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

REPLY TO
ATTN OF:

March 29, 1971

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

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

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

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.	:	3,373,431
Corporate Source	:	Hughes Aircraft Company
Supplementary Corporate Source	:	
NASA Patent Case No.	:	XNP-01735

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

G Parker

Gayle Parker

Enclosure:
Copy of Patent

FACILITY FORM 602

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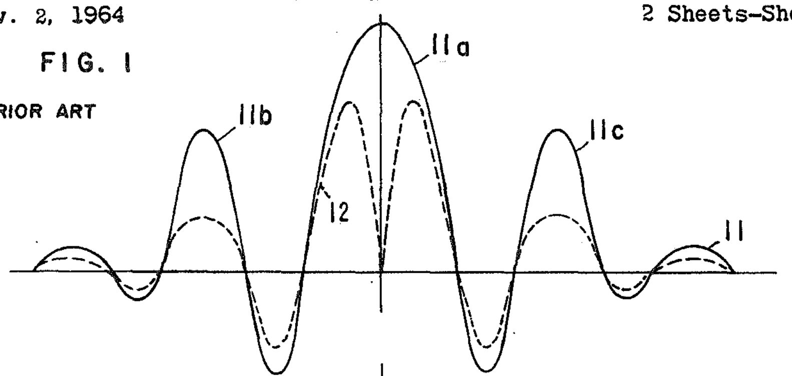
FIG. 1

PRIOR ART



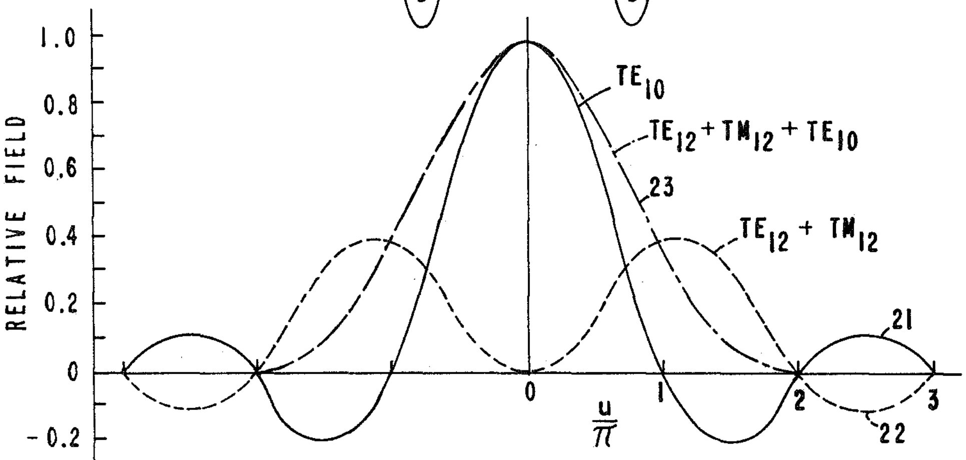


FIG. 2(a)

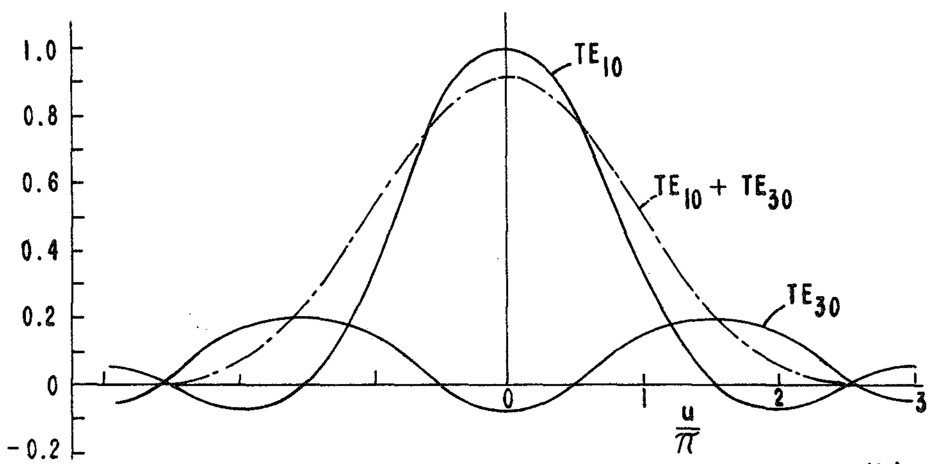
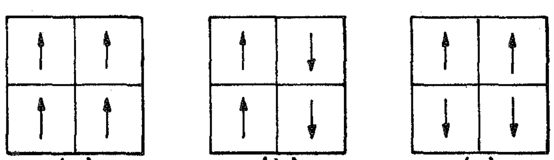


FIG. 2(b)



(a) SUM

(b) H-PLANE DIFFERENCE

(c) E-PLANE DIFFERENCE

FIG. 5

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March 12, 1968 JAMES E. WEBB 3,373,431
ADMINISTRATOR OF THE NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
LOW-NOISE SINGLE APERTURE MULTIMODE MONOPULSE
ANTENNA FEED SYSTEM

