FEED SYSTEM

Filed Aug. 21, 1968

4 Sheets-Sheet 1

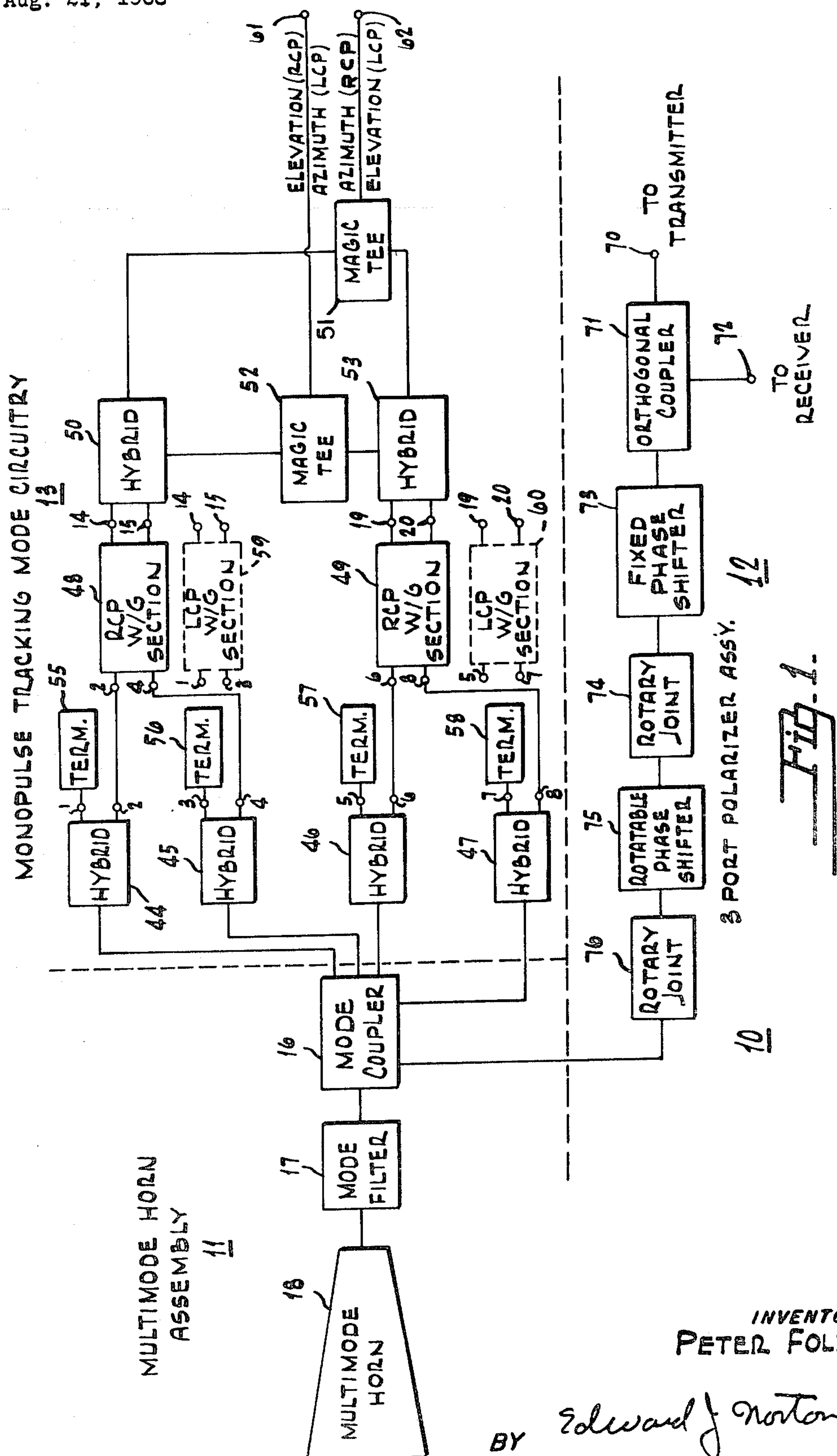

Fig. 1

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Feb. 2, 1971 P. FOLDES 3,560,976

FEED SYSTEM

Filed Aug. 21, 1968 4 Sheets-Sheet 2

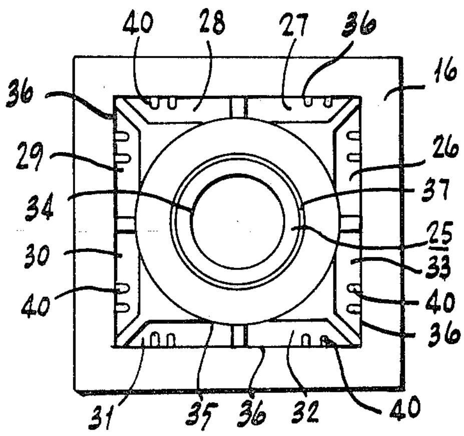

Fig. 2.

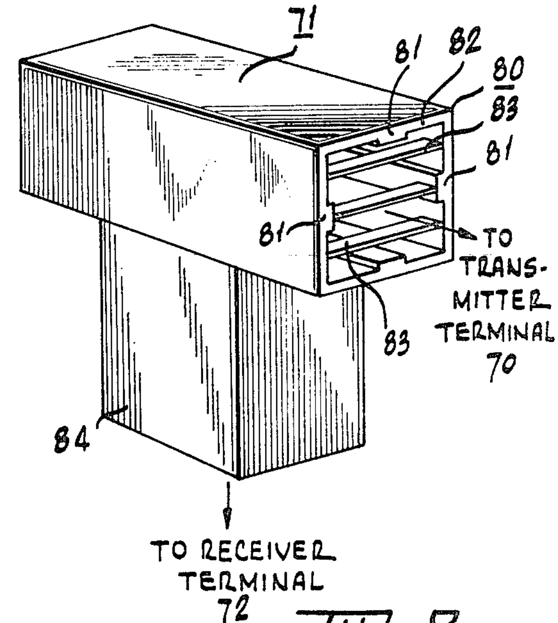

Fig. 8.

