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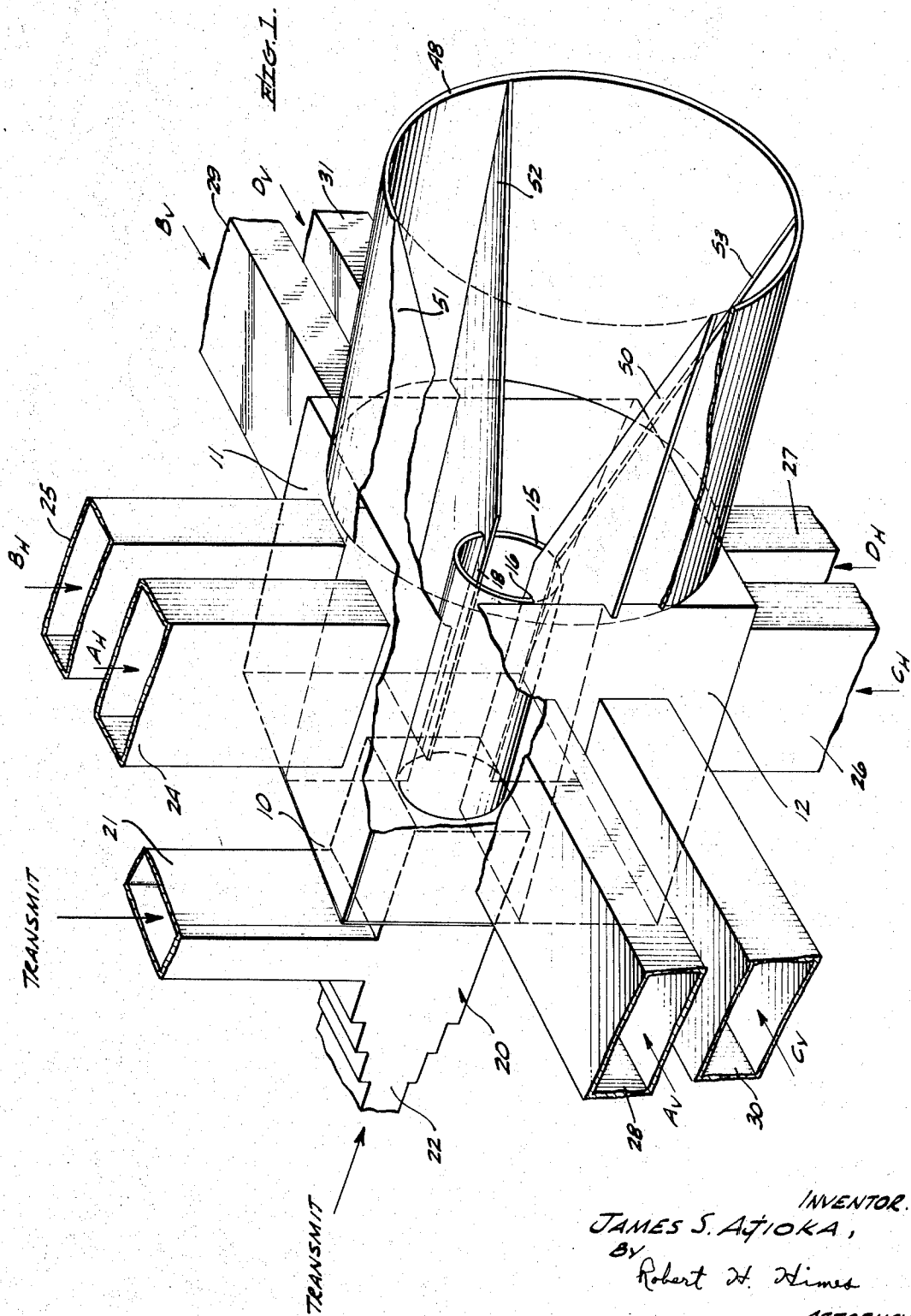
J. S. AJIOKA