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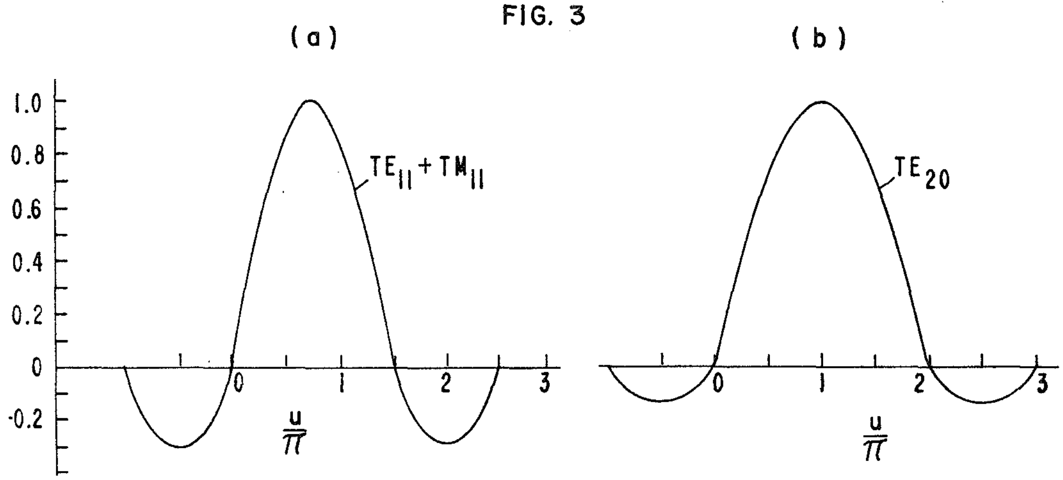
FIG. 3



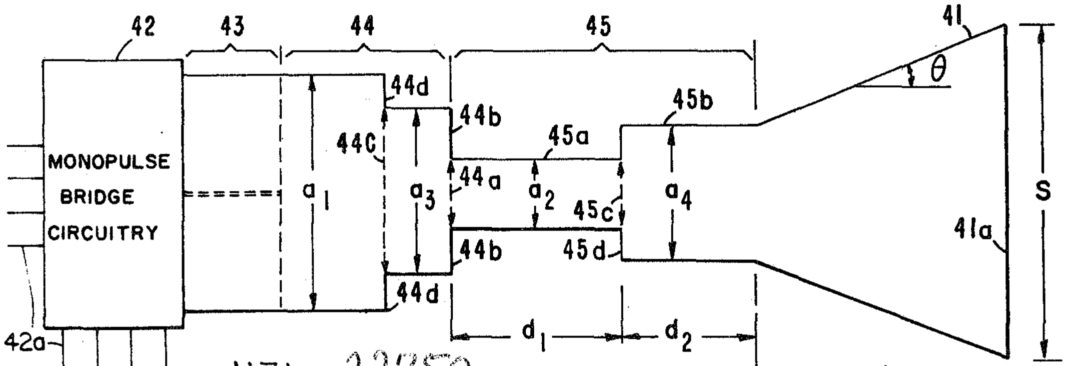


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FIG. 4

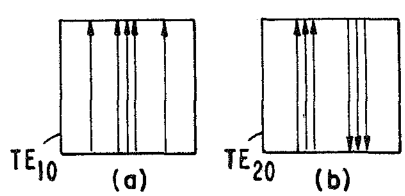

FIG. 6

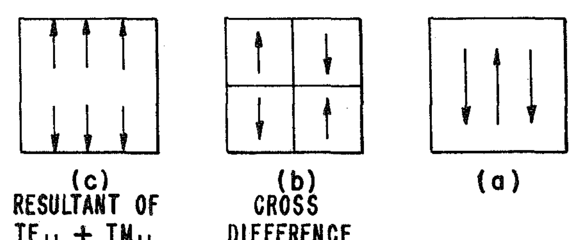

FIG. 7

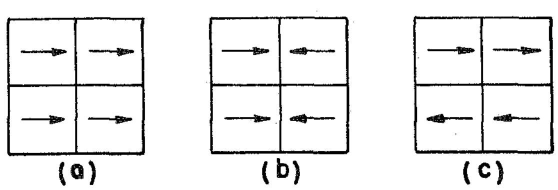

FIG. 8

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LOW-NOISE SINGLE APERTURE MULTIMODE MONOPULSE ANTENNA FEED SYSTEM

James E. Webb, Administrator of the National Aeronautics and Space Administration, with respect to an invention of Paul A. Jensen, Fullerton, Calif.

Filed Nov. 2, 1964, Ser. No. 408,438
8 Claims. (Cl. 343—786)

ABSTRACT OF THE DISCLOSURE

A feed system which includes a monopulse bridge capable of providing sum and dual plane (H and E) difference modes for two orthogonal polarization orientations. A multimode matching section is connected to match the principal modes from the bridge and to inhibit undesired modes. An excitation and control section is used to control the phases of the different modes, as well as, to excite additional modes. When these additional modes are combined with the sum modes they minimize the side lobes of the radiated sum patterns in both the E and H planes.

Origin of the invention

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

This invention relates to microwave communication systems and more particularly to a low-noise multimode monopulse antenna feed system.

In order to automatically track aircraft or long range missiles, various microwave transmitting and receiving systems have been developed. Similarly, radar systems have developed to discover objects by radiating energy which when bouncing off an object, is received and analyzed by the radar system to indicate the position of discovered object.

In all such systems, antennas are used to direct the energy into space and/or collect the received energy therefrom. The antenna may include a reflecting dish and a feed system of one or more horns through which the microwave energy is supplied to the reflecting dish, or received therefrom.

