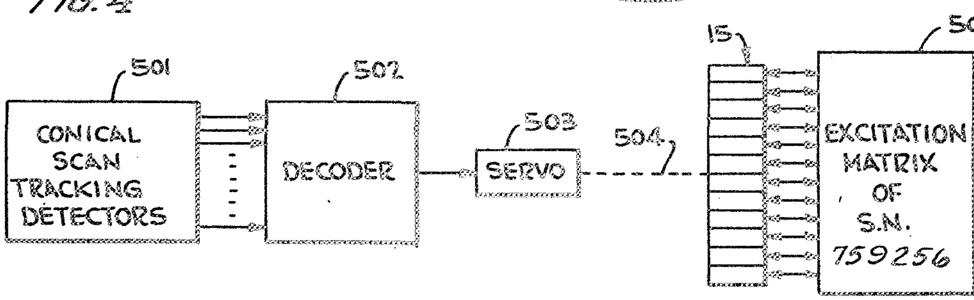


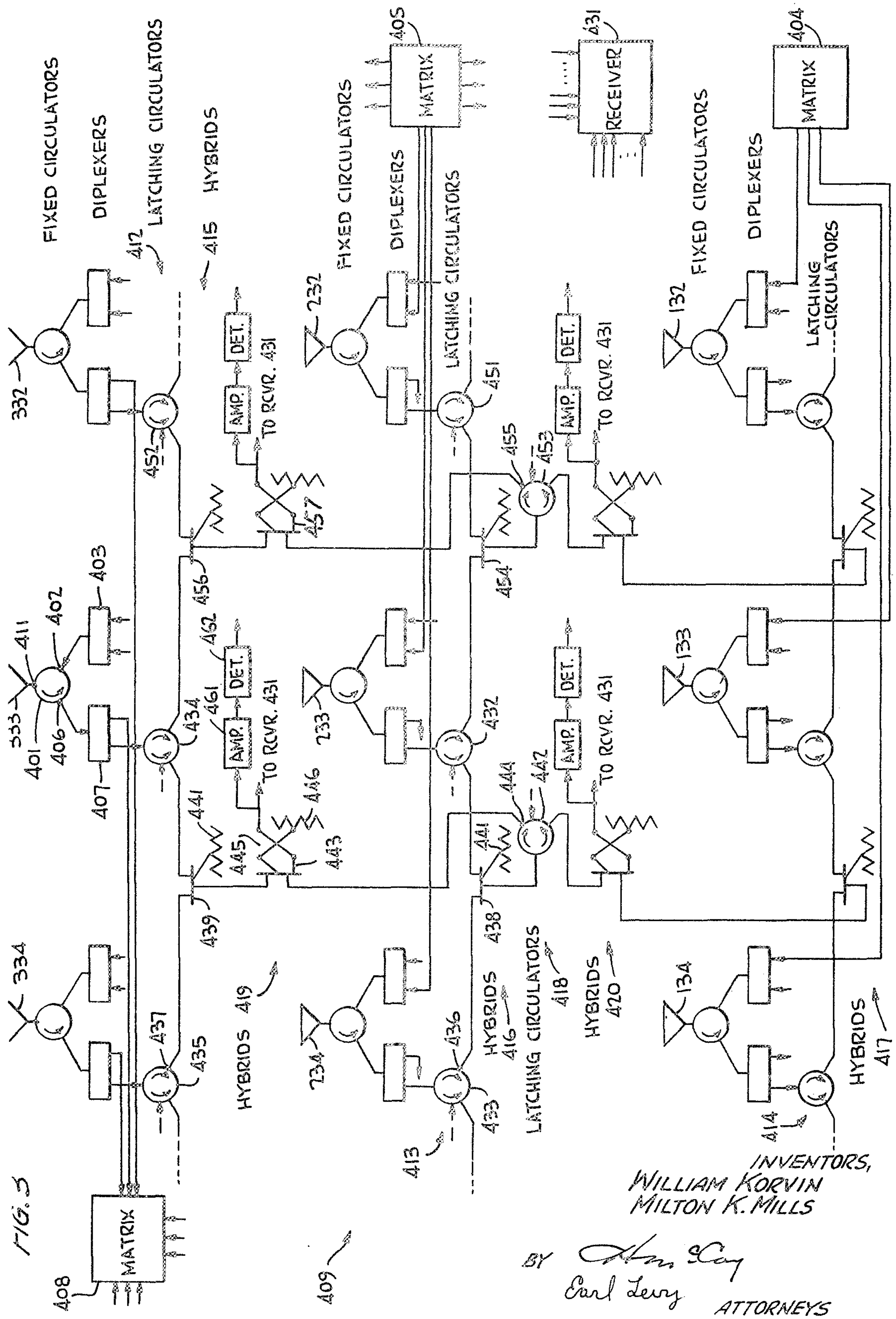
FIG. 4



INVENTORS,
WILLIAM KORVIN
MILTON K. MILLS

BY Carl Levy

ATTORNEYS



INVENTORS,
WILLIAM KORVIN
MILTON K. MILLS
BY
Earl Levy
ATTORNEYS

United States Patent Office 3,534,365
Patented Oct. 13, 1970

3,534,365

TRACKING ANTENNA SYSTEM

William Korvin, Odenton, Md., and Milton K. Mills, Falls Church, Va., assignors to the United States of America as represented by the Administrator of the National Aeronautics and Space Administration

Filed May 1, 1969, Ser. No. 820,963
Int. Cl. H01q 3/26
U.S. Cl. 343—100 19 Claims

ABSTRACT OF THE DISCLOSURE

Disclosed is a conically scanned antenna system comprising a multiplicity of wave guide feed elements arranged in an annular array for exciting a reflector system which generates a secondary radiation beam. The array includes elements extending radially, as well as circumferentially. An excitation network is provided whereby a plurality of elements is simultaneously excited. The beam is scanned both radially and circumferentially, by an excitation network including means for removing excitation from some of the elements while applying excitation to adjacent previously unexcited elements and elements which remain excited. In the center of the annular array, there is provided a separate array for tracking to the reflector boresight axis. The array can be mounted on a synchronous satellite or on a ground based radar.

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 scanned antenna arrays and more particularly to an electronically scanned antenna array including a multiplicity of elements arranged in an annulus.

One of the generally employed electronically scanned antenna systems is the so-called "phased array." In a phased array antenna, the antenna aperture comprises a multiplicity of radiating elements simultaneously excited with a relative phase determinant of the desired direction angle of propagation relative to an antenna system boresight axis. Because the excited elements occupy the entire aperture, phased array antennas include relatively massive electronic components that are heavy, complex and relatively inefficient. Inefficiency results from the attenuation properties of phase shifters which must be included in the phased array excitation network. The inclusion of phase shifters in the phased array excitation network also reduces bandwidth of the antenna because of the well known variation in phase that is introduced on different frequencies. The physical constraints on a phased array, relating to size and weight, are such that a high gain phased array antenna can be mounted on existing spacecraft with only a great deal of difficulty, if at all.

