Dec. 6, 1966 J. S. AJIOKA 3,290,682

MULTIPLE BEAM FORMING ANTENNA APPARATUS

Filed Nov. 2, 1964 6 Sheets-Sheet 1

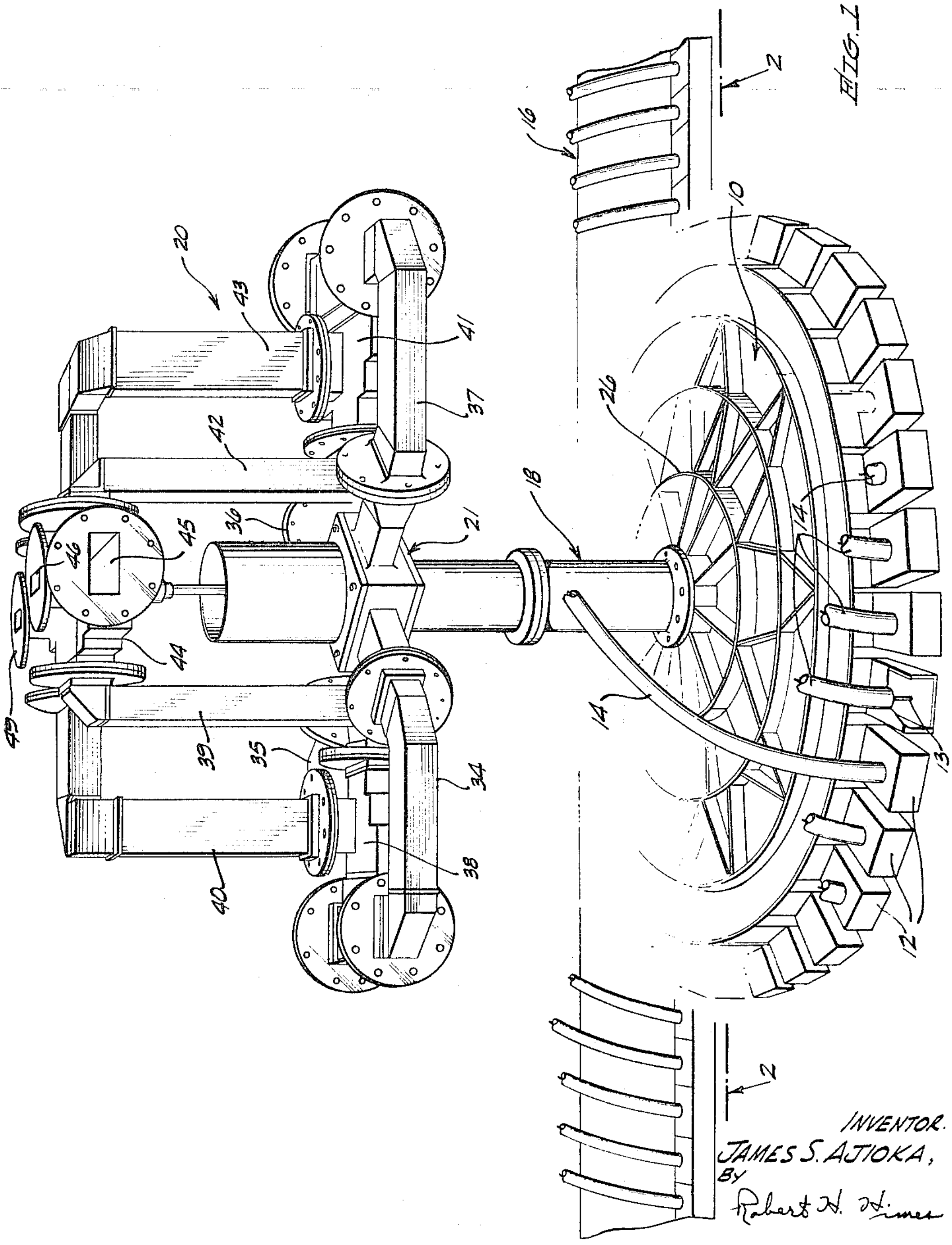

FIG. 1.

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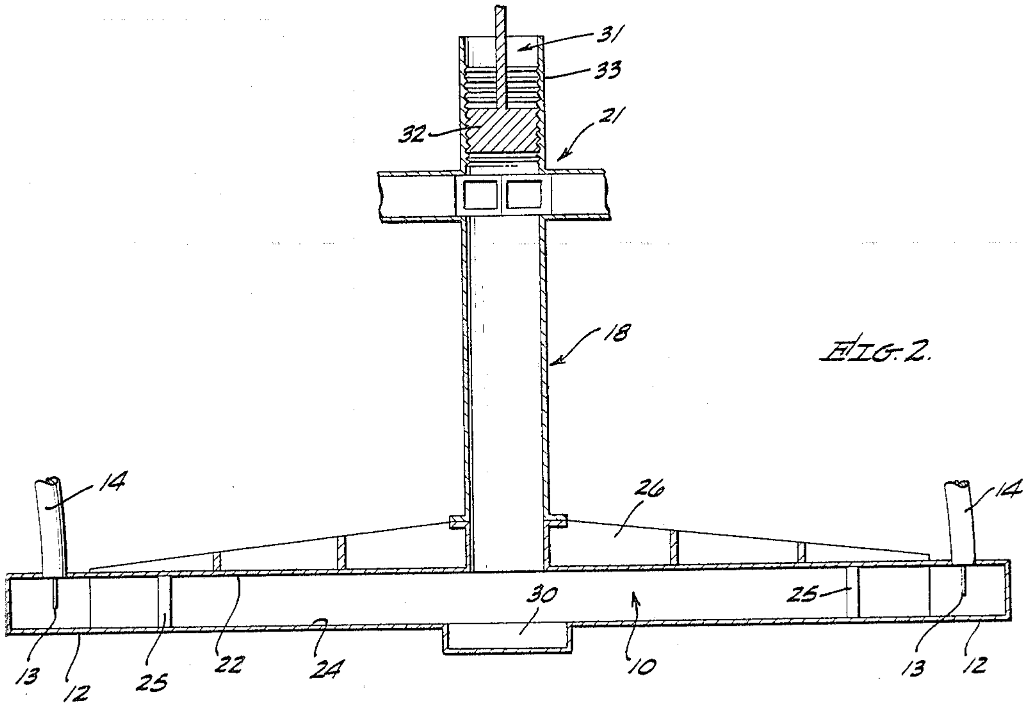

FIG. 2.