Recently, feed systems capable of generating and receiving microwave energy which propagates in a plurality of different modes, have been developed. These are known as multimode feed systems. Some feed systems also employ monopulse techniques in which energy transmitted from and received by the feed system is combined in such a manner that sum and difference radiation patterns are produced during transmission and/or reception. These patterns are then analyzed to determine the position of the detected object or the one which is to be automatically tracked.

Generally, a multimode feed system includes several horns, one or more of which propagate and receive energy in a plurality of modes. When a small number of single mode horns such as in the "Four Horn Feed System" are used, radiation patterns with undesired characteristics are produced. Due to these characteristics, the efficiency of the system is quite low, and the noise level of the antenna is high. Due to the high noise level, such systems are only used in short range communication operations. Other single mode multihorn feed systems employ as many as twelve horns which, though improving the performance of the system, are very complex and expensive to construct and maintain.

Some attempts have been made to provide an efficient

low noise multimode feed system with a single aperture or horn. Such a system, though operative, is limited to a circular horn through which energy having limited modes may propagate. In addition, the prior art multimode common horn feed system does not provide monopulse operation and is incapable of being used simultaneously for tracking and communication purposes. Thus, multimode prior art feed systems capable of monopulse operations are limited to multihorn systems or to systems which do not provide low noise sum channel operation. In addition, such systems provide only limited polarization diversity as well as being limited to relatively short range communication systems due to excessive antenna noise temperature.

Accordingly, it is an object of the present invention to provide an improved feed system which is not limited by the disadvantageous features of the prior art.

Another object of the present invention is the provision of a multimode single aperture feed system capable of monopulse operation.

Yet another object of the present invention is to provide a multimode single aperture monopulse feed system which may be operated for both communication and tracking simultaneously.

Still another object of the present invention is the provision of a low noise single aperture multimode monopulse feed system.

A further object of the present invention is the provision of a low noise aperture multimode feed system which is capable of dual plane monopulse operation, in which microwave energy may be transmitted and received simultaneously.

Still a further object of the invention is to provide a low noise single aperture multimode monopulse feed system with a high degree of polarization diversity.

These and other objects of the invention are achieved in a feed system wherein a monopulse bridge circuitry forms the sum and difference of up to four inputs to provide a dual plane monopulse operation, by providing a sum and dual plane difference channels for each polarization orientation of electromagnetic microwave energy. The bridge circuitry is capable of forming these sum and difference channels for two orthogonal polarization orientations so that the electromagnetic energy propagating through the feed system may be polarized in any sense, such as linear, circular or elliptical. A multimode matching network is connected to the monopulse bridge circuitry so as to match the principal modes of energy radiation necessary to form the sum and difference patterns, as well as inhibit any undesired modes of energy radiation, which are produced or may be reflected back into the monopulse bridge circuitry.

The novel system of the present invention also includes a mode excitation and control network in which additional modes necessary to be combined with the principal mode of energy radiation are excited. As a result, the energy radiated from the feed system or received by it produces a minimum antenna temperature, thereby reducing the noise of the antenna system. The mode excitation and control network is also used to filter out undesirable modes as well as control the phase of the various modes propagating therethrough. Similarly, the common radiating aperture is desired so that the various modes are in proper amplitude and phase relationships, to produce dual plane difference patterns as well as sum patterns with very low side lobes for dual plane monopulse operation. The elimination of the side lobes in the sum patterns represents the elimination of spillover of radiated energy, which generally accounts for the high noise temperature of the antenna. Thus, by suppressing energy spillover, the noise of the system is greatly reduced, thereby greatly increasing the signal-to-noise ratio capabilities of the system. The common radiating aperture is also designed to provide for proper directivity with respect to the antenna or reflector to be illuminated, thereby further increasing the overall performance of the microwave transmitting or receiving system.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIGURE 1 is a diagram of sum and difference radiation patterns in a single plane of a monopulse system;

FIGURES 2(*a*) and 2(*b*) are sum radiation patterns of a plurality of modes in planes E and H respectively;

FIGURES 3(*a*) and 3(*b*) are difference radiation patterns in planes E and H respectively;

FIGURE 4 is a side elevation of the feed system of the present invention;

FIGURES 5(*a*), 5(*b*) and 5(*c*) are diagrams of excitation fields of energy supplied to or from the multimode bridge circuitry incorporated in the present invention;

FIGURES 6(*a*), 6(*b*) and 6(*c*) are diagrams of modes TE_{10}, TE_{20} and $TE_{11}+TM_{11}$ respectively.

FIGURE 7(*a*) is a diagram of excitation field of energy which, when combined, produces a cross-difference mode;

FIGURE 7(*b*) is a diagram of mode TE_{30}; and

FIGURES 8(*a*), 8(*b*) and 8(*c*) are diagrams of excitation fields of energy which, when combined, produces modes TE_{01}, TE_{02} and $TE_{11}+TM_{11}$ respectively.

Reference is now made to FIGURE 1 which is a diagram of conventional radiation patterns in a single plane, such as the E plane produced by a conventional monopulse feed system. Solid line **11** represents a sum radiation pattern, and dashed line **12** represents a difference radiation pattern. Similar sum and difference radiation patterns are produced in the H plane. For example, by generating electromagnetic energy in the principal modes, TE_{10}, TE_{20} and $TE_{11}+TM_{11}$, the sum, H plane difference and E plane difference radiation patterns may be created.