In our co-pending application, Ser. No. 759,256, filed Aug. 29, 1968, for Antenna Feed System and commonly assigned with the present application, there is disclosed an antenna system for avoiding many of the problems associated with prior art phased array antenna systems. In said application, there is disclosed an antenna system capable of simultaneously deriving a plurality of steerable radiation beams by including, in combination with a secondary beam forming reflector, a primary radiation source having several feed elements. To form a primary beam, a plurality of adjacent feed elements is simultaneously in phase excited to the inclusion of other feed elements through a switching matrix. To scan the beam, excitation is removed from one of the feed elements and another, previously unexcited element adjacent the previously excited elements, is excited by the switching matrix. Because the switching matrix includes only wide band devices, such as switches, circulators and hybrids, the frequency dependent problems encountered in phase arrays are obviated. Problems concerned with weight and complexity are decreased because the excited elements did not cover the entire aperture but form a primary radiation source for a reflector system that scans a secondary radiation beam.

The antenna system disclosed in our previously mentioned co-pending application is particularly adapted for tracking targets in the vicinity of an antenna boresight axis. While the principles disclosed in our other application are applicable to wide angle acquisition functions, as well as for tracking into an antenna system boresight axis, the array disclosed therein is generally limited by practical constraints to approximately ±12°, 3 db on axis beamwidth from the antenna boresight axis.

The present invention is an improvement on our previous invention, enabling a target to be acquired and tracked to angles within an annular region extending from approximately ±5° to ±15° from an antenna boresight axis. In combination with the system disclosed in our previous application, a target can be acquired at an off axis angle of ±12°, 3 db on axis beamwidth and tracked into the antenna boresight axis.