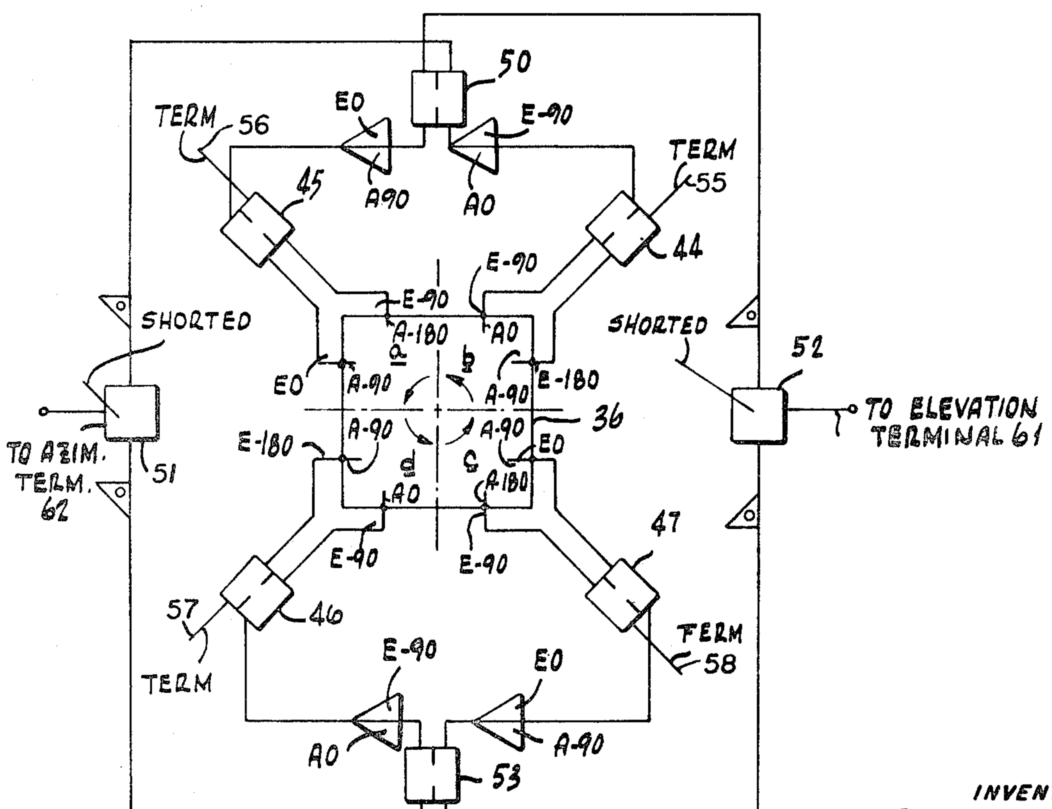

Fig. 4.

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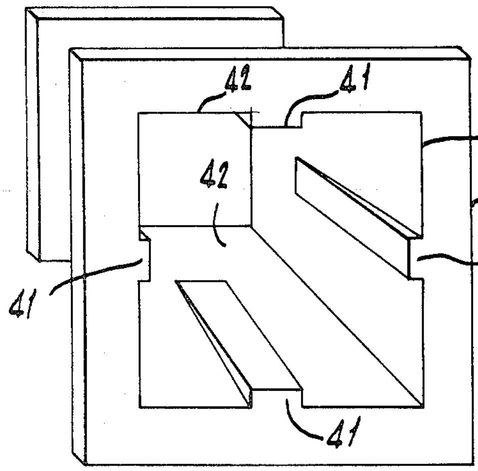


Fig. 5.

Fig. 7.

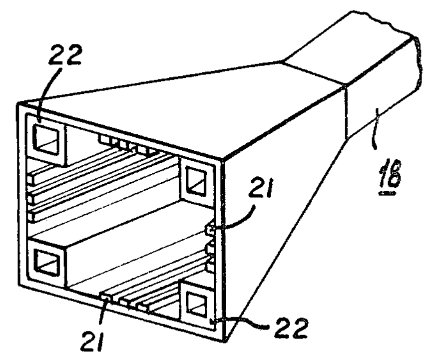
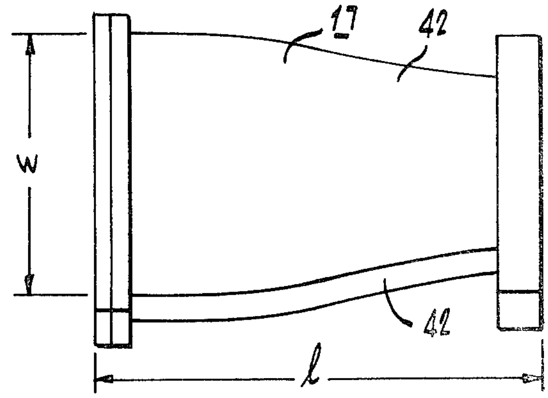


Fig. 6.



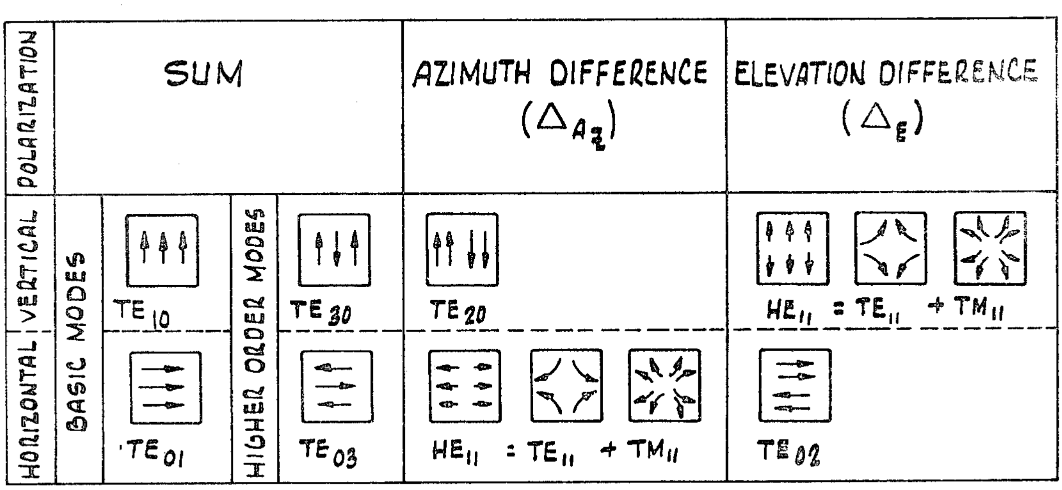


Fig. 3.