From FIGURE 1, it is seen that the sum radiation pattern **11**, in addition to comprising a main lobe **11*a***, also includes secondary side lobes **11*b*** and **11*c***. As is known in the art, these lobes (**11*b*** and **11*c***) represent spillover energy which reduces the amount of energy represented in the main lobe **11*a***. Such spillover energy generally increases the antenna temperature which greatly increases undesired noise. Consequently, feed systems which do not eliminate such energy spillover represented by the side lobes, cannot be used for long range tracking applications, since in such applications, the signals are quite small and with feed arrangements producing high noise, satisfactory signal-to-noise ratios cannot be obtained.

According to the teachings of the present invention, however, a feed system is provided in which, in addition to generating the principal modes necessary to produce the sum and difference radiation patterns, the novel system also generates auxiliary modes which, when combined with the principal modes, provide sum radiation patterns in which the side lobes adjacent to the main lobe are completely suppressed. Thus, the novel feed system of the present invention greatly increases the amount of energy represented in the main lobe, as well as minimize the noise produced by the system. In addition to providing sum radiation patterns with suppressed side lobes, the novel system of the present invention also provides difference radiation patterns in both the H and E planes so that both azimuth and elevation differences may be detected simultaneously.

For explanatory purposes only, let us assume that the sum and difference radiation patterns are to be provided by utilizing the basic TE_{10} mode and modes TE_{20} and

$TE_{11}+TM_{11}$. The radiation patterns of such modes are shown in FIGURES 2 and 3 to which reference is made herein. FIGURE 2(*a*) represents the radiation pattern of mode TE_{10} in the E plane, and FIGURE 2(*b*) represents the radiation pattern of mode TE_{10} in the H plane. Similarly, FIGURES 3(*a*) and 3(*b*) represent the difference radiation patterns of modes $TE_{11}+TM_{11}$ and TE_{20} in planes E and H respectively. By examining the field distributions of the various modes possible, it may be shown that the probable modes necessary to suppress the side lobes of the sum radiation patterns are the TE_{30} mode for the H plane sum pattern, and a combination of the TE_{12} and TM_{12} modes for the E plane sum radiation pattern. The radiation patterns of such modes are shown in FIGURES 2(*a*) and 2(*b*) by lines designated with the appropriate modes.

As seen from FIGURE 2(*a*), by combining the sum radiation pattern in the E plane of the mode TE_{10} with the sum radiation pattern in the E plane of modes $TE_{12}+TM_{12}$, the second lobe of the TE_{10} mode, designated by numeral **21**, is suppressed due to the reverse polarity of lobe **22** of the radiation pattern of modes $TE_{12}+TM_{12}$. Thus, the resultant of the three modes, namely, of modes $TE_{12}+TM_{12}$ and TE_{10} does not have a secondary lobe. Rather, the resultant only comprises the major lobe **23**. Similarly, in the H plane of the sum radiation pattern [FIGURE 2(*b*)], the TE_{10} mode is combined with mode TE_{30} to produce a resultant without a secondary lobe.

According to the teachings of the present invention, therefore, a system is provided in which, in addition to mode TE_{10}, modes TE_{30} and $TE_{12}+TM_{12}$ are excited, so that when combined, dual plane sum patterns may be provided without side lobes or energy spillover. The feed system of the present invention also generates additional modes such as mode TE_{20}, necessary for the H plane difference pattern and the $TE_{11}+TM_{11}$ modes which are necessary for the E plane difference pattern. The difference radiation patterns in planes E and H are respectively shown in FIGURES 3(*a*) and 3(*b*). From FIGURES 2(*a*) and 2(*b*), it should be noted that even though the E and H plane sum patterns do not have the same zeros, the beam widths are quite close to being equal at least down to the 0.1 power point. Also the envelope of the difference radiation pattern in each plane at least to the first null, lies within the corresponding envelope of the sum pattern, thus giving near optimum illumination of both sum and difference simultaneously.

Reference is now made to FIGURE 4 which is a side elevational view of the feed system of the present invention. As seen therein, the system comprises a multimode radiating horn **41** having a single aperture **41*a***, and a monopulse bridge circuitry **42** which is a standard four guide monopulse circuit, providing dual polarization capability. The microwave electromagnetic energy excited in the bridge circuitry **42** is fed through a four guide or port unit **43** to a multimode matching section **44**. The unit **43** and the multimode matching section **44** may be constructed of the same wave guide section. The energy from the multimode matching section **44** is fed to the multimode radiating horn **41** through an excitation and control network **46** which comprises a difference mode phasing section **45*a*** and a sum mode excitation and control section **45*b***.

In operation, the monopulse bridge circuitry **42** forms the sum and difference of up to four inputs to provide a sum and dual plane difference channels for each polarization orientation. When the feed system transmits energy, energy first supplied to the bridge from an external source (not shown) through the plurality of input lines is shaped within the bridge. Thereafter, it is supplied to the four port unit **43** and therefrom it is fed into the multimode matching section **44**. Therein, the principal modes necessary to form the sum and difference patterns are excited. In addition, the matching section **44** is used to inhibit or suppress undesired modes which are excited due to the configuration of the four port unit **43** through which energy is supplied to the matching section **44**.

Energy may be supplied to the bridge through a plurality of inputs **42**_a_ in dual polarization orientations, as well as be received therefrom when the system is in a receiving state.

Briefly, the bridge **42** consists of a plurality of waveguides to which energy is supplied (in the transmit mode of operation). The modes which are excited therein provide sum and difference dual plane patterns. For polarization in two orthogonal polarization orientations, such as vertical and horizontal polarization, duplicate sets of waveguides are required. Monopulse bridges are known by those familiar with monopulse microwave techniques and applications.