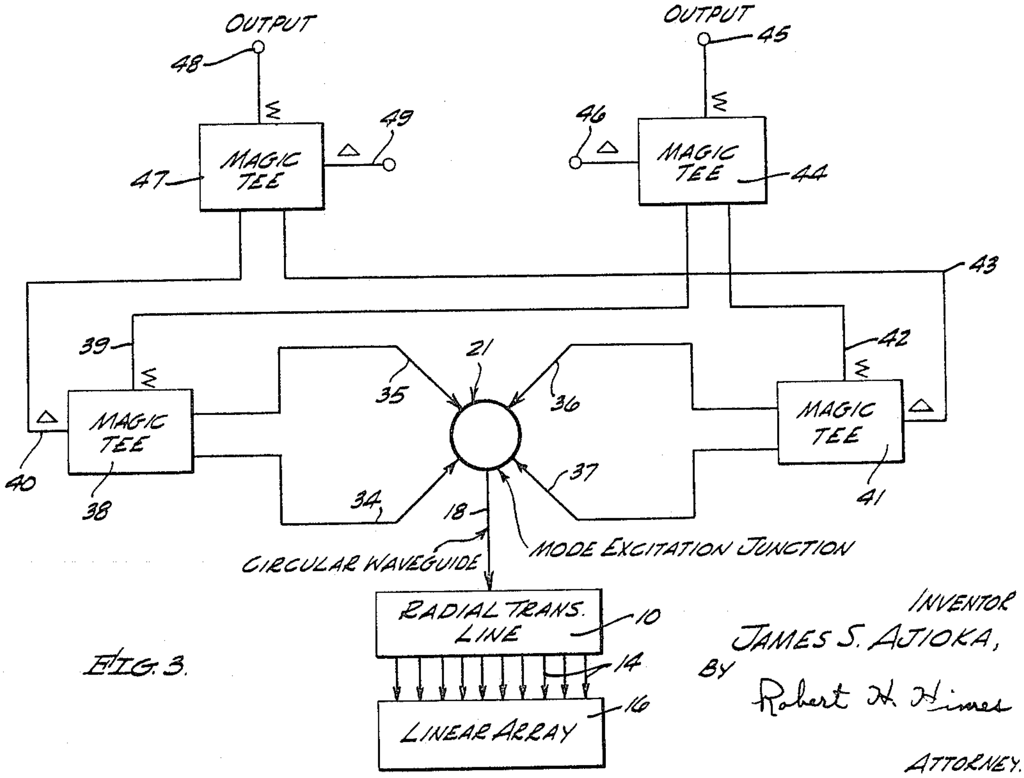

FIG. 3.

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MULTIPLE BEAM FORMING ANTENNA APPARATUS

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6 Sheets-Sheet 3

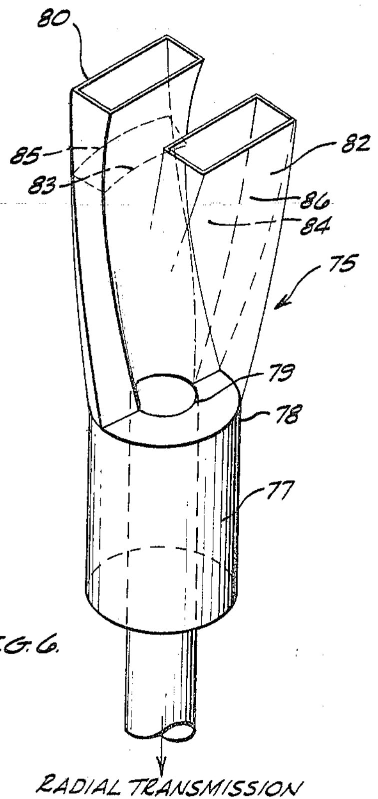

FIG. 6.

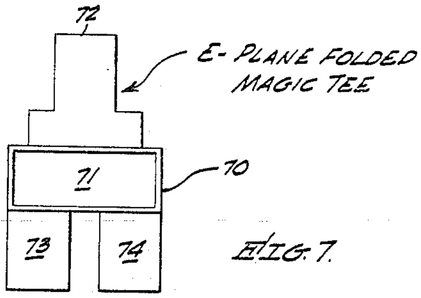

FIG. 7.

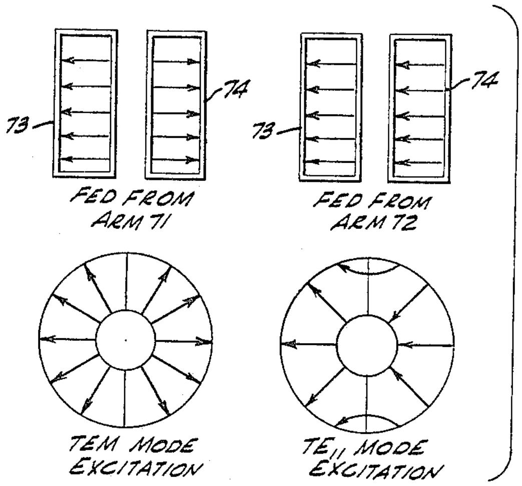

FIG. 8.

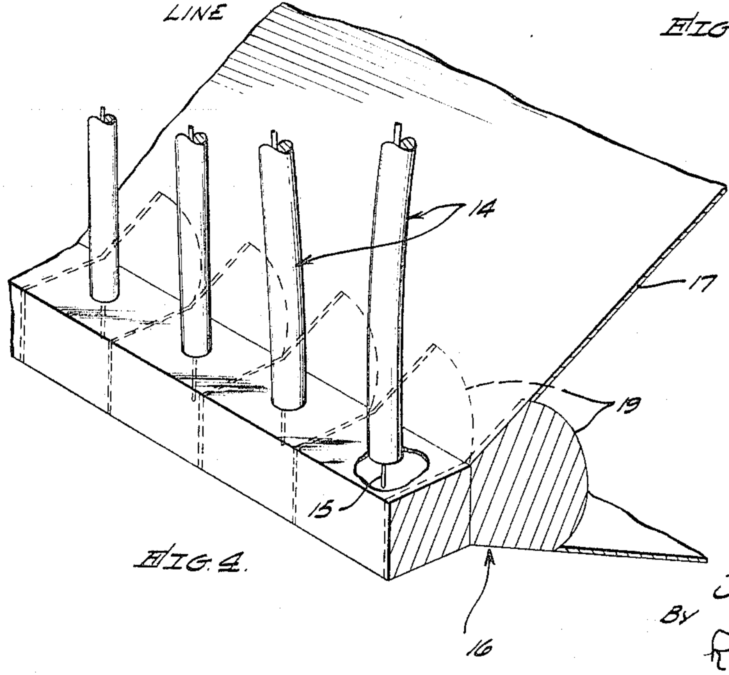

FIG. 4.