3,566,309

DUAL FREQUENCY BAND, POLARIZATION DIVERSE TRACKING
FEED SYSTEM FOR A HORN ANTENNA

Filed Feb. 24, 1969

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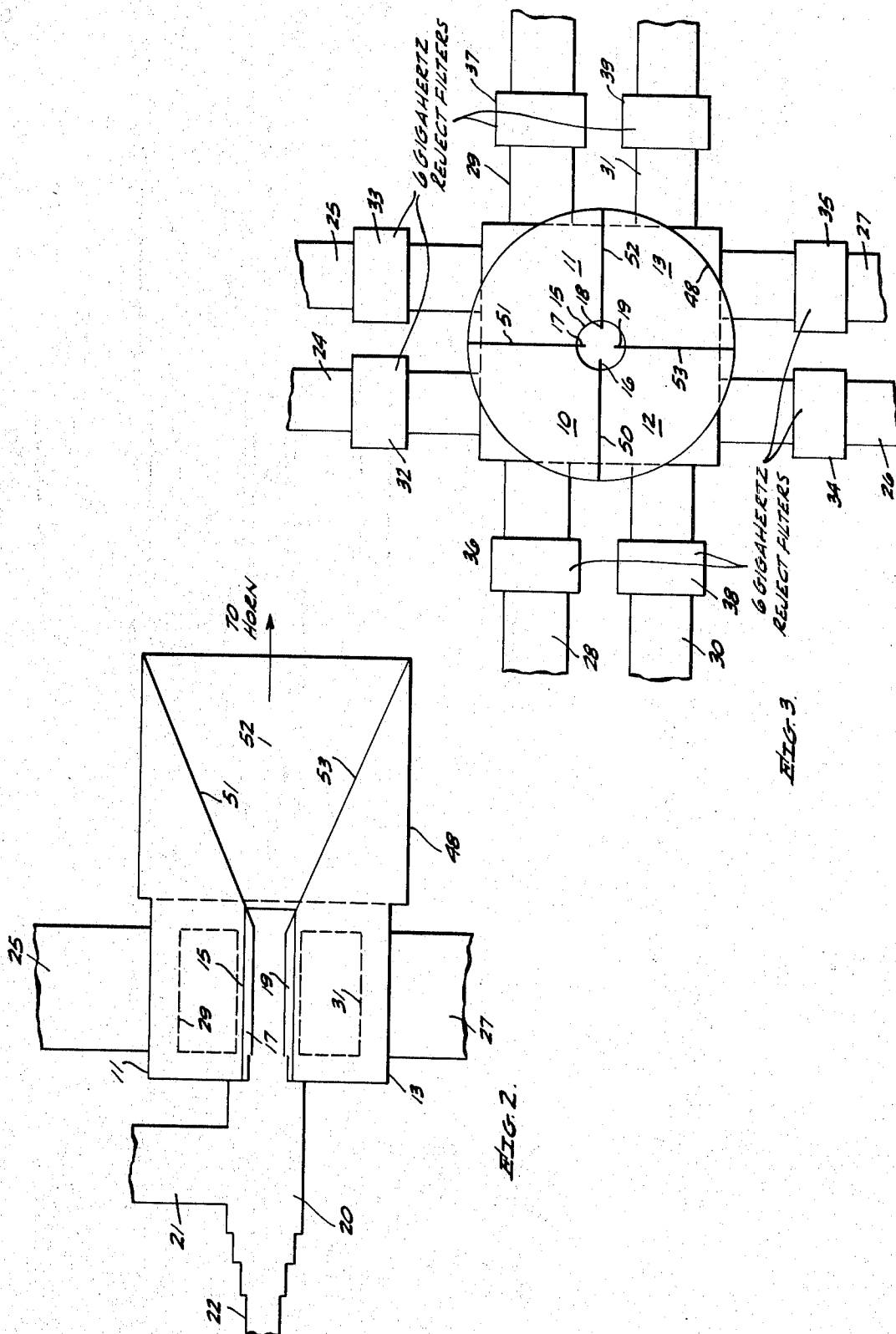
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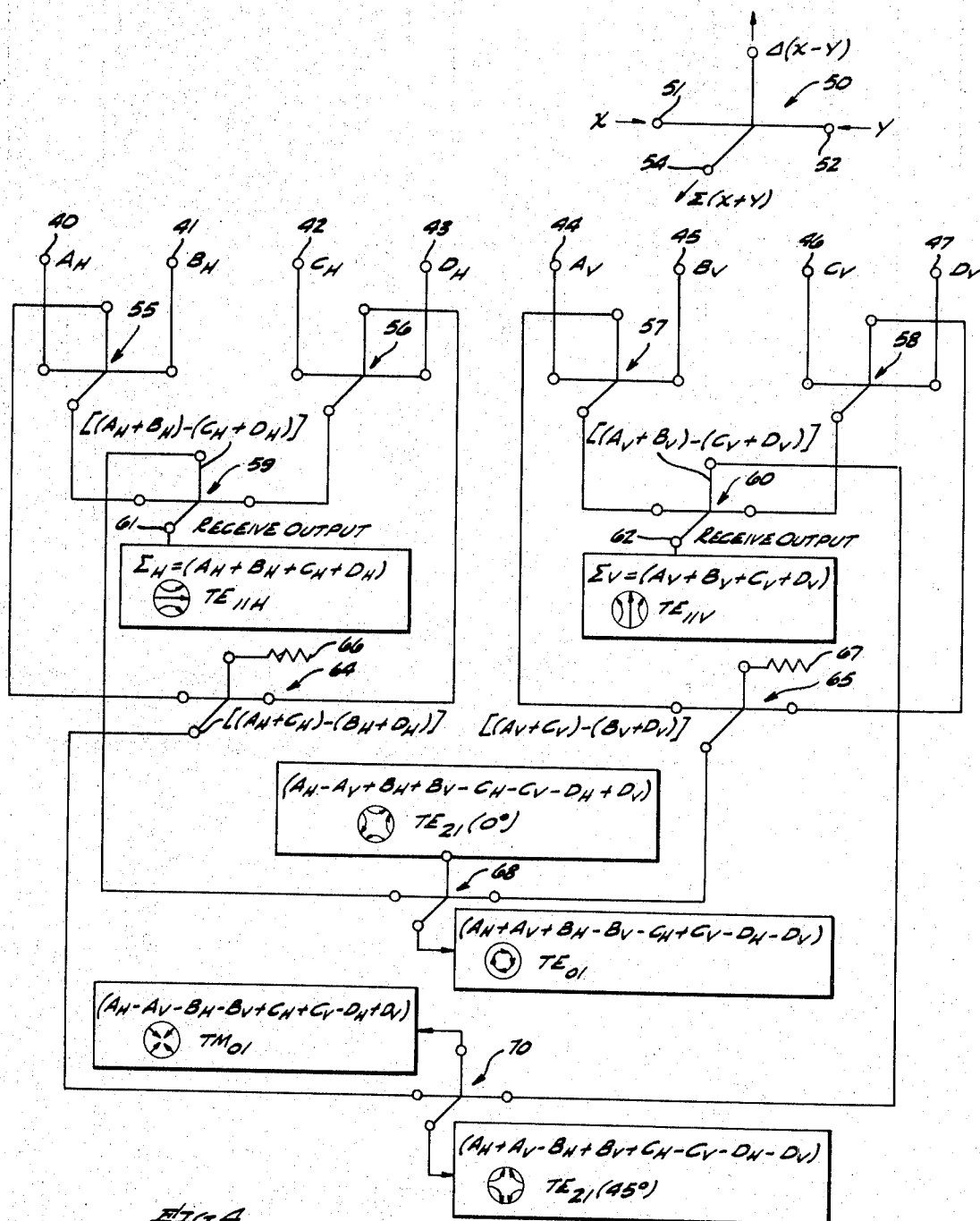


FIG. 4.