For example, in "Introduction to Radar Systems" by Merrill L. Skolnik, published in 1962 by McGraw-Hill Book Company, the basic function of such a bridge is shown on p. 178. Other prior art references to similar circuitry include p. 71 in "Introduction to Monopulse" by Donald R. Rhodes, published by McGraw-Hill Book Company, in 1959, and an article by Leon J. Ricardi and Leon Niro entitled "Design of a Twelve-Horn Monopulse Feed" published by Lincoln Laboratory of MIT. Special attention is directed to FIGURE 3 of the article. The foregoing are but exemplary of available prior art references related to the monopulse bridge. Due to the extensive prior art the bridge circuitry **42** is shown in block form.

Similarly, the four port unit **43** is shown in block form since it merely consists of four adjacent square waveguide ports which together form a larger square. The relative positions of the four ports are as shown in any of the mode diagrams of FIGURES 5, 6 and 8. Like the unit **43** all other units are square waveguides.

The excitation and phasing control section **45** is used to form additional modes necessary to accomplish the desired side lobe suppression. For example, the boundary between sections **45**_a_ and **45**_b_ is designed to excite modes TE_{12}, TM_{12} and TE_{30} [FIGURES 2(_a_) and 2(_b_)] which are necessary to suppress the side lobes in the E and H plane sum radiation patterns. In addition, the difference mode phasing section is used to control the phase relationship between the modes necessary to provide the difference radiation patterns in the E and H planes.

For a better understanding of the present invention, in the following description, let us assume that sum and difference dual plane patterns with suppressed side lobes are to be radiated with principal modes TE_{10}, TE_{20} and $TE_{11}+TM_{11}$, the feed system transmitting energy to the reflector of the antenna.

Reference is now made to FIGURES 5(_a_), 5(_b_) and 5(_c_) which are diagrams of the excitation fields of energy in the four port unit as a function of energy supplied thereto from the monopulse bridge circuit **42**. For example, when energy represented by the field excitation shown in FIGURE 5(_a_) is provided, mode TE_{10} as diagrammed in FIGURE 6(_a_) to which reference is made herein, is excited in the multimode matching section **44**. FIGURES 6(_b_) and 6(_c_) represent modes TE_{20} and the resultant of modes $TE_{11}+TM_{11}$ respectively which are excited in the multimode matching section **44** as a result of the energy represented by the excitation field shown in FIGURES 5(_b_) and 5(_c_) respectively.

In addition, however, to exciting modes TE_{10}, TE_{20} and $TE_{11}+TM_{11}$ as shown in FIGURES 6(_a_), 6(_b_) and 6(_c_) respectively, the matching section **44** also excites undesired modes which must be suppressed. For example, from the field excitation diagrammed in FIGURE 5(_a_), it is seen by one familiar with the art that in addition to mode TE_{10}, [FIGURE 6(_a_)], mode TE_{30}, which is diagrammed in FIGURE 7(_a_), is excited. Therefore, in designing the multimode matching section **44**, boundary conditions between the section **44** and the difference mode phasing section **45**_a_ are introduced in order to suppress such a mode from being reflected back into the bridge circuitry **42**. This is accomplished by designing the boundary **44**_a_ with a step **44**_b_ thus reducing the dimension of the matching section from a height a_1 to a height a_2 at the boundary **44**_a_.

The creation of the boundary step **44**_b_, even though it advantageously eliminates the TE_{30} mode, also produces undesired effects. Namely, the step **44**_b_ causes a mismatch of the principal mode TE_{10} thereby exciting a cross-difference mode, which is diagrammatically shown as a four port field excitation in FIGURE 7(_b_). This mode, unless suppressed, tends to reflect back into the bridge circuitry **42**. However, according to the teachings disclosed herein, the multimode matching section **44** is shaped internally with a plurality of protruding members known in the art as pins or posts. These members are positioned within the matching section so that, in essence, a counter cross-difference mode is excited which cancels the undesired cross-difference mode.

As seen from FIGURE 7(_b_) the cross-difference mode is the TE_{21} mode which also has longitudinal components. By positioning the posts to intercept these longitudinal components the cross-difference mode is cancelled. Buttons, analogous to variable height posts may also be used as impedance matching devices. Posts of variable height are described on p. 271 of "Waveguide Handbook" volume 10 of the Radiation Laboratory Series, published by McGraw-Hill Book Company 1951.

The design of the multimode matching section **44** is also controlled by the manner in which the energy diagrammatically represented in FIGURES 5(_a_) and 5(_b_) is affected in the section to produce modes TE_{20} and $TE_{11}+TM_{11}$ shown in FIGURES 6(_b_) and 6(_c_) respectively. Namely, the section is designed to insure that the principal modes for the H plane difference pattern and E plane difference pattern are properly excited.

It has been found that the TE_{20} mode is properly excited. But, modes TE_{11} and TM_{11} for providing the E plane difference pattern are mismatched at the boundary designated in FIGURE 4 by numeral **44**_a_. Such mismatching is overcome by including within the matching section **44** an auxiliary boundary **44**_c_ by means of an auxiliary step **44**_d_. Thus, the height dimension of the matching section **44** varies from a_1 to a smaller height a_3, and at the outside boundary **44**_a_, the height dimension is again reduced to a_2, $a_1>a_3>a_2$. The length of the matching section from the boundary with the four port unit to a point intermediate boundaries **44**_a_ and **44**_c_ is substantially equal to half a wavelength of the expected energy to be radiated.