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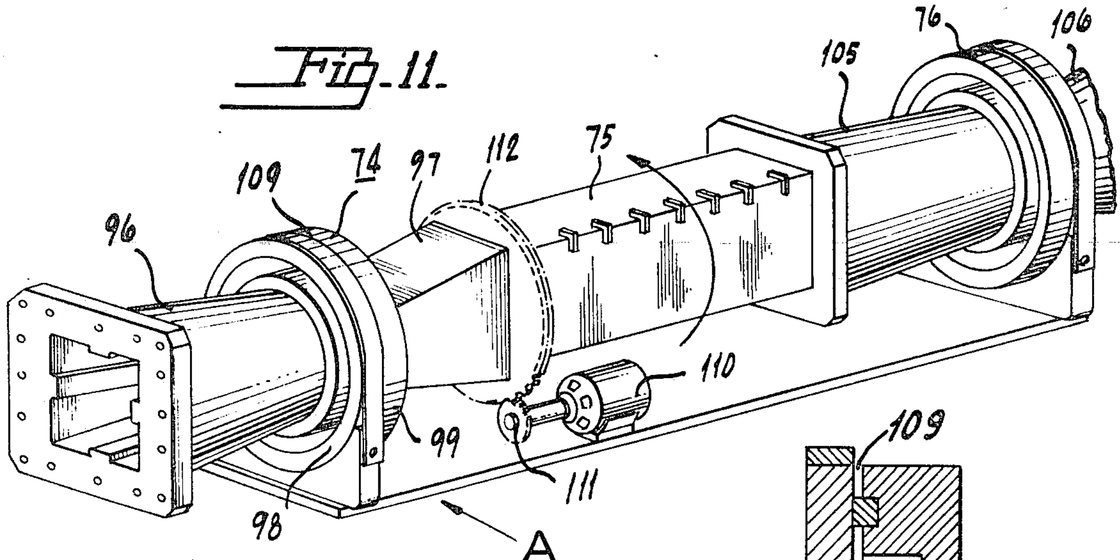

Fig. 11

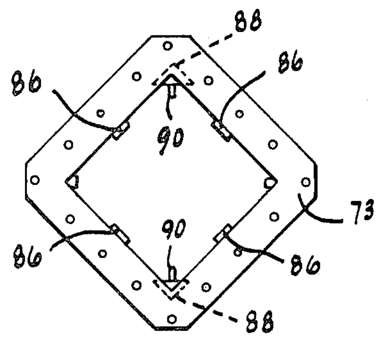

Fig. 10

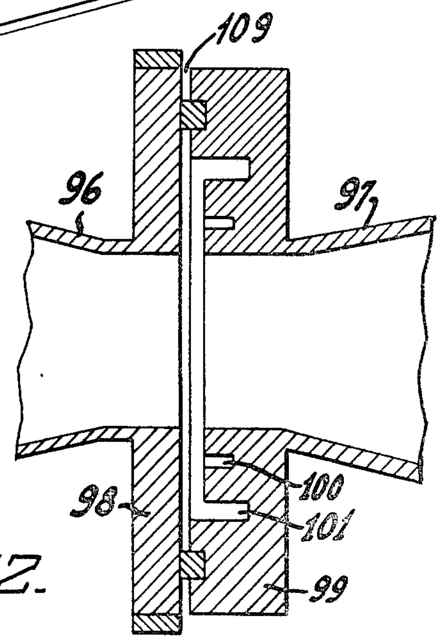

Fig. 12

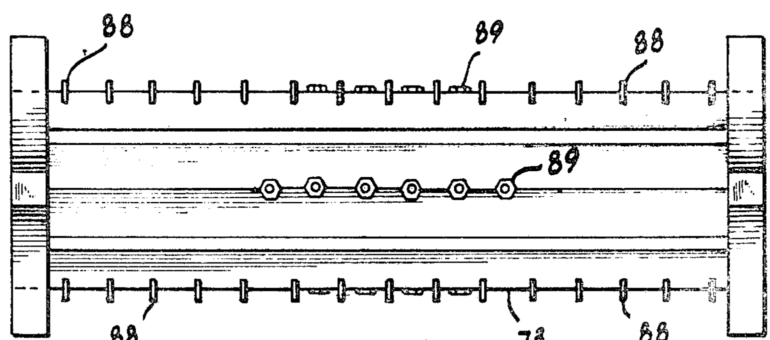

Fig. 9

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3,560,976

FEED SYSTEM

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Int. Cl. H04b *7/10;* H01q *13/02, 15/24*
U.S. Cl. 343—100 17 Claims

ABSTRACT OF THE DISCLOSURE

A feed system suitable for satellite communication earth station antennas and which includes a three port polarizer assembly, multimode horn assembly and tracking difference mode circuitry is described. The three port polarizer assembly is coupled to the horn assembly for providing full polarization mode flexibility for the sum modes. The multimode horn assembly provides excitation and control of both the sum and difference modes and inhibits the undesirable modes. The tracking difference mode circuitry is coupled to the multimode horn to process the difference modes and provide the azimuth and elevation information for monopulse tracking.

BACKGROUND OF THE INVENTION

This invention relates to microwave communication systems and more particularly to a wideband multimode monopulse antenna feed system with high gain to noise temperature ratio which provides the simultaneous functions of receiving, transmitting and automatic tracking, wherein the first two are accomplished by the use of sum signals and the third is accomplished by using difference mode signals.