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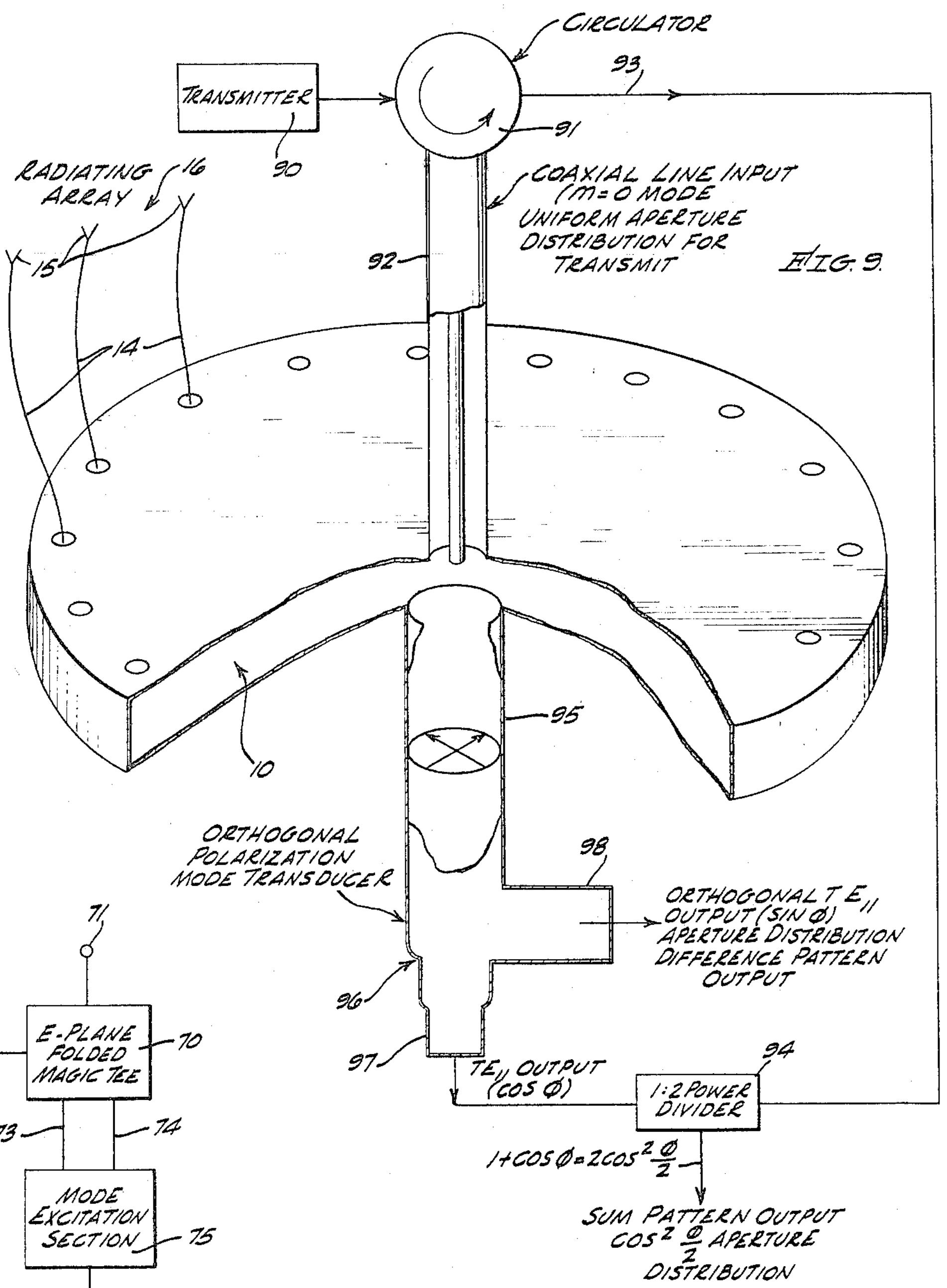

FIG. 9.

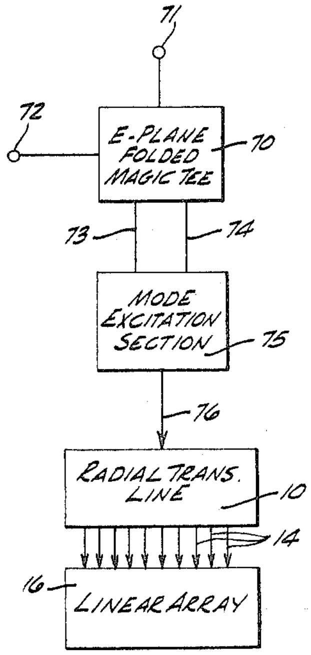

FIG. 5.

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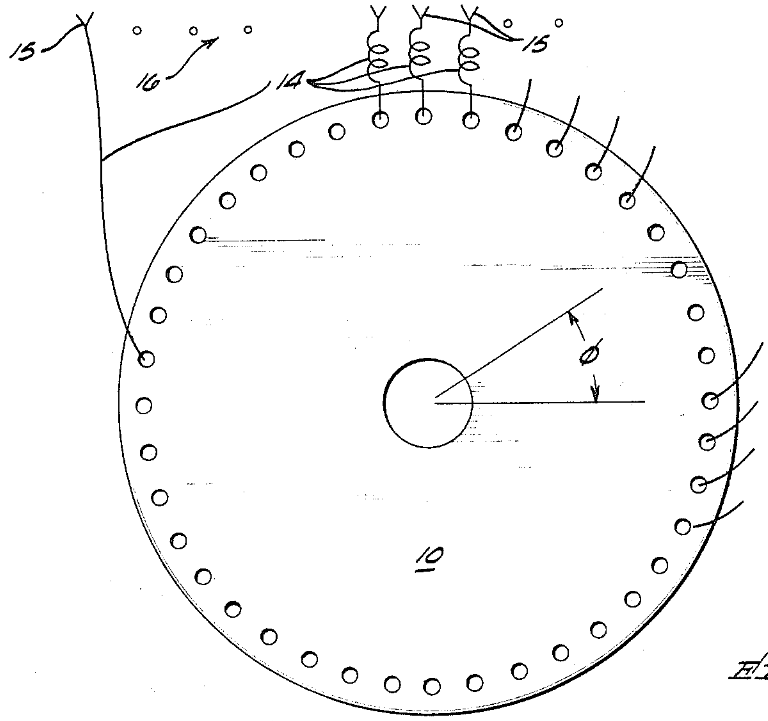

FIG. 11.