To attain the increased acquisition angle the present invention provides an annular array of substantially coplanar radiating elements for deriving a primary pattern broadside of the array, i.e., at right angles to the plane of the array. The feed elements are arranged in a plurality of rings having different radii and are circumferentially disposed about the array. To provide secondary beams having the highest gain, the primary radiating elements of the array are located in the focal surface of the reflector system. Thereby, the elements of the rings having different radii are stepped relative to each other, but each has a common center along the boresight axis of the reflector system.

To scan the secondary radiation pattern derived from a reflector system excited by the feed array of the present invention, energy is transferred or switched between elements of the primary radiation source. By sequentially switching the excitation between the various elements of the radiation source, the secondary radiation beam is conically scanned in an annular pattern enabling wide angle acquisition, as well as directional information, of a target to be derived. By determining the direction of a source with the acquisition array of the present invention, signals can be generated to control a centrally located tracking system of the type disclosed in our previously mentioned co-pending application, enabling tracking of a target into the antenna system boresight axis. For targets located a great distance from the annular array of the present invention tracking is not generally feasible into the antenna system boresight axis because of the relative null along the axis. The annuli radii cannot be extended into the antenna system boresight axis because of physical limitations on the positioning and dimensions of the primary radiators. Hence, for long range tracking into the boresight axis of an antenna system an array of the type disclosed in our previously mentioned co-pending application is located centrally of the annular array of the present invention and both derive broadside primary radiation beams for exciting a common reflector system that derives a secondary beam illuminating an area having a relatively wide angle.

In accordance with one preferred embodiment of the present invention, the primary radiation feed elements are abutting rectangular waveguides or horns excited with linearly polarized energy such that the E field generated by each element extends circumferentially, while the H field extends radially. A plurality of radiating elements are simultaneously, in phase excited to derive a primary beam for exciting the reflector system that generates the secondary beam. To switch the secondary radiation beam with a low crossover level between adjacent beams so that the beam position appears to be smoothly transferred, the switching matrix is activated so that energy is removed from only some of the excited elements while excitation is applied to previously unexcited elements adjacent the elements which remain excited. The position of the secondary radiation pattern can be translated both radially and circumferentially by controlling the excitation of the primary radiation elements between the several rings and about the circumference of the rings.

One application of the present invention involves monitoring the position of low orbiting spacecraft. In such an application, an antenna array in accordance with the present invention is mounted on a synchronous satellite to scan an annular region about the periphery of the earth. In another application, the trajectory of a rocket can be tracked with a ground station radar.

In either of these applications, there is a possibility of jamming to prevent acquisition in a predetermined portion of the area illuminated by the antenna array. Jamming, or other noise, generally subsists only over a relatively small percentage of the entire region which the array of the present invention is capable of covering. In accordance with a feature of the invention, a noise or jamming signal in a relatively small region can be eliminated from the response of a receiver connected to the array by changing a connection to the receiver without affecting the remainder of the excitation network or array.

Another feature of the invention is that the array and excitation network are wide band and constructed so that a number of diverse frequencies can be simultaneously transmitted and received. This result is achieved by utilizing wide band components having the same relative phase shift on each frequency component so that the feed elements are in phase excited at the same frequency.

It is, accordingly, an object of the present invention to provide a new and improved antenna array, particularly adapted for acquisition and tracking purposes.

Another object of the present invention is to provide a new and improved wide band antenna array for electronically generating a conically scanned beam.

Another object of the invention is to provide a new and improved electronically scanned antenna array having a relatively small number of components so that it is lightweight and not particularly complex and has high efficiency, thereby being susceptible to use on spacecraft.

Another object of the present invention is to provide a system for tracking targets with an antenna having the ability to acquire and locate the direction angle of the target over a wide angle and into an antenna boresight axis.

Another object of the present invention is to provide a new and improved radiation array for deriving a conically scanned radiation pattern with an electronic switching network.

Still another object of the invention is to provide a tracking antenna system including an array of radiator elements wherein a selected segment of the area normally covered by the radiation beam produced by the elements can be blocked at will so that noise and other interference in a relatively small area are not fed into a receiver.

A further object of the invention is to provide a new and improved wide band antenna array capable of deriving a plurality of conically scanned radiation patterns simultaneously at diverse frequencies.