Feed systems capable of generating and receiving microwave energy in a plurality of modes have been developed and are known as multimode feed systems. Such multimode feed systems are often used in monopulse tracking wherein the energy transmitted and received by the feed systems is combined in such a manner that sum and difference radiation patterns are produced during transmission and/or reception. These patterns are analyzed to determine the position of the object which may be either an aircraft, a missile, or a satellite or to provide automatic tracking of that aircraft, missile, or satellite. Monopulse tracking systems are discussed in "Introduction to Radar Systems" by Merrill L. Skolnick, published 1962 by McGraw-Hill Book Co. and "Introduction to Monopulse" by D. R. Rhodes, published in 1959 by McGraw-Hill Book Co.

The typical tracking feed system may include several horns or apertures. When only a small number of horns, such as in the four horn system, are used, the radiation patterns have undesirable characteristics which lower the efficiency of the system and have increased noise level. Some attempts have been made to produce an efficient low noise multimode feed system with a single aperture. The prior art single aperture devices although operative have a relatively low gain to noise temperature ratio when they are used as feed systems for reflector type antennas

and when operated over a wide range of frequencies. In addition, the prior art multimode feed systems do not have full polarization mode flexibility in either the sum (communication) channel or the difference (tracking) channel.

Although many feed systems have been built in the past in which one or more of the three functions of transmit, receive and tracking are handled independently by separate parts of the feed, efficient systems with operational simplicity are required with a single aperture in the region of the focus of the primary or secondary reflectors serving simultaneously for all three functions over a relatively wide range of frequencies. Moreover, to obtain the best field distribution efficiency, an undivided radiating source aperture is desirable as it is achieved by a single horn. Also, since the polarization (linear or circular) may vary from satellite to satellite, and the attitude of the linear polarization of the satellite may vary, a full polarization mode flexibility is therefore desirable for optimum gain in the sum mode and for tracking. Also, the receive and transmit polarization in practical systems must be maintained orthogonal (right vs. left circular or orthogonal linear polarization) in order to match the polarization modes of the feed to the employed polarization modes of the satellite.

It is an object of this invention to provide an improved multimode feed system operable over a relatively wide range of frequencies.

BRIEF DESCRIPTION OF INVENTION

In accordance with the teachings of the present invention, a full polarization mode flexibility monopulse multimode feed system is provided wherein the feed system includes a mode coupler having a sum mode coupling port aperture and a separate plurality of difference mode port apertures symmetrically located about the sum port. A sum or communication chanel propagation network is coupled to the sum port and is responsive to the energy supplied to the sum port for providing the first plurality of sum modes. Likewise a separate monopulse tracking network including monopulse bridge circuitry is coupled to the plurality of difference mode ports and is responsive to the energy supplied to these ports for providing circularly polarized difference mode signals for the second plurality of modes. The novel feed system also includes a horn and mode filter for controlling the amplitudes and phase relationships between the first and second plurality of modes in a single aperture.

DESCRIPTION OF A PREFERRED EMBODIMENT

A more detailed description follows in conjunction with the following drawings wherein:

FIG. 1 is a block diagram of the antenna feed system in accordance with one preferred embodiment of the present invention,

FIG. 2 is a sketch of the mode coupler used in accordance with the present invention,

FIG. 3 is a diagram of the wanted modes in the multimode horn,

FIG. 4 is a block diagram illustrating phase relationships for right circular polarization,

FIG. 5 is a perspective view of the mode filter,

FIG. 6 is a sketch of the side view of the mode filter,

FIG. 7 is a perspective view of the horn,

FIG. 8 is a perspective view of an orthogonal coupler,

FIG. 9 is a sketch of the side view of a 90° differential phase shifter in accordance with the present invention,

FIG. 10 is a sketch of the end view of the differential phase shifter of FIG. 9,

FIG. 11 is a sketch of the rotary polarizer assembly, and

FIG. 12 is a fragmentary view in section of the rotary joint taken in the general direction of arrow A.

Referring to FIG. 1, a wideband tracking feed system **10** is provided including a multimode horn assembly **11**, a three port polarizer assembly **12** and tracking mode circuitry **13**. The composite feed assembly for a satellite communication network is required, for example, to cover a wideband 5925 to 6425 mHz. frequency band for transmit and a 3700 to 4200 mHz. frequency band for receive. The three port polarizer assembly **12** maintains propagation of the transmit or receive sum communication signals in orthogonal relationship while the monopulse difference signals are processed at the tracking mode circuitry **13**. The multimode horn assembly **11** includes a mode coupler **16**, a mode filter **17** and a single aperture horn **18**.

FIG. 2 is an end view of the mode coupler **16** looking from the mode filter **17** toward the coupler **16**. The mode coupler **16** is constructed of a large conically shaped port **25** at the center of a square waveguide section and includes eight symmetrically located identical waveguide ports **26** through **33**. The ports **26** through **33** in corner pairs form four circularly polarized exciting subapertures with each port being orthogonally polarized with respect to its corner paired port.

The center conically-shaped transducer port **25** is, for example, for the above stated frequency band about 2.12 inches in diameter at the receiver equipment end **34** of the mode coupler and increases to about 3 inches in diameter at the antenna horn end **35**. A step **36** is formed at the end of the conical port **25** between the 3 inch diameter conical at the end **35** and a 4 inch square waveguide section at the mode filter end of the mode coupler **16**. The step **36** is formed by the edge surface of the coupler **16** extending in front of and in a plane forward of the plane including the openings for the ports **26** through **33** and the end opening **35** for the conical coupler **25**. The length of the conical, center transducer port **25** in this example is about 4.5 inches. The step **36** excites in the horn in addition to the basic TE_{10} mode applied to the mode coupler **16**, the TE_{30} mode as well as a small amount of TE_{12}, TM_{12}, TE_{21} and TM_{21} modes. Refer to FIG. 3 for a diagram of the wanted TE_{10} and TE_{30} modes.

The eight symmetrically located identical waveguide ports **26** through **33** which are used for monopluse tracking terminate at the step **36** at which the TE_{30} mode excitation occurs. For an understanding of the monopulse tracking, the total step aperture **36** of the mode coupler **16** is considered for discussion as divided into four subapertures labeled *a*, *b*, *c* and *d* as shown in FIG. 4. Each corner of subaperture *a*, *b*, *c* and *d* of the mode coupler **16** has a respective horizontally polarized port **28, 27, 32, 31** and a respective vertically polarized port **29, 26, 33** and **30**. Also, the power in each subaperture is equal as provided by the short-slot hybrids **44** through **47** as illustrated in the arrangement shown in FIG. 1 and 4.