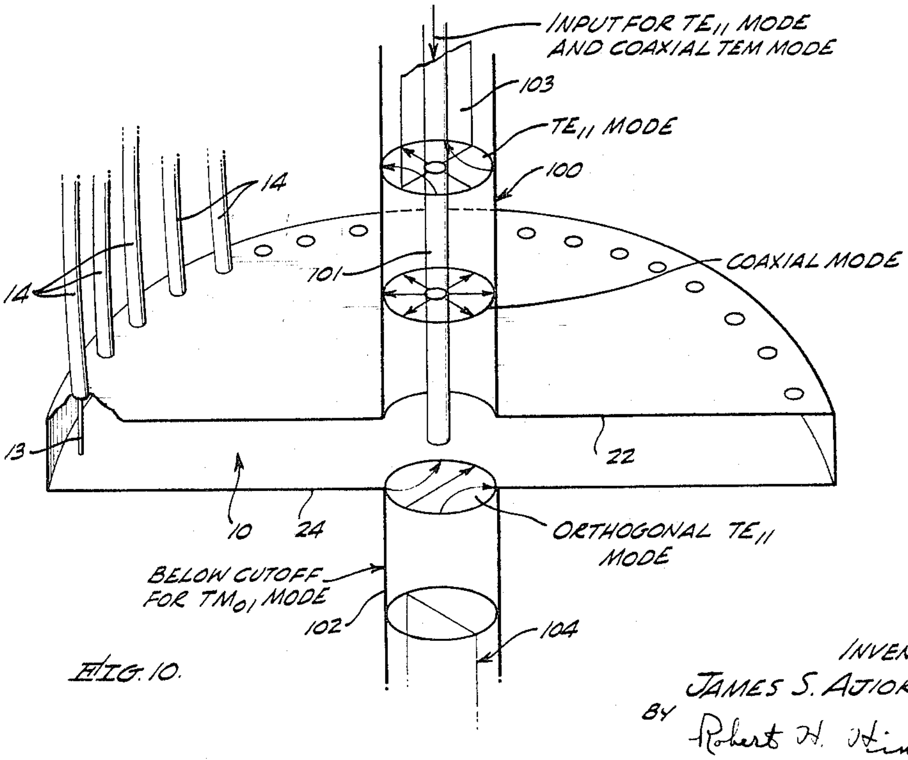

FIG. 10.

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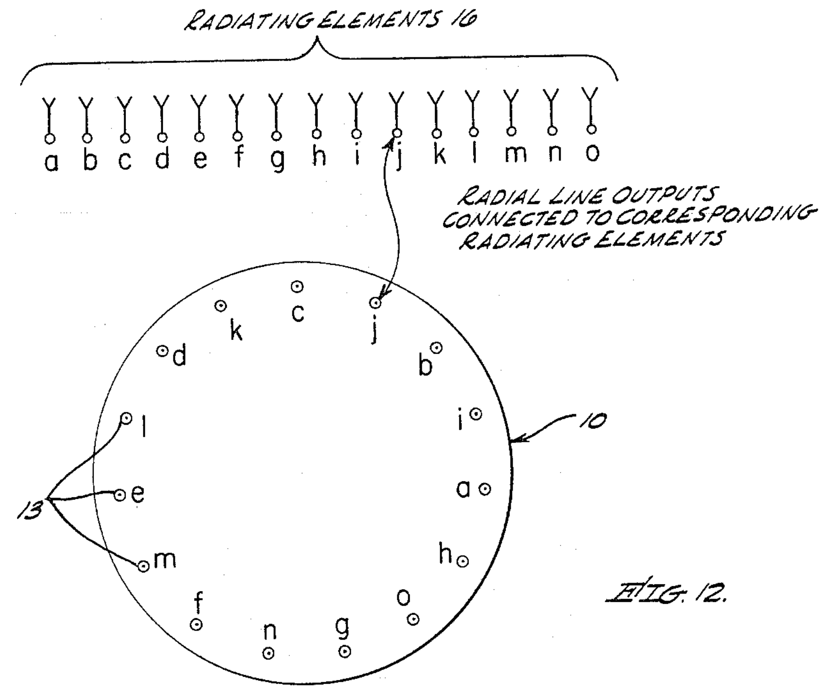

FIG. 12.

PHASE MULTIPLICATION BY TRAVERSING THE RADIAL LINE CIRCUMFERENCE MORE THAN ONCE

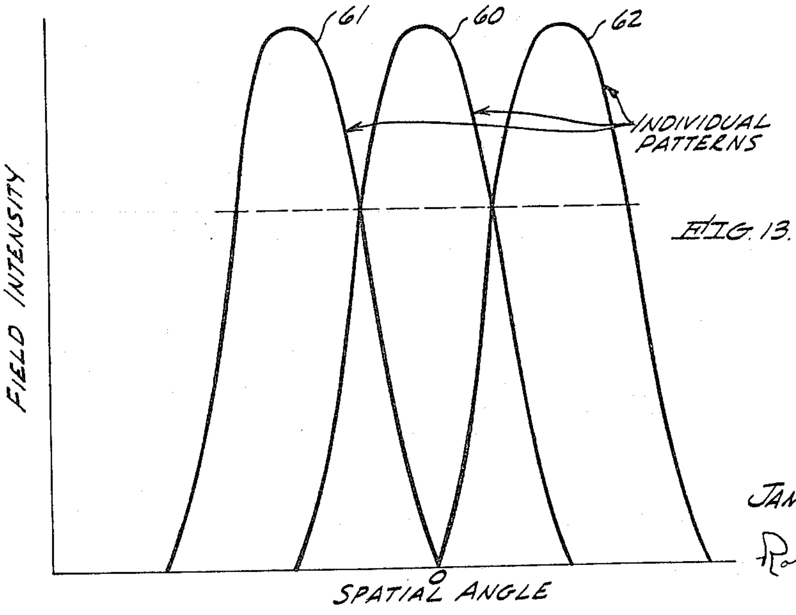

FIG. 13.

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United States Patent Office

3,290,682

Patented Dec. 6, 1966

3,290,682
MULTIPLE BEAM FORMING ANTENNA APPARATUS

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Filed Nov. 2, 1964, Ser. No. 408,205
8 Claims. (Cl. 343—100)

This invention relates to antenna apparatus for forming multiple beams and, more particularly, to an antenna system incorporating a multimode radial transmission line having a plurality of inputs each corresponding to beams having different spatial directions.

In order to achieve increased data rate in contemporary phased array radar systems, it is often desirable to have a number of simultaneous multiple beams that can be scanned as a cluster with monopulse capability for higher angular accuracy. In addition, it is often desirable to have a variety of antenna aperture distributions which may differ for transmit and receive. By way of example, it may be desirable to have a uniform aperture distribution on transmit to achieve the most economical use of power limited devices such as phase shifters or power amplifiers in an active array and, in addition, to achieve maximum antenna gain concomitant with a uniform aperture distribution. On the other hand, it is desirable to reduce clutter on receive which may be achieved by a low side lobe tapered aperture distribution.