The above and still further objects, features and advantages of the present invention will become apparent

upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a side sectional view of one embodiment of the feed of the present invention in combination with a reflector system for deriving a secondary radiation pattern;

FIG. 2 is a plan view of the feed illustrated in FIG. 1;

FIG. 3 is a circuit diagram of the excitation network for driving the feed array of FIGS. 1 and 2;

FIG. 4 is a block diagram of a system adapted to utilize the feed illustrated in FIGS. 1 and 2;

FIG. 5 is a perspective view of the earth and a satellite carrying the feed of the present invention; and

FIG. 6 is a top view of the earth illustrating the manner by which the annular feed of the present invention provides coverage for areas extending beyond the surface of the earth.

Reference is now made specifically to FIG. 1 wherein there is illustrated a side sectional view of parabolic reflector **11**, described as a surface of revolution about boresight axis **12** and having an apex located at the intersection of axes **12** and **13**, the latter being at right angles with the former. Positioned in the focal surface of parabolic reflector **11** is primary feed array **14**, including linear array **15**, preferably including a plurality of abutting horn feed elements as described in our aforementioned copending application, and annular array **16**. Array **16** is concentric with array **15**, each having a center coincident with the boresight axis **12** of parabolic reflector **11** and positioned to direct energy broadside toward the reflector.

Array **16** includes three annuli **17–19**, each coaxial with boresight axis **12**, but having a different radius from the boresight axis. The position of rings **17–19** from axis **13** of reflector **11** increases for rings having greater radii in such a manner that each ring is substantially coincident with a parabolic focal surface **21** for reflector **11**. Similarly, the elements of array **15** are displaced from axis **13** so that they lie along parabolic focal surface **21**, as described in detail in the aforementioned copending application. By positioning the feed elements of arrays **15** and **16** so that they lie along parabolic focal surface **21** the secondary beam reflected from reflector **11** has relatively low amplitude side lobes compared to the amplitude of the main lobe. While FIG. 1 illustrates the primary radiation source, feed **14**, as being positioned in front of parabolic reflector **11**, it is understood that the primary radiation pattern forming array can be replaced with a subreflector excited by an array positioned in the vicinity of the apex of reflector **11**, in accordance with the well-known Cassegrain assembly.

As specifically illustrated in FIG. 2, each of rings **17–19** includes a multiplicity of abutting horns or waveguides having substantially rectangular feed apertures, each of which subtends an arc of the same length about boresight axis **12**. In the specifically illustrated array, each ring includes **48** horns or waveguide elements, with the elements of the innermost ring **17** being **100–147**, the elements of the intermediate ring **18** being **200–247** and the elements of the outermost ring **19** being **300–347**. Each of the elements in array **16** is excited to the TE_{10} mode, with the E plane being directed circumferentially of the array, as indicated by the arrows in feed elements **132, 133, 232, 233, 332, 333, 106, 206** and **306**.

The radial dimension of each of the elements is long enough to support a half wavelength of the H field of the frequency driving the array while the circumferential dimension is preferably a fraction of a half wavelength of this frequency. By selecting the circumferential dimension of each array as a fraction of a half wavelength, a smooth transition in switching between elements can be achieved by simultaneously exciting a sufficient number of elements. To provide a secondary radiation beam having a narrow illumination field at any instant so that accurate position tracking can be attained, the total number of elements simultaneously excited is a relatively small percentage of the total angular coverage of the array. In the specifically illustrated embodiment, a pair of circumferential elements in each of two annuli is simultaneously excited so that the total number of simultaneously excited elements is four. It is to be understood, however, that for smoother transitions and lower amplitude crossover amplitudes between adjacent secondary beams, the number of elements simultaneously excited can be increased as desired.

To switch the position of the beam, in either a circumferential or radial direction, first and second adjacent, previously excited elements are deactivated, third and fourth elements remain excited, while fifth and sixth elements, adjacent the third and fourth elements, are energized with the same phase as the third and fourth elements. For example, in the array of FIG. 2, feed elements **232, 233, 332** and **333** are in phase excited so that a beam having a phase center at the intersection point of these elements is generated. To scan the beam circumferentially in the clockwise direction, elements **232** and **332** are deactivated, elements **234** and **334** are switched to an excited state and elements **233** and **333** remain in an excited state. As the primary beam phase center is switched about the periphery of ring **18** in response to switching between the circumferentially disposed elements an annular, conically scanned secondary radiation pattern is generated by reflector system **11**. At distances quite remote from the antenna, there is a substantial void region in the annular secondary radiation pattern. To switch the beam radially toward boresight axis **12**, excitation is removed from elements **332** and **333**, elements **132** and **133** are switched to an excited state and no change in the excitation of elements **232** and **233** occurs so that elements **132, 133, 232** and **233** are in phase excited. By switching the radiation phase center inwardly from the intersection of rings **18** and **19** to the intersection of rings **17** and **18** the void region in the annular radiation pattern is reduced, as is the outer coverage angle. At both radial positions, however, there is sometimes a sufficient null in the center of the annular secondary pattern to prevent tracking of a target to boresight axis **12**.