HYBRID NETWORK FOR 4 GIGAHERTZ MODE EXCITATION

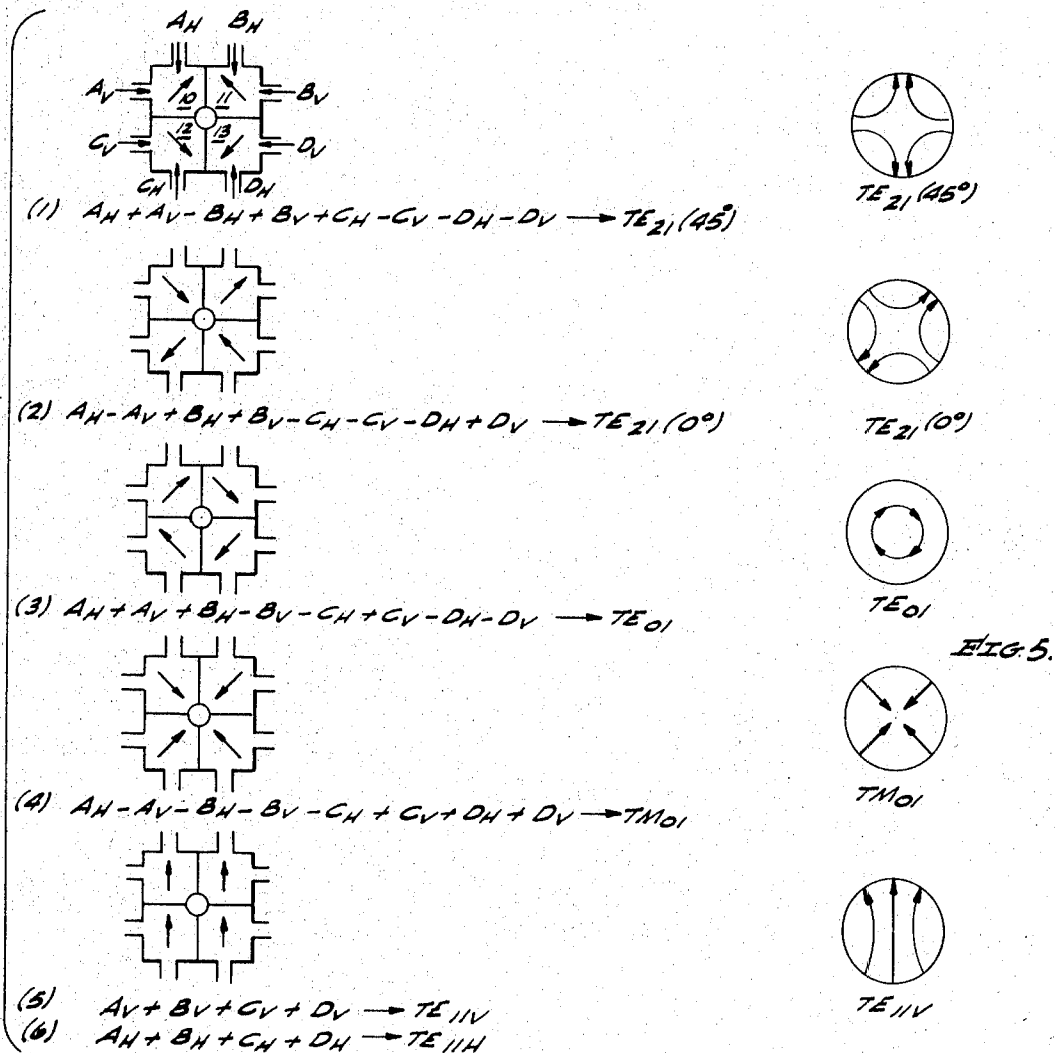
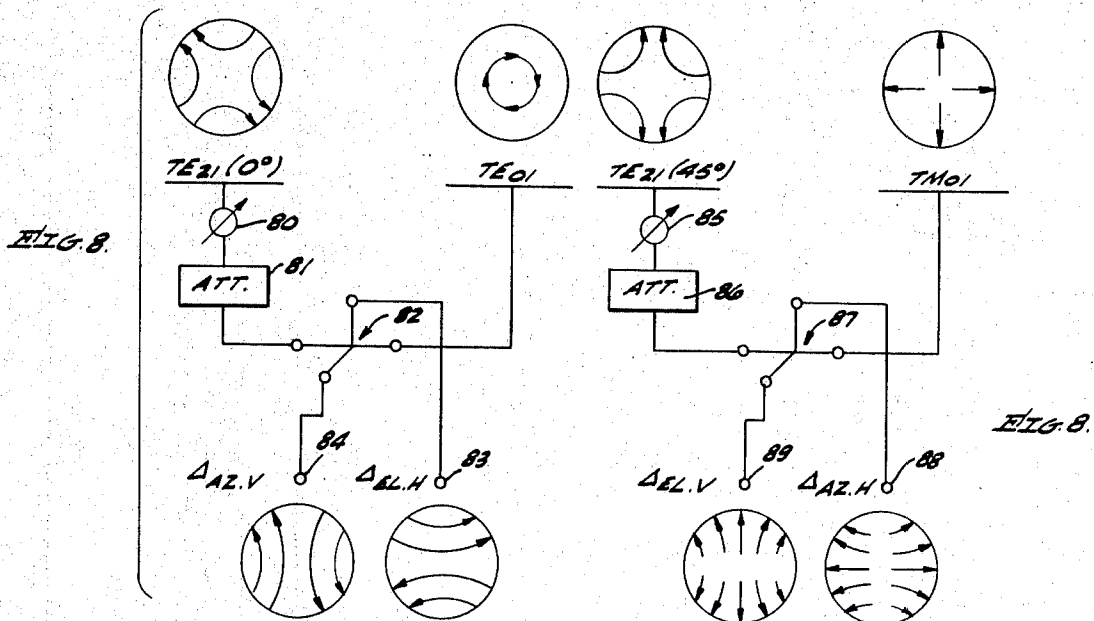
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