Some contemporary simultaneous multiple beam forming devices designed to feed a linear array are the tilt transmission line fed traveling wave array, the Butler hybrid matrix, and the wide angle optical antennas. In general, these systems have a cost and complexity which increases rapidly with the number of radiating elements. In addition, the number of beams produced by a Butler hybrid matrix has a definite mathematical relationship to the number of radiating elements. In particular, the number of beams produced by a Butler matrix is equal to the number of radiating elements.

It is therefore an object of the present invention to provide an improved apparatus for forming multiple beams.

Another object of the present invention is to provide a comparatively inexpensive and ideally lossless multiple beam forming device, the cost and complexity of which does not increase rapidly with the number of radiating elements.

A further object of this invention is to provide a low loss multiple beam forming device capable of handling large amounts of power.

Still another object of the present invention is to provide a multiple beam forming device incorporating a multimode radial transmission line whereby the number of radiating elements can be increased arbitrarily with no extra complexity and at a cost that increases only linearly with the number of elements.

A still further object of the present invention is to provide a multiple beam forming device incorporating a multimode radial transmission line wherein the spatial separation of the beams may be determined by the number of times the circumference of the radial transmission line is traversed in connecting the probes therearound to a linear array.

In accordance with the present invention, a parallel plate radial transmission line is terminated at equally spaced points along its periphery by an array of "pick-up" probes which are, in turn, connected to the radiating elements of a linear array through equal lengths of transmission line. In connecting the transmission lines to the linear array, equally spaced pick-up probes are connected to successive radiating elements of the linear array. When the equally-spaced pick-up probes are adjacent to each other, the total number of probes may be odd or even. On the other hand, when the equally-spaced pick-up probes are not adjacent, the total number of probes must allow for an appropriate progression if it is desired to energize all the probes. In operation, the TEM mode, together with higher order circumferential modes, is excited in the radial line to generate beams having different directions in space.

The above-mentioned and other features and objects of this invention and the manner of obtaining them will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, wherein:

FIG. 1 shows a perspective view of one embodiment of the present invention;

FIG. 2 shows a partial cross-sectional view of section 2—2 of the device of FIG. 1;

FIG. 3 shows a schematic diagram of the apparatus of FIG. 1;

FIG. 4 shows a partially cutaway perspective view of a segment of the linear array in the apparatus of FIG. 1;

FIG. 5 shows a schematic diagram of an alternate embodiment of the present invention;

FIG. 6 shows a perspective view of the mode excitation device in the apparatus of FIG. 5;

FIG. 7 is an outline drawing identifying the ports of the E-plane folded magic tee in the apparatus of FIG. 5;

FIG. 8 shows electric field configurations in the mode excitation device of the apparatus of FIG. 6 corresponding to the input ports of the magic tee of FIG. 7;

FIG. 9 shows a partial cutaway perspective view of an additional embodiment of the present invention which illustrates schematically the manner in which a uniform aperture distribution on transmit, a tapered cosine squared (sum) aperture distribution on receive, and a monopulse sine (difference) aperture distribution on receive may be achieved.

FIG. 10 shows a cross-sectional view of an alternate method of exciting the radial transmission line in accordance with the present invention;

FIGS. 11 and 12 are schematic diagrams showing the connections from the "pick-up" probes around the circumference of the radial transmission line to the radiating elements of the linear array in the devices of FIGS. 1, 5 and 9; and

FIG. 13 shows field intensity radiation patterns corresponding to the $m=0$ and $m=\mp 1$ modes in the devices of FIGS. 1, 5 and 9.

Referring now to FIG. 1 of the drawings, there is shown an embodiment of the present invention which comprises a radial transmission line **10** surrounded by probe assemblies **12** including pick-up probes **13** which are connected through equal length coaxial transmission lines **14** to radiating elements **15**, FIG. 4, of a linear array **16** thereof. The linear array **16** of radiating elements **15** constitutes, for example, a trough **17** of relective material with conductive veins **19** disposed intermediate successive radiating elements **15**. Referring again to FIGS. 1, 2 and 3, the radial transmission line **10** is energized through a circular waveguide **18** which connects a feed system **20** thereto through a mode excitation device **21**.

Referring specifically to FIG. 2, there is shown a cross-section of Sec. 2—2 of the radial transmission line **10** together with the circular waveguide **18** and mode excitation device **21**. The radial transmission line **10** includes parallel conductive plates **22**, **24** which are maintained parallel by spacers **25** and rigid by stiffening veins **26**. The center conductors of transmission lines **14** are connected to the probes **13** of the probe assemblies **12**. Different methods of connecting the probes to the radiating elements **15** of linear array **16** will be hereinafter explained in connection with the description of FIGS. 11 and 12 of the drawings. The radial transmission line **10** includes a concentric cavity 30 extending outwardly therefrom directly opposite the connection of circular waveguide 18 thereto to facilitate coupling circular waveguide 18 to radial transmission line 10. The feed mechanism 20 is coupled to the radial transmission line 10 through circular waveguide 18 in an optimum manner by means of a tuning mechanism 31 which is disposed adjacent to the mode excitation device 21 on the side thereof opposite cylindrical waveguide 18. Tuning mechanism 31 includes a conductive member 32 which provides a conductive surface transversely across an internally threaded conductive cylinder 33 at an adjustable distance from the mode excitation device 21 thereby providing a tuning cavity.

The arrangement of the feed structure 20, FIG. 1, is illustrated in schematic form in FIG. 3. Referring to these figures, the feed structure 20 constitutes the mode excitation device 21 which has waveguide arms 34, 35, 36 and 37. The waveguide arms 34, 35 are connected to the inputs of magic tee 38 which has a sum (Σ) output 39 and a difference (Δ) output 40. Similarly, waveguide arms 36, 37 are connected to the inputs of a magic tee 41 which includes a Σ′-output 42 and a Δ-output 43. The Σ-outputs 39, 42 of magic tees 38, 41 are connected to the inputs of a magic tee 44 which has Σ-output 45 and Δ-output 46. Further, the Δ-outputs 40, 43 of magic tees 38, 41 are connected to the inputs of a magic tee 47 which has a Σ-output 48 and a Δ-output 49. The remaining reference numerals in the schematic of FIG. 3 designate the same elements as for the device of FIG. 1.