To provide circular polarization in the feed for monopulse tracking which is adaptable to receive or transmit right or left circular polarization or linear polarization, the phase relationship between the four subapertures *a*, *b*, *c* and *d* of the step aperture **36** should remain the same. However, each aperture *a*, *b*, *c* and *d* should support the TE_{01} mode (horizontal polarization) and the TE_{10} mode (vertical polarization) and these should be either delayed or advanced 90° relative to each other to excite a circular polarized electromagnetic signal for each subaperture.

The monopulse tracking circuitry for providing the difference modes for either linear polarization or right or left circular polarization is illustrated in FIGS. 1 and 4. The circuit consists of six short-slot hybrids **44** through **47**, **50** and **53** and two magic tee hybrids **51** and **52** and various bends in the waveguides and waveguide sections. The sizes and dimensions of these waveguides and waveguide sections are optimized at the receiver tracking frequency bands. Referring to FIGS. 1, 2 and 4, each of the eight paired ports, **26** through **33**, is coupled to its orthogonal paired port at one of the four short-slot hybrids **44** through **47**. One terminal of each of the hybrids **44** through **47** is terminated at terminals **55** through **58** respectively, and the other terminal is combined for example, with the output of another one of the hybrids **44** through **47** at hybrid **50** or **53**. The proper ports of the hybrids **44** to **47** to be terminated depends upon the polarization, right or left circular polarization. For right circular polarized signals, waveguide section **48** is used with output terminals **14** and **15** coupled to hybrid **50** and waveguide section **49** is used with output terminals **19** and **20** coupled to hybrid **53**. For right circular polarized signals as shown in FIG. 1, output terminals **1, 3, 5** and **7** of hybrids **44** through **47** are terminated and are unused, and terminals **2, 4, 6** and **8** are used and are connected to like numbered terminals in waveguide sections **48** and **49**. For left circular polarized signals, terminals **2, 4, 6** and **8** are terminated and terminals **1, 3, 5** and **7** and waveguide sections **59** and **60** are used. The input terminals **1** and **3** of waveguide section **59** are connected to the like numbered terminal in hybrids **44** and **45** and output terminals **14** and **15** of waveguide section **59** are connected to hybrid **50**. The input terminals **5** and **7** of waveguide section **60** are connected to the like numbered terminal of hybrids **46** and **47** and the output terminals **19** and **20** of waveguide section **60** are connected to hybrid **53**. Also, the roles of the output terminals **61** and **62** change from elevation difference modes to azimuth difference modes and vise versa as indicated in FIG. 1 with respect to the use of right or left circular polarized signals. Each of the four hybrids **44** through **47** which are coupled to the corner paired ports **26** through **33** provides a power division and provides a 90° relative phase shift between paired ports. The combined system of the four subapertures each with the 90° relative phasing of the vertically polarized TE_{10} mode and the horizontally polarized TE_{01} mode with proper phasing between subapertures *a*, *b*, *c* and *d* provides the vertically polarized TE_{20} mode and horizontally polarized hybrid $HE_{11}=TE_{11}+TM_{11}$ modes in the mode filter **17**, which modes, when they are superimposed provide the circularly polarized azimuth difference mode system. See FIG. 3 showing these wanted modes.

Referring to FIG. 4 and considering, for example, for right circular polarized azimuth difference mode, the short-slot hybrids **50** and **53** and magic tees **51** and **52** are arranged so that the phase relationships at each port of the subapertures are as shown. The phase marked after the symbol A in FIG. 4 shows the relative phases in the azimuth difference mode system. The properly phased (*a* and *d* in effective 0° phase, *b* and *c* in effective 180° phase) and vertically polarized TE_{10} modes in the subapertures *a*, *b*, *c* and *d* excite the vertically polarized TE_{20} mode. The similarly phased and horizontally polarized TE_{10} modes in the subapertures *a*, *b*, *c* and *d* wherein *a* and *d* effective phase is 0° and *b* and *c* is effective 180° phase excite the horizontally polarized hybrid

$$HE_{11}=TE_{11}+TM_{11}$$

mode. Since the physical polarization or the direction of the electric field in subaperture *b* is opposite that of *a* and the physical polarization direction of subaperture *c* is opposite that of subaperture *d* and the ports *a* and *d* and *c* and *d* are physically located on opposed ends of that field, the subapertures *a* and *d* in effect are cophased at 180° and subapertures *b* and *c* in effect are cophased at 0° phase. The simultaneous presence and the 90° phasing of the vertically polarized TE_{20} mode and the horizontally polarized hybrid $HE_{11}=TE_{11}+TM_{11}$ mode provides the circularly polarized difference mode with zero radiated field in the vertical plane (horizontal or azimuth difference mode).

The same combined system of the four subapertures with an orthogonal set of proper phasings provides the vertically polarized hybrid $HE_{11}=TM_{11}+TE_{11}$ mode and horizontally polarized TE_{02} mode in the mode filter, which modes, when they are superimposed provide the circularly polarized elevation difference mode system. The phase relation between the circularly polarized subapertures *a*, *b*, *c* and *d* is determined by the remaining four hybrids of the system which are two short-slot hybrids **50** and **53** and the two magic tees **35** and **52**.

Referring to FIG. 4 and considering, for example, the right circularly polarized vertical difference mode, the hybrids **50** and **53** and magic tees **35** and **52** are arranged so that the pshae relationships at each port of the subapertures *a*, *b*, *c* and *d* are as shown. The phase marked after the symbol E or elevation shows the relative phases in elevation difference mode of the subapertures for the combined circularly polarized difference mode comprising the combined horizontally polarized TE_{02} mode and vertically polarized $TE_{11}+TM_{11}$ modes. See FIG. 3 showing these wanted modes. In this example at subaperture *a* the horizontal polarization E or elevation is 0° phase, at subapertures *b* and *d* the horizontal polarization is 180° phase and at subaperture *c* the horizontal polarization is 0° phase relative to the elevation terminal **61**.