To enable a target to be acquired and tracked over an extremely wide angle and into boresight axis **12** of parabolic reflector **11**, linear array **15** is mounted interiorly of the inner radius of ring **17**, with which it is coaxial. To provide tracking into boresight axis **12** along any radial, linear array **15** is rotated in response to the outputs of the elements of annular array **16** to align the linear array waveguide elements with the elements of ring **17** which indicate the angular position of a tracked target. To enable linear array **15** to illuminate a region having substantially the same arc as that illuminated by the simultaneously excited elements of annular array **16**, each of elements **15** has an H plane aperture dimension approximately equal to the boundary between opposite radial edges of the excited region of array **16**. For example, in FIG. 2, the H plane aperture dimension of each of the elements in linear array **15** equals the sum of the sides of feeds **132** and **133** in the E plane direction of the latter horns. It is noted by reference to our previously mentioned application that the E fields of elements **15** extend radially along the array, so that they are orthogonal to the E fields of annular array **16**. Therefore, it is preferable to employ the tracking system of the present invention in combination with targets including a transponder capable of transmitting and receiving circularly polarized electromagnetic waves.

Reference is now made to FIG. 3 of the drawings wherein there is illustrated a circuit diagram of the network for exciting the annular feed array of FIGS. 1 and 2. In the circuit diagram of FIG. 3, only that portion of an excitation matrix for exciting feed elements **132–134, 232–234** and **332–334** with a receive frequency feeding receiver **431** is specifically illustrated, with the remainder of the circuitry being designated by phantom lines. Each of the feed elements of FIG. 3 is excited by a pair of different frequencies in the receive mode and a still further pair of diverse frequencies in the transmit mode. The four different frequencies exciting the feed elements of FIG. 3 can energize each of the feeds simultaneously because of the frequency multiplexing arrangement provided. To simplify the circuit of FIG. 3, the excitation matrix **409** for only one frequency, in the receive mode, is specifically illustrated, with the matrices for both transmit frequencies and the other receive frequency being shown by boxes **404, 405** and **408**. Excitation matrix **408** for the other receive frequency is the same as that specifically illustrated, while the identical transmit excitation matrices **404** and **405** differ from receive matrix **409** only insofar as is required to enable energy to propagate to, rather than from, the feeds.

Considering now the excitation network shown in FIG. 3, each of the elements is excited through a fixed circulator **401**, having an input port **402** responsive to the outputs of frequency multiplexer or diplexer **403** which is in turn driven by two different transmit frequencies generated by matrices **404** and **405**. Fixed circulator **401** includes an output terminal **406** for driving frequency multiplexer **407**, which in turn feeds diverse frequencies to receive matrices **408** and **409**. Fixed circulator **401** includes an additional port **411** for coupling energy from port **402** to the feed element and for coupling energy from the feed element to the circulator output port **406**.

Consideration is now given to the specific apparatus included wthin matrix **409**. In the drawing, matrix **409** is arranged to include three rows **412, 413** and **414** of latching circulators, each driven by an output of a different one of frequency multiplexers **407**. Adjacent output ports of adjacent circulators in each of rows **412–414** are connected to input ports of hybrids connected in three separate rows **415–417**. The sum output ports of the hybrids in row **416** are connected to input ports of latching circulators in an additional row **418**. The latching circulators in row **418** selectively couple energy into input ports of hybrids in rows **419** and **420**. The hybrids of row **419** are also responsive to energy fed to output ports of hybrids in row **415**, while the hybrids of a further row **420** are responsive to energy at the output ports of hybrids in row **417**. The connections to the hybrids in rows **419** and **420** are such that the energy derived from one port of each hybrid is equal to the sum of the energies transduced by the four feeds connected to the hybrid so that the four feeds are in phase excited. The other output port of each hybrid of rows **419** and **420** derives an output equal to the sum of the energies from an adjacent pair of circumferential elements in either rings **18** or **19** minus the sum of the energy from a second pair of adjacent circumferential feed elements in either rings **17** or **18**. One of the output ports of each of the hybrids in rows **419** and **420** is connected to receiver **431**, in a manner described infra, so that the receiver can track signals in the pattern generated by array **16**.