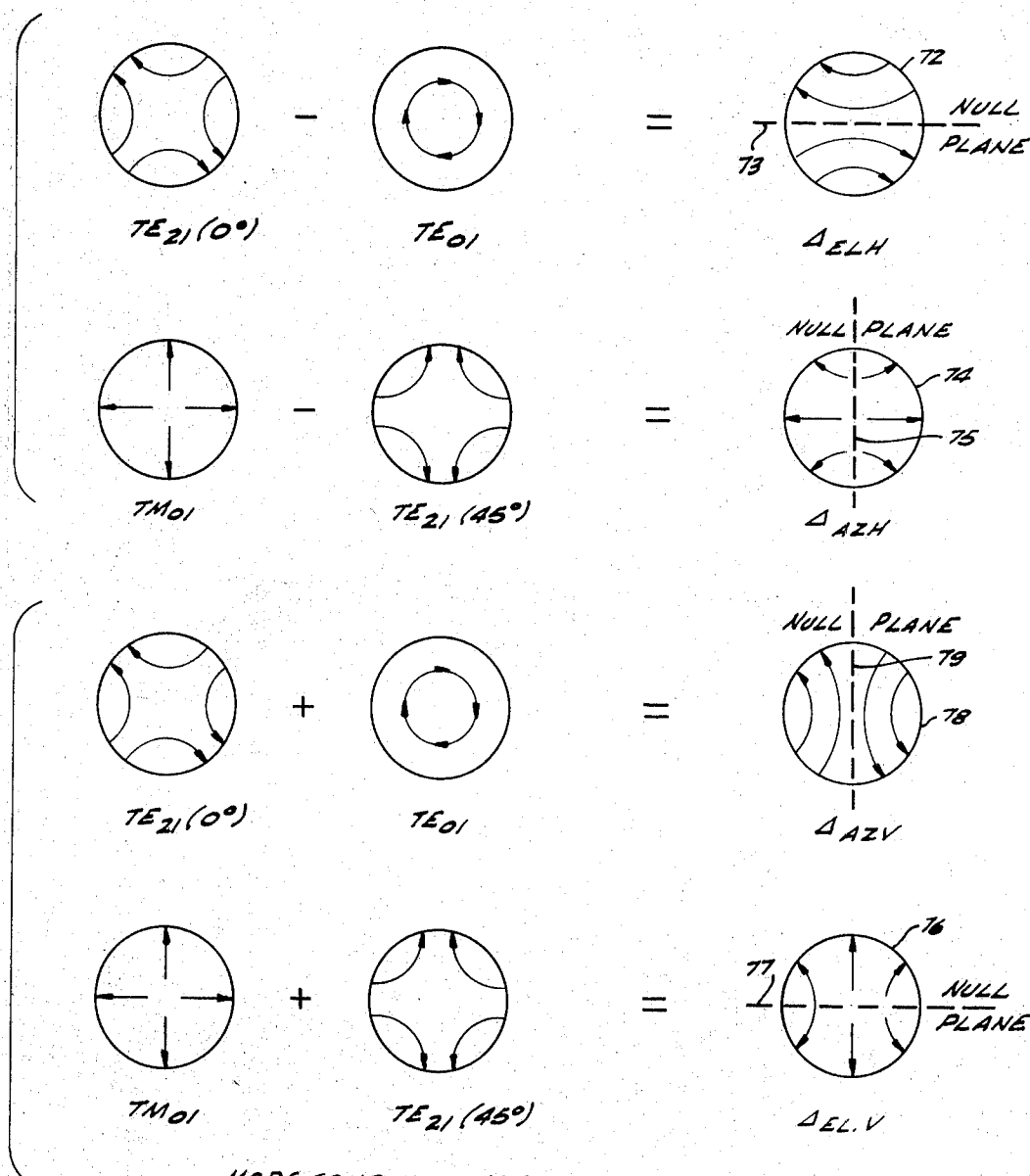
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FIG. 6. MODE COMBINATIONS FOR AZIMUTH ERROR AND ELEVATION ERROR PATTERNS FOR HORIZONTAL POLARIZATION.