Since the physical polarization direction or the direction of the electric field in subaperture *b* is opposite that of subaperture *a* and the physical polarization direction of subaperture *c* is opposite that of subaperture *d*, therefore the effective electrical phase at subaperture *b* is 0° phase and at subaperture *c* is 180° phase. By means of subapertures *a* and *b* being 0° effective relative phase and subapertures *c* and *d* being 180° effective phase between the subapertures for E or elevation system, the vertically polarized hybrid HE_{11} mode and the horizontally polarized TE_{02} modes are excited. The simultaneous presence and 90° phasing of the vertically polarized HE_{11} mode and the horizontally polarized TE_{02} mode provides the circularly polarized elevation difference mode. Each triangle in the FIG. 4 indicates the phase between the hybrids, whereas the phase in the subapertures is indicated by the number following E or elevation and A or azimuth phase. The phase with respect to either the azimuth marked A or elevation marked E indicates the phase of the corresponding terminal at the input of the eight ports of the four subapertures *a*, *b*, *c* and *d* for right circular polarization. Operation for left circular polarization is similar. The roles, however, of the feed terminals **61** and **62** are interchanged when the polarization in the difference mode changes from right circular polarization as shown in FIG. 4 to left circular polarization and thus therefore the azimuth difference mode channel becomes the elevation difference mode.

The tracking mode circuitry at this point on in the direction of the receiver and processing circuitry network for combining the difference mode signals conforms to standard monopulse bridge arrangements such as found on p. 178 of "Introduction of Radar Systems" mentioned previously.

Referring back to FIG. 2, the center conical sum mode transducer port **25** is specially dimensioned and formed having an inner ring **37** which is in the example described above about ⅛ inch thick and about 3 inches from the horn end of the port **25** in order to cut off the propagation of the generated difference modes (hybrid

$$HE_{11}=TE_{11}+TM_{11}$$

and TE_{20}) back into the sum system and thus avoid the deterioration of the difference mode axial ratio. Each of the eight difference mode ports has tuning stubs **40** therein for suppressing the unwanted TE_{12}, TM_{12}, TE_{21} and TM_{21} modes in the throat of the horn and to reduce the coupling between the sum and difference ports and between the various difference mode ports. The higher order difference modes generated by the eight element ring array after being reflected and modified by the conical sum mode transition in the mode coupler are finally filterd and phased by the mode filter **17** and horn **18** to produce the desired difference mode aperture distribution and primary patterns.

With just the four subapertures *a*, *b*, *c* and *d* providing circularly polarized waves radiating directly into space with the 90° phasing between the ports of the subapertures, the feed system would degenerate to a circularly polarized four horn monopulse system. However, since the mode coupler radiates into a single horn instead of space, the system becomes a single horn multimode system which has a more efficient monopulse aperture distribution than a four horn system.

A wideband tracking feed system required for satellite communication networks shall cover, for example, the 5925 to 6425 mHz. band for transmit and the 3700 to 4200 mHz. band for receive operation. The proper wideband phasing and control of the described modes for such cases is provided by mode filter **17** and horn **18**. The mode filter **17** is placed between the mode coupler **16** and the horn **18** wherein the communication (sum) and tracking (difference) mode signals are combined in a single aperture. Referring to FIGS. 5 and 6, the mode filter **17** is a square semi-exponential waveguide section having a ridge **41** on each of the four sides **42** to excite a wideband of frequencies. The mode filter **17** shown in FIGS. 5 and 6 has approximately a "half cosine function" profile along the axis of propagation, a square cross section and symmetrically located ridges **41** in its two main planes. This shape or any such appropriately tapered variation such as the half cosine function profile is arranged so that it results in a minimum square cross section between the two terminating flanges of the mode filter **17**. The "half cosine function" profile is only one example. Any one of many appropriately tapered variations along the axis of propagation may be selected wherein the selection of the length "*l*" of the mode filter and the rate of change in width "*w*" or shape of the profile (such as the amplitude of the above-described cosine function) is arranged so the frequency dependence of the phase between the TE_{20}, TE_{02} and hybrid $HE_{11}=TE_{11}+TM_{11}$ difference modes on one hand and the frequency dependence of the phase between the TE_{10} and TE_{30} sum modes on the other hand is virtually eliminated, and thus a very wide band multimode operation can be achieved. The square cross section of the mode filter **17** has a minimum width ""*w*" of typically 2λ and a minimum length "*l*" of 5λ where λ is the geometrical means of the limits of the nearly one octave frequency band represented by the lower receive and higher transmit frequencies mentioned in the above example. By the dimensions of the filter being so selected, only the desired higher order sum and difference modes can propagate through this filter section and the phase between these wanted modes assures low side lobes in the E and H planes in the primary pattern and leaves the axial ratio for the circularly polarized sum and difference modes unchanged. The exact dimensions of the above-described mode filter for each particular case using the above-given rules is easily achieved by anyone skilled in the microwave antenna art. The output cross section of the mode filter is made large enough so that only a small amount of a differential phase shift takes place between the modes in the multimode horn itself. The basic TE_{10} and the higher order TE_{30} sum modes generated by the step in the mode coupler **16** to the four inch cross section as filtered and phased by the mode filter and horn finally produce the sum mode aperture distribution and patterns. The mode filter **17** and the square semiexponential waveguide section **18** follow in such a manner that the generated higher order modes arrive at the aperture of the horn in the proper phase. The term "proper phase" means that the total aperture field of the horn is more or less axially symmetrically tapered in the complete, for example, 500 mMz. receive frequency band.

Referring to FIG. 7, the final shaping and the frequency stabilizing of the aperture field of the horn is achieved by the shape of the horn **18** which has an increase in the flare angle at the end of the horn. This increased flare angle produces a relatively large quadric phase error in the transmit frequency band and a smaller quadratic phase error in the receive band thus bringing the transmitter band beamwidth even closer to the receiver band beamwidth. The horn **18** also has fins **21** along the flared portion on each of the four sides to approximate even more a Gaussian shaped output pattern. The horn **18** also has a square waveguide section **22** in each of the four corners to increase the speed of the traveling waves in the extra flare section at the low end of the frequency band and doing so to provide a more uniform phase front at the aperture for low frequencies.