The latching circulators in rows **412, 413, 414** and **418** are responsive to bipolarity voltages to control the direction of energy flow from the circulator input terminal to one or the other of the circulator output terminals. If a zero level voltage is applied to the latching circulators, they remain in their present state. If a positive level voltage is applied to the latching circulators, they assume a specific direction of energy circulation. If a negative level voltage is applied to the latching circulators, they reverse the direction of energy circulation. The bipolarity signals are applied to the latching circulators in such a manner as to enable four adjacent feed elements to be simultaneously activated. To switch the phase center of the energy transmitted from the annular array, a different set of control voltages is applied to the latching circulators of rows 412, 413, 414 and 418 to transfer the excitation pattern as described supra.

Consideration will now be given to the specific circuitry connecting receiver 431 to feed elements 233, 234, 333 and 334. As indicated supra, each of feed elements 233, 234, 333 and 334 is connected through a different fixed circulator 401 and frequency multiplexer 407 to a different latching circulator. In particular, feed elements 233, 234, 333 and 334 drive the input ports of latching circulators 432, 433, 434 and 435, respectively. Energy derived from the right output ports 436 and 437 of latching circulators 433 and 435 is applied to input ports of hybrids 438 and 439, respectively, while the left-hand output ports of circulators 432 and 434 are connected to additional input ports of hybrids 438 and 439. The difference output ports of hybrids 438 and 439 are connected to different matching load resistors 441, while the sum output terminals of hybrids 438 and 439 are respectively applied to the input port of latching circulator 442 in row 418 and an input terminal of hybrid 443 in row 419.

Output terminal 444 of latching circulator 442 is connected to the other input port of hybrid 443, the sum output port of which drives receiver 431 through reversing switch 445. The difference output port of hybrid 443 is connected through reversing switch 445 to matching load resistor 446. In normal operation, reversing switch 445 is connected in the position indicated. If, however, it is desired to decouple the beam associated with feeds 233, 234, 333 and 334 from receiver 431 because noise due, for example to jamming or other interference, is extant in the region illuminated by the pattern resulting from excitation of the feeds, reversing switch 445 is activated so that the difference output port of hybrid 443 is connected to receiver 431 and the sum output port drives load resistor 446. Thereby, a null output is derived from the receiver 431 with reversing switch 445 activated to the opposite position from that illustrated.

Because of the similarity between the feed elements and receivers for the remainder of the system, no detailed description of the connections for the remaining circuit elements is provided.

To consider the operation of the matrix illustrated by FIG. 3, assume initially that latching circulators 432 and 434 are activated to transfer energy in the counterclockwise direction while circulators 433, 435 and 442 are energized to transfer energy in the clockwise direction. Under these conditions, feeds 233, 234, 333 and 334 are connected to be in phase excited by receiver 431, whereby the phase center of radiation derived by the feeds is at the geometric center of the feeds, approximately coincident with the common intersection point thereof. Energy is coupled from feeds 333 and 334 to receiver 431 via the counterclockwise and clockwise propagation paths of latching circulators 434 and 435, respectively. The left and right output ports of latching circulators 434 and 435 feed energy into hybrid 439, which drives one input of hybrid 443 with the sum of the energies transduced by elements 333 and 334. The other input to hybrid 443 is responsive to output port 444 of circulator 442, which is in turn responsive to the sum of the energies transduced by elements 233 and 234, as coupled through the counterclockwise and clockwise propagation paths of latching circulators 432 and 433 to hybrid 438. The energy from latching circulator 442 is summed with the energy at the output port of hybrid 439 and coupled to receiver 431.

To scan the radiation beam of annular array 16 in the counterclockwise direction so that the pattern phase center is transferred from the intersection point of feed elements 233, 234, 333 and 334 to the intersection point of feeds 232, 233, 332 and 333, latching circulators 432 and 453 are activated to propagate energy in the clockwise direction and latching circulators 451 and 452, responsive to energy transduced by feed elements 232 and 332, are activated to propagate energy in the counterclockwise direction. Latching circulator 453 is responsive to the sum of the energy transduced by feeds 232 and 233, as coupled from the right and left output ports of latching circulators 432 and 451 through hybrid 454. The energy at output terminal 455 of latching circulator 453 is summed with the energies transduced by feeds 333 and 332, as coupled through latching circulators 434 and 452 to hybrid 456 which in turn drives an input of hybrid 457.