Referring to FIGS. 11 and 12, there is shown the manner in which the probes 13 of the probe assemblies 12 are connected through the equal length transmission lines 14 to the linear aray 16 of radiating elements 15. In particular, FIG. 11 shows a plan view of radial transmission line 10 with the probes 13 of the probe assembly 12 disposed about the outer periphery thereof. In particular, in proceeding along the array 16 of radiating elements 15 from left to right, as shown in the drawing, the elements 15 are connected to equally spaced probes 13 proceeding in a clockwise direction around the periphery of the radial transmission line 10 in a manner such that an integral number or fraction of a number of revolutions are made in proceeding across the entire length of the array 16; that is, if successive radiating elements 15 are connected to successive probes 13 of probe assemblies 12, then only one revolution will be made about radial transmission line 10. In proceeding along the entire length of the array 16, the transmission lines 14 are as previously specified, all of equal length. Referring to FIG. 12, there is shown the manner in which phase multiplication is achieved by traversing the circumference of the radial transmission line 10 more than once in progressing along the entire array 16 of successive radiating elements 15. In particular, terminals of the radiating elements 15 are designated *a, b, c* . . . *m, n, o* in proceeding from left to right along the length of the array, as viewed in the drawing, and corresponding terminals to the probes 13 about the circumference of the radial transmission line 10 are designated in a similar manner whereby terminals designated with a common letter, i.e., *a, b, c* . . . or *o*, are connected together with an equal length transmission line 14. In the schematic shown in FIG. 12, a phase multiplication of two is achieved by connecting successive radiating elements 15 to alternate probes 13 about the circumference of radial transmission line 10. In the event that it is desired to achieve a phase division, i.e., progress only a fraction of the way around the circumference of radial transmission line 10, it is either necessary to parallel certain of the probes 13 or, alternatively, to terminate the probes 13 not used.

In the operation of the device of FIG. 1, the number of modes that can be supported by circular waveguide 18 determines the number of beams that can be realized from the linear array 16. For the purpose of explanation, the diameter of circular waveguide 18 will be made sufficient

to simultaneously support the TM_{01} mode and to support the orthogonal TE_{11} modes. In that these modes are all orthogonal, there is no interaction between individual electric and magnetic fields within the circular waveguide 18. The electric field corresponding to the TM_{01} mode produces electric fields A_1, B_1, C_1 and D_1 in the waveguide arms 34, 35, 36 and 37, respectively, that are all of the same phase. When this is the case, the Σ-outputs 39, 42 of magic tees 38, 41 apply signals (A_1+B_1) and (C_1+D_1) to the inputs of magic tee 44 whereby an output

$$(A_1+B_1+C_1+D_1)$$

appears at the Σ-output 45 thereof with no signal appearing at Δ-output 46. Also, the signals appearing at the Δ-outputs 40, 43 of the magic tees 38, 41 are (A_1-B_1) and (C_1-D_1), respectively, which signals equal zero, whereby no signals are applied to the inputs of magic tee 47. This situation, where all signals A_1, B_1, C_1, D_1 are of the same phase, generates the $m=0$ mode in radial transmission line 10 which develops a beam 60, FIG. 13, that is normal to the linear array 16. The characteristics of the feed structure 20 together with the circular waveguide 18, radial transmission line 10 and linear array 16 are, of course, reciprocal, whereby it is possible to transmit or receive through the Σ-arm 45. In the event it is desired to transmit and receive, it is, of course, necessary to use duplexing apparatus in the conventional manner.

Considering now the orthogonal TE_{11} mode whereby signals A_2, B_2 of one polarity are excited in the arms 34, 35, respectively, and signals C_2, D_2 of opposite polarity are established in the input arms 36, 37, respectively. In this event, signals (A_2+B_2) and $-(C_2+D_2)$ appear at the Σ-arms 39, 42 of magic tees 38, 41 where they are applied to the inputs of magic tee 44. In that these signals are of opposite polarity, a zero amplitude signal now appears at Σ-arm 45 and a signal $(A_2+B_2+C_2+D_2)$ appears at Δ-arm 46. In that identical signals are applied to the inputs of magic tees 38, 41, zero amplitude signals appear at Δ-output arms 40, 43 thereof, whereby no output is generated at Σ-arm 48 and Δ-arm 49 of magic tee 47.

In the last situation, the remaining TE_{11} orthogonal mode energizes signals B_3, C_3 of one polarity in arms 35, 36 of mode excitation device 21 and signals A_3, D_3 of opposite polarity in input arms 34, 37. Thus, in this instance, signals of opposite polarity are applied to the inputs of magic tees 38, 41 whereby no signals appear at the Σ-outputs 38, 42 thereof. A signal represented by (A_3+B_3) does appear at the Δ-output arm 40 of magic tee 38, and signals $-(C_3+D_3)$ appears at Δ-output arm 43, which signals are applied to the inputs of magic tee 47. In that these signals are of opposite polarity, no signal appears at the Σ-output arm 48 and the signal $(A_3+B_3+C_3+D_3)$ appears at the Δ-output arm 49. These latter two cases correspond to the orthogonal TE_{11} modes in circular waveguide 18 which, in turn, develop the higher order circumferential modes $m=\pm 1$ in the radial transmission line 10. The $m=\pm 1$ modes in radial transmission line 10 correspond to beams 61, 62, FIG. 13, which are spatially displaced on either side of the beam 60 corresponding to the $m=0$ mode.

As explained above, the TM_{01} mode corresponds to $m=0$, and higher order circumferential modes corresponding to $m=\pm 1$ orthogonal modes are excited in the radial line 10. The circumferential variation of these modes are characterized by $A_m e^{\pm jm\phi}$ where A_m is the amplitude of the mth mode and m is an integer. Because of the orthogonality properties of the modes, they do not couple. In addition, by virtue of the equal length transmission lines 14 connected between the circumferentially dispersed pick-up probes 13 and the radiating elements 15 of the linear array 16, the circumferential phase variation $e^{\pm jm\phi}$ is transformed to a linear progressive phase $e^{\pm 2m\pi x/L}$, where L is the length of the array, and x is the aperture variable, i.e., $(\varphi=0)$ corresponds to $(x=0)$ and $(\varphi=2\pi)$ corresponds to $(x=L)$. Thus, there are two beams for each value of m (except $m=0$), one left and right. For $m=0$, there is a single beam at broadside, such as beam **60**, FIG. 13.

The aperture distribution for each of the beams is uniform and the far field pattern is given by:

$$E=\frac{\sin^{N\Psi/2}}{N^{\sin\Psi/2}}$$

where N is the number of elements in the array. The expresssion E applies to an odd number of elements (N), but similar arguments apply for even N.

$$\Psi=\frac{2\pi d}{\lambda}\sin\theta-\alpha$$

θ=angle of beam from broadside

$d=L/N-1$—inter-element spacing

$\alpha=\pm 2m\pi/N-1$=inter-element phase shift

$$(E)=\frac{\sin\left[\frac{2\pi N}{(N-1)}\left(\frac{L}{\lambda}\sin\theta\pm m\right)\right]}{N\sin\frac{2\pi}{N-1}\left(\frac{L}{\lambda}\sin\theta\pm m\right)}$$

The maxima of the pattern occur when the numerator and denominator are both zero.

$$\frac{2\pi N}{N-1}\left[\frac{L}{\lambda}\sin\theta_p\mp m\right]=(2p+1)\pi$$

where p indicates the pth sidelobe from the main beam.

$$\sin\theta_p=\left[\frac{\lambda}{L}P(N-1)\pm m\right]$$

The main beam corresponds to $p=0$.