Thus far, we have concerned ourselves with the processing of the tracking mode signals and not the communication signal. Referring back to FIG. 1, the sum mode signals at the mode coupler **16** are fed to a three port polarizer section **12** through the conical center port **25**. The three port polarizer includes an orthogonal coupler **71**, a fixed 90° differential phase shifter **73** and a rotating 90° differential phase shifter **75**.

Referring to FIG. 8, the orthogonal coupler **71** is constructed of a square waveguide section **80** having a ridge **81** on the inside surface of each of the sides **82** to excite a wideband of frequencies. The coupler **71** acts to combine the transmit signals from transmit terminal **70** and the receive signals toward receive terminal **72** to a common square waveguide dimensioned and ridge loaded to propagate both signals. The transmitted signals are, for example, in the TE_{10} mode and the receive signals are, for example, in the orthogonal TE_{01} mode. Three internal irises **83** or narrow metal strips are provided within the orthogonal coupler **71** at the transmit end of the coupler. These irises are placed orthogonally to the electric field of the TE_{10} mode of the transmitter. The TE_{10} mode signals from the transmitted are coupled toward the first fixed phase shifter **73** with negligible reflection at the irises **83** and the orthogonal receive signals from the first fixed phase shifter **73** in the TE_{01} mode are reflected at irises **83** in the side arm of the orthogonal coupler **71** to the receiver terminal **72**. In this manner, these irises do not interfere with the transmitted wave, but act as a 90° elbow for the waves coming to receiver terminal **72** through the side arm **84**.

The first fixed phase shifter **73** illustrated in FIGS. 9 and 10 is a square waveguide section having a ridge **86** on each of the four sides to excite wideband of frequencies and is the next element in the direction toward the horn **18** from the orthogonal coupler **71**. This square waveguide section is capable of propagating signals in both the TE_{10} mode, for example, for the transmitter signals, and the orthogonal TE_{01} mode for the receiver signal. The first phase shifter **73** has fifteen irises **88** in this above-mentioned example in the lower right-hand corner of the waveguide when viewing the waveguide in the direction of propagation and has fifteen irises **88** in the upper left-hand corner of the waveguide. The series of corner irises **88** act in such a manner that an incoming wave with polarization parallel to the side wall of the square waveguide such as the TE_{10} or TE_{01} mode is split into two equal power orthogonal components and a nominally 90° differential phase shift takes place between the two components by the time these components are propagated through the phase shifter **73**. The end result of the power split and differential phase shift is that the unit converts the incoming linearly polarized wave into a left circularly polarized wave or right circularly polarized wave for a vertically or horizontally (transmit or receive respectively) polarized wave respectively. For this combination of polarization, the irises **88** in the phase shifter **73** are in the upper left- and lower right-hand corners, when one views the three port polarizer from the transmit input terminal. For the proper wide band operation of these irises **88** a post **90** has to be placed in the middle of each iris. These posts **90** resonate in the upper part of the frequency band for instance at 6.2 gH_z. in the above example and the irises **88** resonate in the lower part of the frequency band for instance at 4 gH_z. in the above example. In this manner their combined impedance remains nearly constant as a function of frequency and wide band operation is obtained. The residual mismatch effects of these strips or irises are compensated by tuning screws **89** which can be used also to further optimize the axial ratio produced by the phase shifter in the transmit and receive frequency band in the above example.

Since the orthogonal coupler **73** assures orthogonality between the transmitted and received waves, the corresponding received polarization is right circularly polarized or left circularly polarized.

The next unit in the three port polarizer towards the antenna is the rotating polarizer assembly **75**, see FIG. 11. The assembly consists of a rotary joint **74** with a square to circular waveguide transition **96** and then a circular to square waveguide transition **97**, a rotating 90° differential phase shifter **75** and a second rotary joint **76** with a square to circular waveguide transition **105** and a short section of a circular waveguide **106** coupled to the center port **25** of mode coupler **16**.

Referring to FIGS. 11 and 12, the first rotary joint **74** has a square to circular waveguide transition section **96**, a circular to square waveguide transition **97** and a pair of coaxial rotary flanges **98** and **99** wherein the gap **109** between the rotating flanges of the transitions is about 0.025 inch. The coaxial flanges **98** and **99** are located coaxially with both transitions and cover the gap between the transitions. Each of the combined rotary joint coaxial flanges **98** and **99** has two grooves **100** and **101** within the inner circumference of the rotary joint coaxial flange cover wherein the distance from the end of the groove **100** or **101** in the rotary joint to the end edge of the transitions is half a wavelength ($\lambda/2$) at the transmitter frequency for one groove and for the other groove is half a wavelength ($\lambda/2$) at the receiver frequency. The grooves **100** and **101** therefore act to provide two chokes, one resonant at the receiver frequency to reflect back into the waveguide the received signal and the other to reflect back the transmitted signal to thusly reduce radiation losses at the rotary joint.

The first rotary joint **74** acts with respect to the circularly polarized transmitted wave as a double transformer with a square to circular waveguide transition and a circular to square waveguide transition connected back to back. The output terminals of the first rotary joint **74** have a square waveguide cross section supporting the properly phased TE_{10} and TE_{01} modes. The center of the rotary flange **98** is circular. The diameter of the circular section of the waveguide is about the same as that of a side of a square so as to assure propagation of the circular TE_{11} mode. The output of the first rotary joint **74** is coupled to a rotating 90° differential phase shifter **75** which is electrically identical to the first fixed differential phase shifter **73** in FIGS. 9 and 10, having therein the 30 irises and posts with 15 of each in the appropriate two corners.