From the multimode matching section **44** wherein the principal modes are excited and undesired modes are suppressed, the principal modes propagate towards the aperture **41**_a_ of the common radiating horn **41** through a difference mode phasing section **45**_a_. The height dimension of the section is a_2, namely the height of the boundary **44**_a_. The length of the section designated d_1 is controlled to provide the proper phase relationship between the principal difference modes $TE_{11}+TM_{11}$ which provide the E plane difference pattern and the resultant of the mode TE_{20} and additional modes $TE_{22}+TM_{22}$ which are excited by the boundary designated **45**_c_ between sections **45**_a_ and **45**_b_, as will be explained hereinafter. The boundary **45**_c_ between the difference mode phasing section **45**_a_ and the sum mode excitation and control section **45**_b_ is created by means of a step **45**_d_ so that the height dimension of the sum mode excitation and control section equals a_4 which is greater than a_2. The length of the sum mode excitation and control section **45**_b_ is designated in FIGURE 4 by d_2.

The presence of the step **45**_d_ produces a mismatch in several of the principal modes, therefore exciting additional modes, some of which are desirable while others need be suppressed. The magnitude of the step **45**_d_ is controlled as a function of the desired amplitudes of the additional modes.

Principal sum mode TE_{10} is excited by the step **45*d*** of the boundary **45*c*** to produce additional modes TE_{30} and $TE_{12}+TM_{12}$. As previously explained in conjunction with FIGURES 2(a) and 2(b), it is these three additional modes that are necessary to suppress the major side lobes of the sum patterns in the H and E planes. Therefore, the step **45*d*** is adjusted to insure that these three additional modes are excited with proper amplitude so that when they are combined with the principal sum mode TE_{10}, the side lobes are suppressed. Thus, by providing a simple sum mode excitation and control section, which is a simple waveguide with a square cross-section having a height dimension greater than that of the preceding waveguide section **45*a***, a step **45*d*** is formed. This step which is most conveniently created produces additional modes which, when combined with a principal mode, produces sum patterns with suppressed side lobes. The simplicity of the step is most efficient since energy losses are greatly minimized.

Principal difference modes TE_{20}, TE_{11} and TM_{11} are also excited by the boundary **45*c***. TE_{20} excites higher order modes TE_{40}, TE_{22} and TM_{22}. TE_{11} excites mode TE_{13}, and TM_{11} excites mode TM_{13}. Of these additional modes TE_{40}, TE_{13} and TM_{23} are suppressed from propagating to the radiating aperture **41*a*** by selecting the height dimension a_4 to be smaller than the cutoff height dimension of these three modes. Namely

$$a_4 < a_{\text{cutoff}} TE_{40}$$

$a_{\text{cutoff}}TE_{13}$ or $a_{\text{cutoff}}TM_{13}$. Thus, the only additional difference modes are TE_{22} and TM_{22} excited by TE_{20}. These are not suppressed and therefore need be controlled to provide the proper difference pattern in the H plane.

In designing the common radiating horn **41**, various known factors must be considered. Generally, the size S of the aperture **41*a*** is a function of the reflector bowl of the antenna with which the feed system is used. In addition, the flare angle θ of the horn **41** is generally limited by the size S of the aperture **41*a*** as well as the wavelength of the energy to propagate therethrough. Also, the flare angle should be selected so that the phase error across the aperture **41*a*** is not excessive.

The choice of the flare angle greatly affects the required horn length d_3 for a given aperture size S and a given height dimension a_4 of the central section **45*b***. Since the phasing between the modes is a function of length, i.e.

$$\Delta\phi = \int_0^L (\beta_1 - \beta_2)\,dl$$

where $\Delta\phi$=differential phase shift between modes, β_1 and β_2 are propagation constants of two of the modes and l is length along the horn, the flare angle must be chosen carefully to insure that a correct phasing of all the modes at the aperture **41*a*** results.

From the foregoing description, it is thus seen that the total length (d_2+d_3) from the boundary **45*c*** to the aperture **41*a*** must be controlled so that the various principal modes are in proper phase relationship to insure the suppression of the side lobes of the sum patterns in the E and H planes. It should be noted that in designing the sum mode excitation and control section **45*b***, its length d_2 should be sufficient to insure that the additional difference modes such as TE_{40}, TE_{13} and TM_{13} are adequately filtered or suppressed therein.

As previously explained, in addition to difference modes TE_{20} and $TE_{11}+TM_{11}$, additional difference modes $TE_{22}+TM_{22}$ which are excited by the boundary **45*c*** propagate through the horn **41** to the aperture **41*a***. The phase relationship between the modes producing the difference patterns in the E and H planes is of particular significance when electromagnetic energy polarized in other than a linear orientation is propagated. For example,

when the energy is circularly or elliptically polarized, the phase relationship between the modes $TE_{11}+TM_{11}$ providing the E plane difference pattern and the resultant of the mode TE_{20} and the additional modes $TE_{22}+TM_{22}$ excited thereby is quite critical. To accomplish such proper phase relationship, the length d_1 of the difference mode phasing section **45*a*** together with the flare angle θ are controlled. Thus, when nonlinear polarized energy propagates through the feed system, in addition to controlling the phase relationship between the modes necessary to provide sum patterns with suppressed side lobes, the resultant modes for providing difference patterns in the E and H planes are in proper phase relationship.