The nulls of the pattern occur when the numerator is zero and the denominator is not zero.

$$\frac{2\pi N}{N-1}\left[\frac{L}{\lambda}\sin\theta+m\right]=2q\pi$$

where q indicates the qth null

$$\sin\theta_q=\frac{\lambda}{L}\left[q\frac{(N-1)}{N}+m\right]$$

Thus, in principle the multimode radial transmission line antenna feed results in multiple beams with uniform aperture distributions and far field patterns with all the side lobe maxima occurring at common angles and similarly for all the nulls. Since the peak of any main beam occurs at nulls for all other patterns, there is no coupling between beams.

Referring now to FIG. 5, there is shown a schematic diagram of an alternate system for energizing the TEM mode and the higher order circumferential mode in the radial transmission line **10**. In particular, an E-plane folded magic tee **70** having input arms **71** and **72** and output arms **73**, **74** is connected through a mode excitation section **75** which is, in turn, connected through a coaxial line **76** to the radial transmission line **10**. The probe assemblies **12** of radial transmission line **10** are connected as previously specified through equal length transmission lines **14** to the linear array **16**. Referring to FIG. 6, there is shown a partially cutaway perspective view of the mode excitation section **75**. This section **75** includes a segment **77** of coaxial line having dimensions suitable for connecting to the coaxial line **76** which leads to the radial transmission line **10**. The segment **77** includes an outer cylindrical conductor **78** and an inner coaxial cylindrical conductor **79**, both of which terminate at a common plane transverse to the axis of rotation thereof. Waveguide arms **80** and **82** having inner broad walls **83** and **84** and outer broad walls **85** and **86**, respectively, provide the transition from the waveguide to the coaxial line segment **77**. In particular, opposite halves of the cylindrical conductor **79** are separated and flattened to form the inner broad walls **83**, **84**, and corresponding halves of the outer cylindrical conductor are expanded and flattened to form the outer broad walls

85, **86** of the waveguide arms **80**, **82**, respectively. Lastly, narrow walls of the waveguide arms **80**, **82** commence as radial connections dividing the halves of the coaxial line segments **78**, **79** from whence they extend between the inner and outer broad walls **83**, **85** and **84**, **86**. This necessitates a twist of 90° for each narrow wall. The waveguide arms **80**, **82** are connected to the output arms **73**, **74**, respectively, of the E-plane folded magic tee **70**, FIG. 7, and the coaxial line **77** is connected to the coaxial line **76**. Referring to FIG. 8, energization of arm **72** of E-plane folded magic tee **70** generates electric fields that are in phase in output arms **73**, **74**. When applied to the mode excitation section **75**, the coaxial line **76** is energized with TE_{11} mode excitation. Alternatively, when arm **71** of E-plane folded magic tee is fed, electric fields of opposite polarity are generated in output arms **73**, **74**. When electric fields of opposite polarity are applied to the mode excitation section **75**, a TEM mode of propagation is generated in the coaxial line **76**. As in the case of the device of FIG. 1, TEM mode excitation of the radial transmission line **10** corresponds to the $m=0$ mode of operation, i.e. a broadside beam from the linear array **16**; and the orthogonal TE_{11} modes of excitation correspond to the $m=\pm 1$ mode of operation, i.e. spatially displaced beams on both sides of the broadside beam from the radial array **16**. As before, the extent to which the beams are displaced from the broadside beam is a function of the manner in which the equal length transmission lines **14** are connected from the radial transmission line **10** to the linear array **16**.

Referring now to FIG. 9 of the drawings, there is shown a system employing the device of the present invention for transmitting on a single beam corresponding to the $m=0$ mode of operation and for receiving on a cosine squared antenna aperture distribution. In particular, the output of a transmitter **90** is applied to the input of a circulator **91** which, in turn, is connected through a coaxial line **92** which is connected to the radial transmission line **10** in a manner to energize the TEM mode of excitation. The probes **13** disposed about the circumference of the radial transmission line **10** are connected over the equal length transmission lines **14** to the radiating elements **15** of linear array **16** in the same manner as for the device of FIG. 1. The remaining arm **93** of circulator **91** is connected to an input to a 1:2 power divider **94**. Further, a circular waveguide **95** is connected from a centrally disposed port on the bottom side of radial transimission line **10**, as viewed in the drawing, to an orthogonal mode transducer **96** which provides an output arm **97** for the TE_{11} mode and an output arm **98** for the orthogonal TE_{11} mode. The TE_{11} and orthogonal TE_{11} modes are orthogonal and, accordingly, can be designated as having cos φ and sin φ phase relations. The output arm **97** of orthogonal mode transducer **96** is connected to the remaining input of power divider **94**. The power divider **94** then provides an output which constitutes the sum of the signal appearing at arm **93** of circulator **91** and the cos φ output from arm **97** of orthogonal mode transducer **96** whereby the sum pattern output is equivalent to a $(1+\cos\theta)=2\cos^2\theta/2$ antenna aperture distribution. In operation, energy from transmitter **90** is directed directly to the radial transmission line **10** and the linear array **16** by the circulator **91**. Upon reception, however, the circulator **91** directs received energy out arm **93** whereby it is combined with energy appearing at arm **97** of orthogonal mode transducer **96** by the power divider **94** to provide the received signal having the cosine squared antenna aperture distribution.

Referring to FIG. 10, there is shown an alternate system for exciting the radial transmission line **10** with the coaxial TEM mode and orthogonal TE_{11} modes. In particular, a coaxial line **100** having a center conductor **101** is connected to a centrally disposed port in the upper conductive sheet **22** of radial transmission line **10** with the center conductor **101** extending into the parallel plate region but not through to the plane of the opposite side **24** thereof. A circular wave-guide **102** is connected to a centrally disposed port in side **24** of radial transmission line **10**. A septum **103** is disposed diametrically across the waveguide **100** and is oriented to be orthogonal to the E-field of the TE_{11} mode in coaxial line **100**. In operation, the coaxial line **100** is energized with the TEM coaxial mode and the TE_{11} mode with the electric field thereof normal to the plane of septum **103**. The circular waveguide **102** is simultaneously energized with the orthogonal TE_{11} mode with the electric field. It is apparent that the orthogonal TE_{11} mode energy cannot escape through the coaxial line **100** because of septum **103**, the TE_{11} mode energy cannot escape through the circular waveguide **102** because of septum **104**, and the TEM mode energy cannot escape through the circular waveguide **102** because there is no center conductor and the guide **102** is below cutoff for the TM_{01} mode. In other respects, the device of FIG. 10 operates in the same manner as described for the devices of FIGS. 1, 5 and 9.