The rotating polarizer assembly accepts the circularly polarized waves from the fixed phase shifter **73** transforms these waves back to linear polarized waves at the outputs of the rotary joint **76**. The attitude of the output polarization is now however an orientation function of the rotating polarizer and the orthogonal relationship between the receive and transmit band waves remains at all attitudes. The output of the 90° differential phase shifter **75** toward the horn is fed to a second rotary joint **76** similarly built as shown and described in connection with FIG. 12 with the chokes resonating at the receive and transmit bands respectively. The output of the second rotary joint **76** is applied to the 2.125 inch diameter center circular waveguide port **25** which is part of the mode coupler **16**. Since the output polarization is always parallel to one side of the square waveguide, the output terminal of the fixed 90° polarizer and the position of the rotating polarizer determines the orientation of the linearly polarized transmitted waves. The rotatable 90° polarizer may be rotated using a motor **110** and gears **111** and **112** to align the sum mode circuitry with the linear polarization of the satellite. The attitude of the linear polarization is a function of the angle between the two phase shifters. The original orthogonal relationship however between the transmit and receive frequency band waves remains in all the attitudes. By removing the second phase shifter **75** and the two rotary joints **74**, **76** from the system, right or left circularly polarized signal operation is obtained for use with the transmission and reception of circular polarized signals at the horn.

What is claimed is:

1. A monopulse multimode feed system for propagating energy supplied thereto over a wide band of frequencies and comprising:

a mode coupler having a sum mode coupling port and a separate plurality of difference mode ports,

first means coupled to said sum port and responsive to said energy supplied thereto for providing a first plurality of modes having at least one state of polarization,

second means coupled to said separate plurality of difference mode ports and responsive to said energy supplied thereto for providing a second plurality of modes which are circularly polarized,

and third means coupled to said mode coupler including an energy propagating horn having a single aperture for controlling the amplitudes and phase relationships over said wide band of frequencies between the energy in said first and second pluralities of modes for providing radiation patterns with low side lobes in the E and H planes in the primary pattern and for maintaining the axial ratio for the circularly polarized difference modes.

2. The monopulse feed system as claimed in claim **1** wherein said sum mode coupling port is conically shaped.

3. The monopulse feed system as claimed in claim **1** wherein said mode coupler has a square waveguide cross section at the end of the coupler in the direction of said horn.

4. The monopulse feed system as claimed in claim **3** wherein said mode coupler includes means at said sum mode coupling port and within said square waveguide cross section whereby said first plurality of modes including the symmetrical TE_{10} and TE_{30} modes and TE_{12} and TM_{21} and TE_{21} and TM_{12} modes are excited into said third means.

5. The monopulse feed system as claimed in claim **4** wherein said separate plurality of difference mode ports are orthogonally paired and are located symmetrically about said sum mode port.

6. The monopulse feed system as claimed in claim **5** wherein said difference mode ports are eight in number and wherein a pair of said difference mode ports is orthogonally positioned at each of the four corners of said square waveguide cross section.

7. The monopulse feed system as claimed in claim **6** wherein said second means includes four 90° differential phase shifter and power splitters with a different one of said phase shifter and power splitters coupled to each pair of said orthogonally paired waveguide ports to provide circular polarization in said feed.

8. The monopulse feed system as claimed in claim **7** wherein each of said 90° differential phase shifted and power splitters is a short-slot hybrid.

9. The monopulse feed system as claimed in claim **8** wherein said second means includes means for properly phasing said paired waveguide ports relative to each other to excite TE_{20}, TE_{02}, and hybrids $TE_{11}+TM_{11}$ modes in the output of the mode coupler and to provide simultaneous presence and 90° phasing of the vertically polarized TE_{20} mode and horizontally polarized hybrid $TE_{11}+TM_{11}$ mode whereby a circularly polarized difference mode with a null plane in one plane is obtained and to provide the simultaneous presence and 90° phasing of the horizontally polarized TE_{02} mode and vertically polarized hybrid $TE_{11}+TM_{11}$ mode whereby a circularly polarized difference mode with a null plane in a plane orthogonal to said one plane is obtained.

10. The monopulse feed system as claimed in claim **9** wherein said means for properly phasing said paired waveguide ports includes a fifth and sixth hybrid with the output of a first one of said hybrids combined with the output of a second one of said hybrids at said fifth hybrid and with the output of a third one of said hybrids combined with the output of a fourth one of said hybrids at said sixth hybrid.

11. The monopulse system as claimed in claim **1** wherein said third means includes a mode filter having a single square aperture cross section and wherein the length and the change in width of said square aperture cross section of said mode filter is determined so as to control the frequency dependency of the phasing of the TE_{10} and TE_{30} modes over said wide band of frequencies to assure low side lobes in the primary pattern and to control the frequency dependency of the phasing of the TE_{20}, TE_{02} and hybrid $HE_{11}=TE_{11}+TM_{11}$ modes over said wide band of frequencies to maintain the axial ratio for the difference modes.

12. The monopulse feed system as claimed in claim **11** wherein the minimum width is on the order of 2λ and its length is on the order of 5λ, where λ is the geometrical means of the limits of an operating band of said wide band of frequencies.

13. The monopulse feed system as claimed in claim **12** wherein said square waveguide section has a half cosine function profile.

14. The combination as claimed in claim **1** wherein said horn is a square pyramidal horn having a flare angle close to the aperture of the horn that increases substantially so as to produce a large quadratic phase error at the higher frequencies of said wide frequency band to bring the higher frequency band beamwidth close to the lower frequency band beamwidth.

15. The combination as claimed in claim **6** wherein said conically shaped port has an inner iris ring in order to cut off the propagation of the generated difference mode back into the sum system.

16. The combination as claimed in claim **6** wherein each of the eight difference mode ports has tuning stubs therein for suppressing the unwanted TE_{12}, TM_{21} and $TE_{21}+TM_{12}$ modes and to reduce coupling between the sum and difference ports and between the difference ports.

17. The combination as claimed in claim **1** wherein said first means includes:

a first 90° differential phase shifter responsive to linearly polarized signals applied thereto and converts the linearly polarized waves into opposite sense circularly polarized waves,

a second 90° differential phase shifter coupled between the first phase shifter and the sum ports responsive to said circularly polarized waves present at its input to convert the circularly polarized waves present at its input into linearly polarized waves, and

means for rotating one of said phase shifters relative to the other where the attitude of the linear polarization is a function of the angle between the two positions of the two phase shifters.

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