MODE COMBINATIONS FOR AZIMUTH AND ELEVATION ERROR PATTERNS FOR VERTICAL POLARIZATION.

FIG. 7.

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DUAL FREQUENCY BAND, POLARIZATION DIVERSE TRACKING FEED SYSTEM FOR A HORN ANTENNA

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U.S. Cl. 333—6

12 Claims

ABSTRACT OF THE DISCLOSURE

The apparatus of the present invention constitutes a feed to a single horn-type antenna providing one frequency band for communications and monopulse tracking and a higher frequency band for high power transmitting. More particularly, the higher frequency band is of the order of 50–100 percent higher than the frequency band for the receive and tracking frequencies. In this latter frequency band, the antenna is capable of receiving communications and having monopulse tracking capability with polarization diversity, i.e., orthogonal linear, orthogonal circular, rotatable linear or arbitrary elliptical polarizations. Cross-polarization of all patterns is very low and cross-talk between azimuth and elevation tracking channels is substantially zero. Also, high efficiency tracking can be achieved over a broad frequency range without retuning of components such as couplers or filters.

BACKGROUND OF THE INVENTION

A contemporary dual frequency feed system with monopulse capability for use as a feed to a horn-type antenna is described in the NASA document, TELSTAR I NASA SP-32, vol. 2, June 1963, pp. 1283–1307. In this method, the tracking signal in the receive band (lower frequency band) uses the TM_{01} mode and the TE_{11} modes which are lightly coupled to the main circular waveguide that feeds the horn (see page 1303 of the above document). The disadvantages of this scheme are:

(a) Narrow bandwidth capability

There is loss in communication signal and addition of noise proportional to the amount of the fundamental TE_{11} mode coupled out for tracking if tracking is done on the communication signal. This is because the tracking signal (TE_{11} mode from the coupler) is abstracted before the signal is preamplified. If the tracking is done on a beacon signal in the same general band as communications, narrow band-pass filters that pass only the beacon signal to the coupler and reject the communication frequencies are required. This contributes to very narrow band tracking capability. In addition, two sets of couplers (orthogonal and laterally displaced couplers, shown on page 1303 of the above document) are required to get all the tracking information. The phasing between these orthogonal and laterally displaced couplers, together with their phases relative to the TE_{11} mode is very critical. This method of extracting tracking information is inherently very narrow band; i.e., it is not a simple adjustment to change to a different beacon or tracking frequency. Even for single frequency operation, many phase trimmers and attenuators are required.

(b) Restricted to circular polarization

This method is generally only applicable to circularly polarized signals. For linear polarization, there is no tracking information in the plane normal to the axis of polarization resulting in target loss (see pp. 1294–1295 of above document). Even in the case of circular polarization, a 3 db

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loss due to cross polarization is incurred, since the TM_{01} is radially polarized.

(c) Non-separable azimuth and elevation tracking

The azimuth and elevation tracking signals are not independent. That is, the tracking error signal in azimuth depends on the elevation angle. To circumvent this problem, an additional coordinate converter is required (see pp. 1297–1298 of above document).

SUMMARY OF THE INVENTION

The present invention eliminates all of the disadvantages of the contemporary method cited. For purposes of explanation only, a transmit frequency in the 6 GHz. band and a receive and track frequency in the 4 GHz. band is used. In accordance with the present invention, a feed system is provided which includes a mode launcher that comprises a square array of four 4 GHz. orthogonal polarization mode transducers with a 6 GHz. launcher at the center of the array. Each quadrant of the quadarray has a horizontal polarization port and a vertical polarization port constituting a total of eight 4 GHz. output ports. These eight ports are excited by a hybrid arithmetic network in the proper amplitudes and phases to achieve the desired independent modes. The square quadarray transitions to a common circular waveguide which constitutes the interface between the feed system and the antenna system. This common circular waveguide is of a diameter that is large enough to support all the desired modes but is below cutoff for undesired higher order modes. A 6 GHz. transmit port comes in with a ridge-loaded circular waveguide at the center of the quadarray. The waveguide ridges extend and become common to the common walls of the quadarray to form a tapered-ridge transition to the common multi-mode circular waveguide. This tapered-ridge transition launches the 6 GHz. transmit wave into the common large circular waveguide with little coupling back into the 4 GHz. components. Additional decoupling is afforded by 6 GHz. band-reject filters in each of the 4 GHz. quadrants.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a partially cut-away perspective view of the quadarray mode launcher of the dual frequency band feed system of the present invention;

FIG. 2 shows a longitudinal section of the quadarray mode launcher of FIG. 1;

FIG. 3 shows a front view of the quadarray mode launcher of FIG. 1, together with the placement of transmit frequency reject filters in the receive waveguides;

FIG. 4 is a schematic representation of a hybrid network to interface with the eight 4 GHz. waveguide arms of the quadarray mode launcher of FIGS. 1 and 3;

FIG. 5 illustrates 4 GHz. mode excitation diagrams in the quadarray mode launcher of FIGS. 1–3;

FIG. 6 illustrates mode combinations for azimuth error and elevation error patterns for horizontal polarization;

FIG. 7 illustrates mode combinations for azimuth error and elevation error patterns for vertical polarization; and

FIG. 8 illustrates schematic diagrams of hybrid networks for generating azimuth and elevation error signals for horizontal and vertical polarization, together with attenuators and phase trimmers to properly balance the modes in amplitude and phase for boresighting the antenna system.

Referring now to FIGS. 1, 2 and 3 of the drawings, there are shown cut-away, perspective and sectional views of the quadarray mode launcher assembly of the feed system of the present invention. The disclosed feed system, by way of example, is adapted to transmit horizontally and vertically polarized 6 GHz. signals, to receive horizontally and vertically polarized 4 GHz. signals and

to extract tracking information from either or both of these latter signals. In particular, the quadarray mode launcher includes a square array of four 4 GHz. orthogonal polarization mode transducers 10, 11, 12, 13 with a circular waveguide 15 extending through the center thereof having ridges 16, 17, 18, 19 spaced in quadrature there-through and coinciding with the common walls of the mode transducers 10, 11, 12, 13. A 6 GHz. orthogonal polarization transducer 20 feeds the ridge-loaded circular waveguide 15 from the left extremity, as viewed in the drawings, and includes a waveguide arm 21 which provides a transmit input for horizontally polarized 6 GHz. signals and a waveguide arm 22 which provides a transmit input for vertically polarized 6 GHz. signals.