From the foregoing description, it is believed evident as to the manner by which the phase center of the radiation derived from rings 18 and 19 of array 16 is stepped between adjacent beam positions with a relatively low amplitude cross-over determined by the circumferential spacing of the elements in the rings. To shift the phase center radially of array 16 from the intersection of annuli 18 and 19 to the intersection of rings 17 and 18, the latching circulators of row 414 are activated to propagate energy in either the clockwise or counterclockwise direction. In adidtion, the circulators of row 418 are selectively activated to enable energy to be propagated in the counterclockwise direction from the output ports of the hybrids in row 416 to the hybrids in row 420.

For certain applications relating to tracking a target which feeds energy of the frequency coupled to the left-hand output port of frequency multiplexers 407 into matrix 409, the terminal of each reversing switch 445 connected to receiver 431 is connected through an isolation network 461, which may be a unilaterally conducting amplifier to detecting network 462. In response to the input signal to detector 462 exceeding a predetermined level for a certain time period, the detector derives a binary output signal indicating that a target is in the region illuminated by the excited radiators of array 16. Thereby, an indication of the location of a target can be ascertained from the conically scanned beam derived from array 16.

To enable the position indicating information derived from detectors 462 to be utilized in combination with the boresight axis illuminating array 15, the system of FIG. 4 is provided. In the system of FIG. 4, the output of conically scanned tracking detectors 462, one of which is provided for each of the circumferential positions of the array 16, is represented by network 501. The circumferential poistion indicating binary signals derived from network 501 are fed to decoder 502 which derives an analog signal indicative of the angular position of a source illuminating the annular array 16 of FIGS. 1 and 2. The analog output of decoder 502 is fed to servo network 503, having a mechanical shaft output 504 for rotating array 15 about boresight axis 12 of parabolic reflector 11. Array 15 is rotated in response to the output of network 501 so that it is positioned along a radial coincident with the radial path of a target being tracked by the conically scanned radiation pattern generated by array 16.

Once a target has been tracked to the inner radius of fixedly positioned array 16, linear array 15 tracks it into the antenna system boresight axis 12. The elements of linear array 15 are excited by matrix 505, of the type described in our copending application previously mentioned, which also controls the position of the linear array. While a linear array is specifically illustrated for illuminating the region within the annular radiation beam pattern of array 16, it is to be understood that a planar array can also be utilized, as disclosed in the copending previously mentioned application.

One application of the present invention, relating to monitoring the position of low orbiting spacecraft 510, is illustrated in FIGS. 5 and 6. In FIG. 5, a synchronous satellite 511 is positioned in space above a fixed subsatellite point on earth, as is achieved by causing the satellite to rotate at the same velocity as the earth at an altitude of approximately 23,000 miles. On synchronous satellite **511** there is mounted an array and excitation network, of the type illustrated by FIGS. 1–3. The annular array **16** of FIGS. 1 and 2 conically scans the earth to provide an annular illumination pattern **512**, extending from approximately ±5 to ±12.5 degrees from the antenna system boresight axis, which is usually coincident with the local vertical of the synchronous satellite. To enable a region **513** within the core of the annulus **512** to be illuminated, linear array **15**, or its planar equivalent, is provided. To track objects very close to the surface of the earth, or objects moving into proximity with the inner illumination boundary of annulus **512**, annuli **17** and **18** are activated to the exclusion of annulus **19** to generate a secondary radiation beam **514**. For objects at a higher altitude from the earth's surface and displaced from the satellite local vertical by more than approximately ±9 degrees, annuli **18** and **19** are excited to the exclusion of annulus **17** to derive secondary beam **515**. By utilizing the present invention, therefore, a relatively wide portion of the earth can be illuminated and the shadow zone of the antenna system of satellite **511** is confined only to that portion of the earth which is blocked and cannot be in line of sight communication.

For certain applications, there is no need to include a central array in combination with the annular array of FIGS. 1 and 2. Typical examples of such applications are relatively short range radar tracking systems wherein there is sufficient energy down the boresight axis of the reflector system from the inner ring **17** of the annular array to enable a target, such as a missile, to be accurately tracked. The position of a close target tracked on the boresight can be often ascertained with sufficient accuracy by conically scanning the inner pattern of array **16**. As the target moves away from the antenna system boresight axis the annular array is activated so that exterior pattern is excited.