From the foregoing description, it is seen that the present invention provides a novel feed system wherein multimodes are propagated to produce sum and difference radiation patterns in dual planes, namely, in both the E and H planes. The sum patterns in both planes have suppressed side lobes so that a minimum amount of spillover energy is propagated, thereby greatly reducing the noise of the antenna fed by the system of the invention.

The system hereinbefore, has been described in conjunction with electromagnetic energy polarized in a vertical linear direction applied by the bridge circuitry **42** as schown in FIGURES 5(*a*), 5(*b*) and 5(*c*). However, the invention is not limited to a single polarization orientation. Rather, the conventional bridge circuitry **42** may be operated to generate energy polarized in a horizontal linear direction as shown in FIGURES 8(*a*), 8(*b*) and 8(*c*) to which reference is made herein. FIGURE 8(*a*) is a field excitation diagram of energy which, when matched in the multimode matching section **43**, results in a mode TE_{01}. Similarly, energy represented by the field excitations shown in FIGURES 8(*b*) and 8(*c*) are matched to provide modes TE_{02} and the resultant of modes TE_{11} and TM_{11} respectively.

The matching section **44** as well as the sections **45*a***, **45*b*** and the horn section **41**, are prefectly symmetrical about the propagation axis of the feed system, so that additional modes TE_{03} and $TE_{21}+TM_2$ (for the dual plane sum patterns may be excited by mode TE_{01}. Also, modes $TE_{22}+TM_{22}$ may be excited by mode TE_{02}. Since the system is symmetrical, the phase relationships between the modes is controlled so that sum patterns in both the E and H planes with suppressed side lobes may be obtained with principal mode TE_{01}. In addition, dual plane difference patterns may be obtained from modes $TE_{11}+TM_{11}$ and $TE_{02}+TE_{22}+TM_{22}$.

The monopulse bridge circuitry **42** may also be operated to provide energy so that the energy propagated through the aperture **41*a*** is polarized in any desired orientation such as circular or elliptical. This is accomplished by controlling the phase relationship between the vertically and horizontally polarized energy simultaneously provided by the bridge. The direction of phase relationship, namely whether the vertically polarized energy leads or lags the horizontal polarized energy controls whether the propagated energy is polarized in a left or right polarization direction respectively.

In one specific embodiment, designed for transmission at 2300 megacycles (mc.), the dimensions of the various parts of the feed system shown in FIGURE 4 were as follows: S=24; d_1=8.400; d_2=21.500; d_3=67; a_1=6.56; a_2=5.400; a_3=5.727; a_4=7.940; the four port unit **43** was 4.5 inches long, with each port 3.2 x 3.2 inches square; in the multimode matching section **44**, the 6.56 x 6.56 section was 2.083 inches long, while the 5.727 x 5.727 section was 1.200 inches long.

There has been accordingly shown and described herein a novel and useful feed system capable of dual plane monopulse operation. The electromagnetic energy may be polarized in a single or dual orthogonal polarization so as to provide energy polarized in any selection state or orientation. In addition to the principal modes necessary to provide the sum and difference patterns of monopulse operation, the system of the present invention excites additional modes which almost completely cancel the primary side lobes in the sum pattern thus providing a low noise system.

Even though hereinbefore, the invention has been described in a transmitting mode of operation, it is apparent to those familiar with the art, that the novel feed system may be operated in a receiving mode of operation. Similarly, the polarization diversity enables simultaneous transmit and receive operation.

It is apparent to those familiar with the art, that modifications may be made in the arrangements as shown without departing from the true spirit of the invention. Therefore, all such modifications and equivalents are deemed to fall within the scope of the invention as claimed in the appended claims.

What is claimed is:

1. A monopulse multimode feed system for propagating energy supplied thereto comprising first means to which said energy is supplied for providing energy in a first plurality of modes and having at least one state of polarization; second means including step means responsive to the energy in at least some of said first plurality of modes for providing energy in a second plurality of modes; and third means including an energy propagating horn having an aperture for controlling the amplitudes and phase relationships between the eneryg in said first and second pluralities of modes for providing at least sum radiation patterns with suppressed side lobes in the E and H planes, said first plurality of modes comprises at least mode TE_{10}, and said second plurality of modes comprising at least modes TE_{30}, TE_{12} and TM_{12} being provided as a function of the height dimension of said second means, said third means controlling as a function of the dimensions thereof the amplitudes and phase relationships between modes TE_{10}, TE_{30}, $TE_{12}+TM_{12}$ for combining modes TE_{10} and TE_{30} to provide a sum pattern with suppressed side lobes in the H plane and controlling modes TE_{10} and $TE_{12}+TM_{12}$ to provide a sum pattern with suppressed side lobes in the E plane.

2. A monopulse feed system as recited in claim 1 wherein said first plurality of modes further comprises modes TE_{20}, TE_{11} and TM_{11}, said second plurality of modes further comprises modes TE_{22} and TM_{22}, and said system further including difference mode phase control means for controlling as a function of the dimensions thereof the phase relationships between a first resultant mode of modes TE_{11} and TM_{11} to provide a difference pattern in the E plane and a second resultant mode of modes TE_{20}, TE_{22} and TM_{22} so as to provide a difference pattern in the H plane.