Each 4 GHz. orthogonal polarization mode transducers 10, 11, 12, 13 of the quadarray has a horizontal polarization port and a vertical polarization port constituting a total of eight 4 GHz. output ports. Waveguide arms 24, 25, 26, 27 connect the horizontal polarization ports of mode transducers 10, 11, 12, 13, respectively with the corresponding signals designated as A_H , B_H , C_H , and D_H . Similarly, waveguide arms 28, 29, 30, 31 connect to the vertical polarization ports of mode transducers 10, 11, 12, 13 respectively with the corresponding signals designated as A_V , B_V , C_V and D_V . The waveguide arms 24-31 include 6 GHz. reject filters 32-39, respectively, FIG. 3, and connect to input terminals 40-47, respectively, of the hybrid network for 4 GHz. mode excitation, FIG. 4.

The quadarray of mode transducers 10, 11, 12, 13 transitions to a common circular waveguide 48 of a diameter large enough to support all the desired modes but below cutoff for undesired higher order modes. The ridges 16, 17, 18, 19 of the ridge-loaded circular waveguide 15 extend into tapered ridges 50, 51, 52, 53, respectively, which extend from the common walls of the quadarray of mode transducers 10, 11, 12, 13 to the opposite extremity of common circular waveguide 48 thereby to provide a tapered-ridge transition from the mode transducers 10-13 to the common circular waveguide 48. This tapered ridge transition launches the 6 GHz. transmit wave into the common large circular waveguide 48 with little coupling back into the 4 GHz. orthogonal polarization mode transducers 10-13. Additional decoupling is afforded by the 6 GHz. band-reject filters 32-39 in the waveguide arms 24-31. For the present case, the common circular multimode waveguide 48 transitions to a circular cross-section of 5.85" and may include an output flange to mate with the input of a horn-reflector antenna, not shown. Conductive sheet is disposed normal to the axis of common circular waveguide 48 between the outer wall of the quadarray of mode transducers 10, 11, 12, 13 and the circular waveguide 48 at the junction thereof to prevent leakage of microwave energy therefrom.

The desired modes are launched into the common circular waveguide 48 by proper excitation of the eight 4 GHz. waveguide arms 24-31 of the quadarray of orthogonal polarization transducers 10-13, as shown in FIG. 5. Each quadrant of the orthogonal polarization transducers 10-13 is designated by A, B, C, D, respectively, and the horizontal and vertical polarization ports are designated by the subscripts H and V, respectively. Using this notation, following are the algebraic notations for the TE_{21} (45°), TE_{21} (0°), TE_{01} , TM_{01} , TE_{11V} and TE_{11H} modes in the common circular waveguide 48:

$$\begin{aligned} A_H + A_V - B_H + B_V + C_H + C_V - D_H - D_V &\rightarrow TE_{21}(45^\circ) \quad (1) \\ A_H - A_V + B_H + B_V + C_H - C_V - D_H + D_V &\rightarrow TE_{21}(0^\circ) \quad (2) \\ A_H + A_V + B_H - B_V - C_H + C_V - D_H - D_V &\rightarrow TE_{01} \quad (3) \\ A_H - A_V - B_H - B_V - C_H + C_V + D_H + D_V &\rightarrow TM_{01} \quad (4) \\ A_V + B_V + C_V + D_V &\rightarrow TE_{11V} \quad (5) \\ A_H + B_H + C_H + D_H &\rightarrow TE_{11H} \quad (6) \end{aligned}$$

In the above relations 1-6 a convention is used wherein an electric field vector pointing to the right, as viewed in the drawing, is considered positive for the horizontally polarized field components and an electric field vector

pointing up, as viewed in the drawing is considered positive for the vertically polarized components. In the event that coaxial arms are employed in lieu of the waveguide arms 24-31, the polarization would be the same as the orientation of the coaxial arm instead of being orthogonal to it as in the case of rectangular waveguide.

Referring to FIG. 4, there is shown a schematic diagram of a hybrid network for 4 GHz. mode excitation of the quadarray mode launcher of FIGS. 1-3 in accordance with the relations 1-6, FIG. 5. In this schematic, a magic tee symbol 50 is employed wherein x , y signals are applied to input ports 51, 52 respectively, shown horizontally, whereupon the difference signal $\Delta(x-y)$ appears at the difference output port 53, shown vertically, and the summation signal $\Sigma(x+y)$ appears at the sum output port 54, shown pointing forward, in perspective. As previously specified, the inputs 40-47 of the hybrid network are connected to the waveguide arms 24-31, respectively, whereby the signals A_H , B_H , C_H , D_H , A_V , B_V , C_V , and D_V are applied thereto. The input terminals 40, 41 are connected to the input ports of a magic tee 55, the input terminals 42, 43 are connected to the input ports of a magic tee 56, the input terminals 44, 45 are connected to the input ports of a magic tee 57 and the input terminals 46, 47 are connected to the input ports of a magic tee 58. The summation output ports of magic tees 55, 56 and 57, 58 are connected, respectively, to the input ports of magic tees 59, 60 whereby the summation output ports 61, 62 thereof constitute receive output ports for horizontally and vertically polarized signals, respectively. That is, the horizontally polarized signal

$$\Sigma(A_H + B_H + C_H + D_H)$$

is available at the receive output port 61 if a signal having horizontally polarized components is received and the vertically polarized signal $\Sigma(A_V + B_V + C_V + D_V)$ is available at the receive output port 62 if a signal having vertically polarized components is received.