While there has been described and illustrated one specific embodiment of the invention, it will be clear that variations in the details of the embodiment 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, if it is desired to transmit and/or receive more than two different frequencies simultaneously, the frequency multiplexers, illustrated as diplexers in FIG. 3, can be replaced with triplexers, quadriplexers, etc. Also, the feed elements can be excited with circularly polarized energy, rather than linear, with an accompanying increase in crossover level because only one element can be excited at a time.

We claim:

1. An array for generating a primary radiation beam pattern for illuminating a reflector system that derives a secondary radiation beam, said system having a boresight axis, comprising several radiating elements arranged in a plurality of annuli, each of said annuli having a different radius and a common axis coincident with said boresight axis, each of said annuli including a multiplicity of circumferentially disposed ones of said elements, and means for exciting only a selected number of said elements at the same time for deriving a primary radiation beam from combinations of the selected number of said elements.

2. The system of claim **1** wherein said exciting means includes means for exciting and deactivating adjacent ones of said elements to enable a conically scanned secondary beam to be derived.

3. The system of claim **1** wherein said reflector system has an apex and a second axis transverse to said boresight axis and intersecting said apex, each of said annuli being displaced from said second axis by a different distance so that it lies in a focal surface of said reflector system.

4. The system of claim **1** wherein the secondary radiation pattern resulting from excitation of said annular array is annular in shape and further including a second array of radiating elements extending through the boresight axis and into proximity with the annuli having the shortest radius, said second array illuminating said reflector to derive an additional secondary beam pattern within the inner radius of the secondary beam pattern derived from the annular array.

5. The array of claim **1** further including a receiver responsive to said exciting means, and said exciting means includes means for at will decoupling said receiver from any of the selected number of said elements.

6. The array of claim **1** further including transmitter and receiver means, and said exciting means includes means for simultaneously coupling energy between said elements and both said transmitter and receiver means.

7. The array of claim **1** wherein said exciting means includes frequency multiplexing means for simultaneously exciting said elements with different frequencies.

8. An array for generating a primary radiation beam pattern for illuminating a reflector system that derives a secondary radiation beam, said system comprising several radiating elements arranged in a plurality of annuli, each of said annuli having a different radius and a common axis coincident with said boresight axis, each of said annuli including a multiplicity of circumferentially disposed ones of said elements, and means for selectively in phase exciting a plurality of adjacent ones of said elements simultaneously.

9. The system of claim **8** wherein said exciting means includes means for simultaneously in phase exciting a plurality of circumferentially adjacent ones of said elements with linearly polarized energy.

10. The system of claim **9** wherein said exciting means includes 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.

11. The system of claim **8** wherein at least three annuli are provided, and said exciting means includes means for simultaneously in phase exciting with linearly polarized energy a plurality of adjacent ones of said elements on different annuli, said plurality being less than the number of said annuli.

12. The system of claim **11** wherein said exciting means includes means for simultaneously in phase exciting a plurality of circumferentially adjacent ones of said elements with linearly polarized energy.

13. The system of claim **8** wherein at least three annuli are provided, and said exciting means includes means for simultaneously in phase exciting with linearly polarized energy a plurality of circumferentially adjacent ones of said elements and a plurality of adjacent ones of said elements on different annuli, said plurality being less than the number of said annuli.

14. The system of claim **13** wherein said exciting means includes means for circumferentially and radially 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.

15. A system for generating secondary radiation beams from a reflector comprising a first feed illuminating said reflector for deriving an annular secondary radiation pattern, and a second feed illuminating said reflector for deriving a second radiation pattern steerable within the inner radius of the annular pattern.

16. The system of claim **15** wherein said annular pattern is conically scanned.

17. The system of claim **15** further including means for controlling the position of the second pattern in response to a signal derived from the first feed.

18. A radiating feed array comprising several radiating waveguide elements arranged in a plurality of annuli, each of said annuli having a different radius and a common axis, each of said annuli including a multiplicity of circumferentially disposed ones of said elements, said elements being positioned to excite a radiation beam broadside of the annuli and in the general direction of said axis.

19. The array of claim 18 wherein the elements in each of said annuli are coplanar at right angles to the axis and the planes of the different annuli are stepped relative to each other in a direction extending along the axis.

References Cited

UNITED STATES PATENTS

2,852,772 9/1958 Gitzendanner ------- 343—100

RODNEY D. BENNETT, Primary Examiner

R. E. BERGER, Assistant Examiner

U.S. Cl. X.R.

343—777, 854