3. A monopulse multimode feed system for propagating energy as recited in claim 1 wherein said first plurality of modes comprises at least modes TE_{01}, and said second plurality of modes comprising at least modes TE_{03}, TE_{21} and TM_{21} being provided as a function of the height dimension of said second means, said third means controlling as a function of the dimensions thereof the amplitudes and phase relationships between modes TE_{01}, TE_{03}, $TE_{21}+TM_{21}$ for combining modes TE_{01} and TE_{03} to provide a sum pattern with suppressed side lobes in the H plane and controlling modes TE_{01} and $TE_{21}+TM_{21}$ to provide a sum pattern with suppressed side lobes in the E plane.

4. A monopulse feed system as recited in claim 3 wherein said first plurality of modes further comprises modes TE_{02}, TE_{11} and TM_{11}, said second plurality of modes further comprises modes TE_{22} and TM_{22}, and said system further including difference mode phase control means for controlling the phase relationships between a first resultant mode of modes TE_{11} and TM_{11} for providing a difference pattern in the E plane and a second resultant mode of modes TE_{02}, TE_{22} and TM_{22} for providing a difference pattern in the H plane.

5. A feed system for propagating energy comprising: means for exciting energy in at least a TE_{10}, TE_{20}, TE_{11} and TM_{11} modes; control means for exciting said energy in said TE_{10} mode to provide energy in TE_{30}, TE_{12} and TM_{12} modes and for exciting said energy in TE_{20} mode to provide energy in modes TE_{22} and TM_{22}; a wave guide section including a radiating horn having an aperture for controlling the amplitude and phase relationship of said energy in modes TE_{10}, TE_{30}, TE_{12} and TM_{12} so as to provide sum radiation patterns with suppressed side lobes in the E and H planes of electromagnetic radiation; and difference mode phase control means for controlling the phase relationship between a first resultant mode of modes TE_{11} and TM_{11} and a second resultant mode of modes TE_{20} and $TE_{22}+TM_{22}$, for providing difference patterns in the E and H planes respectively.

6. A feed system for propagating energy supplied thereto comprising: means to which said energy is supplied for providing energy in at least TE_{01}, TE_{02}, TE_{11} and TM_{11} modes; mode control means including step means responsive to the energy in said TE_{01} mode for providing as a function of the dimensions of said step means additional modes TE_{03}, TE_{21} and TM_{21} and for providing in response to the energy in said TE_{02} mode energy in modes TE_{22} and TM_{22}, means including an energy propagating horn having an aperture for controlling as a function of the geometrical configuration thereof the amplitudes and phase relationships of the energy in said modes TE_{01}, TE_{03}, TE_{21} and TM_{21} so as to provide sum radiation patterns with suppressed side lobes in the E and H planes of electromagnetic radiation; and difference mode phase control means for controlling the phase relationship between a first resultant mode of modes $TE_{11}+TM_{11}$ and a second resultant mode of modes TE_{02} and $TE_{22}+TM_{22}$, to provide difference patterns in the E and H plane respectively.

7. A monopulse multimode feed system for propagating energy supplied thereto comprising: first means including mode matching means to which said energy is supplied for providing energy in first and second pluralities of modes polarized in dual orthogonal orientations; mode control means having a preselected height dimension responsive to at least some of the energy in said first and second pluralities of modes for providing energy in third and fourth pluralities of modes as a function of the height dimension thereof; and third means including an energy propagating horn having an aperture for controlling as a function of the dimensions thereof the amplitudes and phase relationships of the energy in at least some of said first and third pluralities of modes and in at least some of said second and fourth pluralities of modes so as to provide at least sum radiation patterns with suppressed side lobes in dual orthogonal polarization orientations in the E and H planes of electromagnetic radiation, said first and second pluralities of modes comprise at least modes TE_{10} and TE_{01} respectively, said third plurality of modes comprises at least modes TE_{30}, TE_{12} and TM_{12}, said fourth plurality of modes comprises at least modes TE_{03}, TE_{21} and TM_{21}, said third means being symmetrical about the propagaiton axis thereof for controlling the interrelationship between modes TE_{10}, TE_{30}, TE_{12} and TM_{12} so as to combine mode TE_{10} with modes $TE_{12}+TM_{12}$ to provide a first set of sum patterns with suppressed side lobes in the H and E radiation planes respectively, said third means further controlling the interrelationship between modes TE_{01}, TE_{03}, TE_{21} and TM_{21} so as to combine mode TE_{01} with mode TE_{03} and mode TE_{01} with modes $TE_{21}+TM_{21}$ to provide a second set of sum patterns with suppressed side lobes in the H and E radiation planes respectively.

8. A monopulse feed system as recited in claim 7 wherein said first plurality of modes further includes modes TE_{20}, TE_{11} and TM_{11} in a first polarization orientation, said second plurality of modes further includes modes TE_{02}, TE_{11} and TM_{11} in a second polarization orientation orthogonal to said first orientation, each of said

third and fourth pluralities of modes includes modes TE_{22} and TM_{22} in dual orthogonal polarization orientation, and said system further including difference mode phase control means for controlling the phase relationships between modes $TE_{11}+TM_{11}$ and the resultant of modes TE_{20} and $TE_{22}+TM_{22}$ in said first polarization orientation to provide a first set of difference patterns in the E and H planes, said difference mode phase control means further controlling the phase relationship between modes $TE_{11}+TM_{11}$ and the resultant of modes TE_{02} and TE_{22} and TM_{22} in said second polarization orientation to provide a second set of difference patterns in the E and H planes.

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