The difference output ports of magic tees 55, 56 and 57, 58 are connected, respectively, to the input ports of magic tees 64, 65, the respective difference output ports of which are terminated by impedances 66, 67. The difference output port of magic tee 59, together with the summation output port of magic tee 65, are connected to input ports of a magic tee 68 whereby the difference output port thereof provides a dominant rectangular waveguide mode signal representative of

$$(A_H - A_V + B_H + B_V - C_H - C_V - D_H + D_V)$$

corresponding to TE_{21} (0°) in common circular waveguide 48 (Relation 2) and the summation output port thereof provides a TE_{01} signal representative of

$$(A_H + A_V + B_H - B_V - C_H + C_V - D_H - D_V)$$

corresponding to TE_{01} in common circular waveguide 48 (Relation 3). In addition, the summation output port of magic tee 64, together with the difference output port of magic tee 60 are connected to the input ports of a magic tee 70 whereby a dominant rectangular waveguide mode signal representative of

$$(A_H - A_V - B_H - B_V + C_H + C_V - D_H + D_V)$$

corresponding to TM_{01} in the common circular waveguide 48 (Relation 4) is available at the difference output port thereof and a dominant rectangular waveguide mode signal representative of

$$(A_H + A_V - B_H + B_V + C_H - C_V - D_H - D_V)$$

corresponding to TE_{21} (45°) in the common circular waveguide 48 (Relation 1) is available at the summation output port thereof.

Referring to FIG. 6 there is shown the mode combinations for azimuth error and elevation error field distributions 72, 74, respectively, when a horizontally polarized signal is received. In particular, the TE_{21} (0°) field less

the TE_{01} field provides the field pattern 72 which will have a horizontal null plane represented by dashed line 73 through the center thereof when the common circular waveguide 48 and associated horn or reflector (not shown) is "on target".) The electric field vectors on opposite sides of the null plane 73 are generally horizontal and of opposite directions, whereby there is no net signal in a balanced situation. Since the electric field vectors of pattern 72 can be balanced by moving the common circular waveguide 48 and the associated horn or reflector antenna (not shown) vertically, the difference field $TE_{21}(0^\circ) - TE_{01}$ constitutes an elevation error signal for a horizontally polarized receive signal. Similarly, the difference field $TM_{01} - TE_{21}(45^\circ)$ constitutes a horizontally polarized field pattern 74 having a vertical null plane 75 through the center thereof, whereby the patterns 72, 74 provide elevation and azimuth error indications, respectively, for a horizontally polarized receive signal.

Referring to FIG. 7 there is shown the mode combinations for azimuth error and elevation error patterns 76, 78, respectively, when a vertically polarized signal is received. In particular, the TM_{01} field plus the $TE_{21}(45^\circ)$ field provides the pattern 76 which will have a horizontal null plane represented by dashed line 77 through the center thereof when the common circular waveguide 48 and associated horn or reflector system (not shown) is on target. That is, the electric field vectors of pattern 76 are vertically polarized and of opposite direction on opposite sides of the null plane 77 whereby there is no net signal in a balanced situation. Since the electric field vectors of pattern 76 can be balanced; i.e., made equal and opposite, by moving the common circular waveguide 48 and associated horn or reflector system (not shown) vertically, the summation field $TM_{01} + TE_{21}(45^\circ)$ constitutes an elevation error signal for a vertically polarized receive signal. Similarly, the summation field $TE_{21}(0^\circ) + TE_{01}$ constitutes a vertically polarized pattern 78 having a vertical null plane 79 through the center thereof whereby the patterns 76, 78 provide elevation and azimuth error indications, respectively, for a vertically polarized receive signal.

Referring to FIG. 8 there is shown a schematic of a hybrid network for combining modes in a manner to achieve azimuth and elevation tracking signals for horizontal and vertical polarized receive signals by sensing the electric field patterns 72, 74, 76, 78 of FIGS. 6 and 7. In this schematic the same notation for a magic tee is employed as in the case of FIG. 4. In particular, the difference output port of magic tee 68, FIG. 4, is connected through a phase shifter 80 and an attenuator 81 to an input port of a magic tee 82, the remaining input port of which is connected to the summation output port of magic tee 68, FIG. 4. The difference and summation output ports of magic tee 82 then sense the presence of patterns 72 and 78, thereby providing an elevation error signal at a port 83 for a horizontally polarized receive signal and an azimuth error signal at a port 84 for vertically polarized receive signal, respectively. In addition, the difference output port of magic tee 70, FIG. 4, is connected through a phase shifter 85 and attenuator 86 to an input port of a magic tee 87, the remaining input port of which is connected to the summation output port of magic tee 70, FIG. 4. The difference and summation output ports of magic tee 87 then sense the presence of patterns 74 and 76, thereby providing an azimuth error signal at a port 88 for a horizontally polarized receive signal and an elevation error signal at a port 89 for a vertically polarized receive signal. The purpose of the attenuators 81, 86 is to equalize the signals applied to the respective inputs of the magic tees 82, 87 and accordingly is to be placed ahead of the input port receiving the strongest signal. The phase shifter 80, 85, on the other hand, may be inserted ahead of either input port of the magic tees 82, 87.

In the above description, frequency ranges and dimensions have been given by way of example only.