Although the invention has been shown in connection with certain specific embodiments, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention. By way of example, it is apparent to those skilled in the art that the parallel plates **22**, **24** of radial transmission line **10** may be spherical, cylindrical or even folded. Also, the radial transmission line **10** may be excited by additional higher order circumferential modes. This excitation may be accomplished by the foregoing techniques or, alternatively, by the use of an array of input probes excited in the proper amplitude and phases (i.e., a circular or linear array).

I claim:

1. An antenna system for providing multiple beams, said antenna system comprising a radial transmission line; means for providing a plurality of equally spaced pick-up probes about the circumference of said raidal transmission line; a linear array of radiating elements; means for connecting successive adjacent radiating elements commencing from one extremity of said linear array through respective equal length transmission lines to successive uniformly spaced pick-up probes of said plurality of equally spaced probes disposed about the circumference of said radial transmission line; and means coupled to said radial transmission line for simultaneously exciting a fundamental mode and no less than one additional higher order circumferential mode therein thereby to provide a corresponding number of beams from said linear array, each of said beams having a unique direction in space.

2. An antenna system for providing multiple beams, said antenna system comprising a radial transmission line; means for providing a predetermined number of equally spaced pick-up probes about the circumference of said radial transmission line; a linear array of a number of radiating elements equal to said predetermined number; means for connecting adjacent radiating elements commencing from one extremity of said linear array through respective equal length transmission lines to successive adjacent pick-up probes of said predetermined number thereof; and means coupled to said radial transmission line for simultaneously exciting a TEM mode and no less than one additional higher order circumferential mode therein thereby to provide a corresponding number of beams from said linear array, each of said beams having a unique direction in space.

3. An antenna system for providing multiple beams, said antenna system comprising a radial transmission line; means for providing a predetermined number of equally spaced pick-up probes about the circumference of said radial transmission line; a linear array of a number of radiating elements equal to said predetermined number; means for connecting adjacent radiating elements commencing from one extremity of said linear array through respective equal length transmission lines to successive alternate pick-up probes of said predetermined number thereof; and means coupled to said radial transmission line for simultaneously exciting a TEM mode and no less than one additional higher order circumferential mode therein thereby to provide a corresponding number of beams from said linear array, each of said beams having a unique direction in space.

4. An antenna system for providing multiple beams, said antenna system comprising first and second spaced coextensive parallel conductive circular plates for providing a radial transmission line; means for providing a predetermined number of equally spaced pick-up probes between the parallel conductive circular plates about the circumference thereof; a linear array of radiating elements; means for connecting successive radiating elements commencing from one extremity of said linear array through respective equal length transmission lines to successive uniformly spaced pick-up probes of said predetermined number thereof; and means coupled through the center portion of no less than one of said first and second parallel conductive circular plates for simultaneously exciting a fundamental mode and no less than one additional higher order circumferential mode therebetween to provide a corresponding number of beams from said linear array, each of said beams having a unique direction in space.

5. An antenna system for providing multiple beams, said antenna system comprising first and second spaced coextensive parallel conductive circular plates for providing a radial transmission line; means for providing a predetermined number of equally spaced pick-up probes between the parallel conductive circular plates about the circumference thereof; a linear array of radiating elements; means for connecting successive radiating elements commencing from one extremity of said linear array through respective equal length transmission lines to successive uniformly spaced pick-up probes of said predetermined number thereof; a multimode excitation device for providing a transition from a circular waveguide to first, second, third and fourth rectangular waveguide arms, said circular waveguide being coupled to said radial transmission line through a centrally disposed aperture in said first circular plate; first and second magic tees each having first and second arms and a sum arm and a difference arm, said first and second arms of said first magic tee being connected to said first and second waveguide arms of said mode excitation device and said first and second arms of said second magic tee being connected to said third and fourth waveguide arms of said mode excitation device; and third and fourth magic tees each having first and second arms, a sum arm and a difference arm, said first and second arms of said third magic tee being connected to said sum arms of said first and second magic tees and said first and second arms of said fourth magic tee being connected to said difference arms of said first and second magic tees, whereby excitation of said sum arm of said third magic tee produces a broadside beam from said linear array and excitation of said difference arms of said third and fourth magic tees produces beams on both sides of said broadside beam from said linear array.

6. The antenna system for providing multiple beams as defined in claim 4, wherein said last-named means includes an E-plane folded magic tee having first and second waveguide arms, a sum waveguide arm and a difference waveguide arm; a mode excitation section having a coaxial line segment and first and second transition segments extending from opposite halves of said coaxial line segment to said first and second waveguide arms, respectively, of said magic tee; and a coaxial transmission line extending from said coaxial line segment to a centrally disposed aperture in said first circular plate, the

center conductor of said coaxial transmission line extending into the region between said first and second parallel plates of said radial transmission line.

7. The antenna system for providing multiple beams as defined in claim 4, wherein said last-named means includes a coaxial transmission line coupled to said radial transmission line through a centrally disposed aperture in said first plate, the center conductor of said coaxial transmission line extending into the region between said first and second spaced circular plates; a circular waveguide coupled to said radial transmission line through a centrally disposed aperture in said second plate; and first and second orthogonal conductive septums disposed diametrically across said coaxial transmission line and said circular waveguide, respectively, the edges thereof nearest said radial transmission line being spaced back from said first and second plates whereby said coaxial transmission line provides coaxial and TE_{11} modes of excitation in said radial transmission line and said circular waveguide provides orthogonal TE_{11} mode excitation in said radial transmission line.

8. An apparatus for transmitting on a single broadside beam and receiving on a beam having a cosine squared antenna apertured distribution, said apparatus comprising first and second spaced coextensive parallel conductive circular plates for providing a radial transmission line; means for providing a predetermined number of equally spaced pick-up probes between the parallel conductive circular plates about the circumference thereof; a linear array of a number of radiating elements equal to said predetermined number; means for connecting successive radiating elements commencing from one extremity of said linear array through respective equal length transmission lines to successive uniformly spaced pick-up probes of said predetermined number thereof; a circulator having first, second and third arms, excitation applied to said first arm emerging from said second arm and excitation applied to said second arm emerging from said third arm; a coaxial line connected from said second arm of said circulator to said radial transmission line through a centrally disposed aperture in said first plate; a transmitter having an output arm connected to said first arm of said circulator; an orthogonal mode transducer having a TE_{11} output arm and an input arm connected to said radial transmission line through a circular waveguide connected around a centrally disposed aperture in said second plate; and means including a 2:1 power divider responsive to said TE_{11} output arm of said orthogonal mode transducer and said third arm of said circulator for providing a sum pattern output having a cosine squared antenna aperture distribution.

No references cited.

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