What is claimed is:

1. A feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band that is substantially higher than said first frequency band, said feed system comprising a first waveguide with quadrangular symmetry about the longitudinal axis thereof, having a cut-off intermediate said first and second frequency bands, said first waveguide having longitudinal ridges disposed in quadrature along the inner surface thereof; means coupled to one extremity of said first waveguide for transmitting electromagnetic energy within said second frequency band therethrough; first, second, third and fourth orthogonal polarization transducers for operation over said frequency band, each of said first, second, third and fourth orthogonal polarization transducers having a horizontal and a vertical polarization output and being disposed about said first waveguide with common walls in alignment with said ridges thereof with input ports in a common plane on the side thereof opposite from said one extremity of said first waveguides; a common circular waveguide capable of propagating electromagnetic energy within both said first and second frequency bands disposed symmetrically about said longitudinal axis of said first waveguide at the extremity thereof opposite from said one extremity adjacent to said first, second, third and fourth orthogonal polarization transducers; a tapered-ridge transition extending from each of said common walls of said first, second, third and fourth orthogonal polarization transducers and said longitudinal ridges in said first waveguide to the circular cross section of said common circular waveguide; and means coupled to said horizontal and vertical polarization outputs from said first, second, third and fourth orthogonal polarization transducers for receiving polarization diverse tracking and communication signals within said first frequency band.

2. The feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band that is substantially higher than said first frequency band as defined in claim 1, wherein means for rejecting electromagnetic energy within said second frequency band is interposed in series with each horizontal and vertical polarization output of said first, second, third and fourth orthogonal polarization transducers.

3. The feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band that is substantially higher than said first frequency band as defined in claim 1, wherein said means coupled to one extremity of said first waveguide for transmitting electromagnetic energy within said second frequency band therethrough additionally includes means for polarizing said transmitted electromagnetic energy in a selected one of a plurality of polarization states.

4. A feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band that is substantially higher than said first frequency band, said feed system comprising a first circular waveguide of predetermined diameter having a cut-off intermediate said first and second frequency bands, said first circular waveguide having longitudinal ridges disposed in quadrature along the inner surface thereof; means coupled to one extremity of said first circular waveguide for transmitting electromagnetic energy within said second frequency band therethrough; first, second, third and fourth orthogonal polarization transducers, each with a horizontal and a vertical polarization output, for operation over said first frequency band and said first, second, third and fourth orthogonal polarization transducers being disposed about said first circular waveguide with common walls in alignment with said ridges thereof and input ports in a common plane on the side thereof opposite from said one extremity of said first circular waveguide; a common circular waveguide of a diameter

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substantially larger than said predetermined diameter disposed symmetrically about the longitudinal axis of said first circular waveguide at the extremity thereof opposite from said one extremity and adjacent to said first, second, third and fourth orthogonal polarization transducers; a tapered-ridge transition extending from each of said common walls of said first, second, third and fourth orthogonal polarization transducers and said longitudinal ridges in said first circular waveguide to the inner periphery of said common circular waveguide, and means coupled to said horizontal and vertical polarization outputs from said first, second, third and fourth orthogonal polarization transducers for receiving polarization diverse tracking and communication signals within said first frequency band.

5. The feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band that is substantially higher than said first frequency band as defined in claim 4 wherein said polarization diverse tracking and communication signals within said first frequency band include the $TE_{21}(45^\circ)$, $TE_{21}(0^\circ)$, TE_{01} , TM_{01} , TE_{11} (vertical) and TE_{11} (horizontal) modes.

6. A feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band, said second frequency band being substantially higher than said first frequency band, said feed system comprising a first waveguide having quadrangular symmetry about a longitudinal axis thereof and a cut-off intermediate said first and second frequency bands, said first waveguide having longitudinal ridges disposed in quadrature along the inner surface thereof; an orthogonal polarization transducer for operation over said second frequency band coupled to one extremity of said first waveguide; first, second, third and fourth conductive cubicles disposed about said first waveguide with common walls in alignment with said ridges thereof, said cubicles being open on the side thereof opposite from said one extremity of said first waveguide; a common circular waveguide of a diameter capable of supporting basic modes of said first and second frequency bands disposed symmetrically about said longitudinal axis of said first waveguide adjacent to said open side of said first, second, third and fourth cubicles; means coupled to each of said first, second, third and fourth cubicles for separately coupling to horizontal and vertical polarized electromagnetic energy therein, and a tapered-ridge transition extending from each of said common walls of said first, second, third and fourth cubicles and said longitudinal ridges in said first waveguide to the inner periphery of said common circular waveguide.

7. The feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band, as defined in claim 6 wherein said tapered-ridge transition occurs over a distance greater than the diameter of said common circular waveguide.

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8. The feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band as defined in claim 6, additionally including means coupled to said means coupled to each of said first, second, third and fourth cubicles for separately coupling to horizontally and vertically polarized electromagnetic energy therein for receiving $TE_{21}(45^\circ)$, $TE_{21}(0^\circ)$, TE_{01} , TM_{01} , TE_{11} (horizontal) and TE_{11} (vertical) modes within said common circular waveguide as dominant modes in respective separate waveguides.

9. The feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band as defined in claim 8, additionally including means coupled to said separate waveguides corresponding to said $TE_{21}(0^\circ)$ and TE_{01} modes in said common circular waveguide for generating an elevation error signal for a horizontally polarized signal in said common circular waveguide.

10. The feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band as defined in claim 8, additionally including means coupled to said separate waveguides corresponding to said $TE_{21}(0^\circ)$ and TE_{01} modes in said common circular waveguide for generating an azimuth error signal for a vertically polarized signal in said common circular waveguide.

11. The feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band as defined in claim 8 additionally including means coupled to said separate waveguides corresponding to said $TE_{21}(45^\circ)$ and TM_{01} modes in said common circular waveguide for generating an elevation error signal for a vertically polarized signal in said common circular waveguide.

12. The feed system for receiving and tracking over a first frequency band and for transmitting over a second frequency band as defined in claim 8 additionally including means coupled to said separate waveguides corresponding to said $TE_{21}(45^\circ)$ and TM_{01} modes in said common circular waveguide for generating an azimuth error signal for a horizontally polarized signal in said common circular waveguide.

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333—21; 343—786