United States Patent

Beguin

[15] **3,699,583**

[45] **Oct. 17, 1972**

[54] **PHASE CORRECTION APPARATUS FOR CIRCULAR POLARIZATION OPERATION MONOPULSE ANTENNA HORN**

[72] Inventor: **Daniel Edmund Beguin,** Saint-Prix, France

[73] Assignee: **International Standard Electric Corporation,** New York, N.Y.

[22] Filed: **July 26, 1971**

[21] Appl. No.: **166,065**

[52] **U.S. Cl.**.....**343/756,** 343/786

[51] **Int. Cl.**.....**H01q 19/00**

[58] **Field of Search**.....343/756, 778, 786, 909

[56] **References Cited**

UNITED STATES PATENTS

3,624,655 11/1971 Sato.....343/756

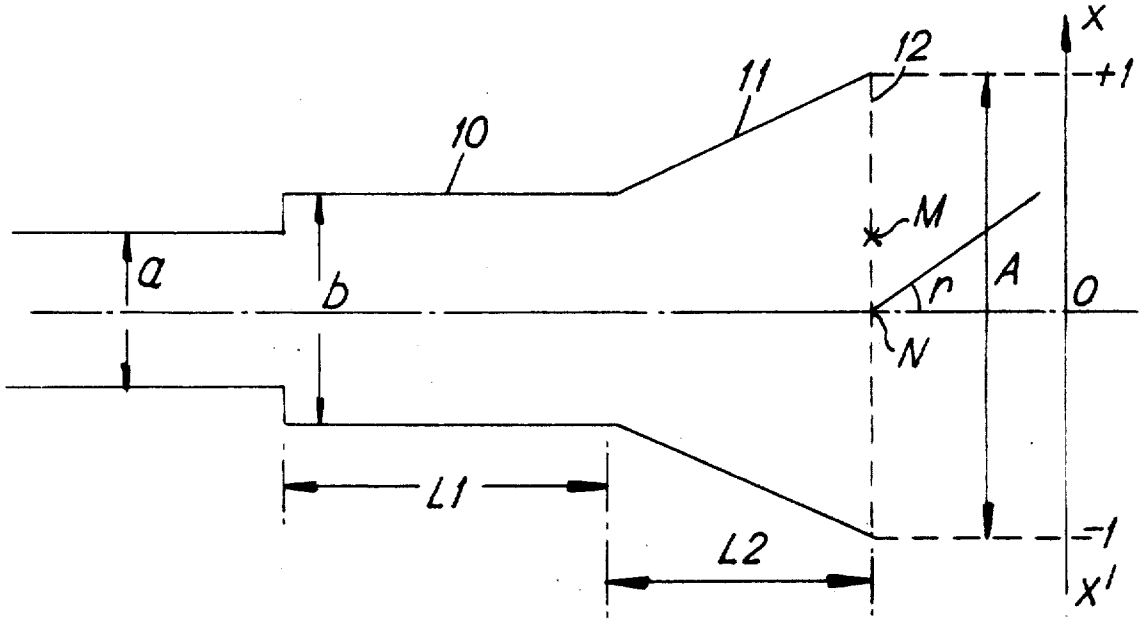
Primary Examiner—Eli Lieberman

Attorney—C. Cornell Remsen, Jr. et al.

[57] **ABSTRACT**

A multimode horn arrangement with circular polarization grid inserted into the horn aperture. For multimode operation of a monopulse system the phasing section length is chosen to compensate for polarizer phase errors.

3 Claims, 8 Drawing Figures



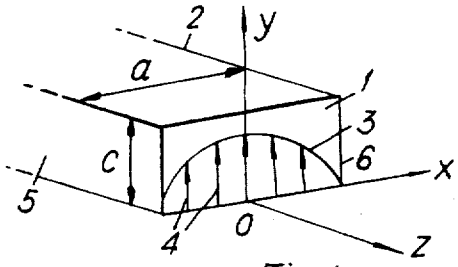


Fig. 1.

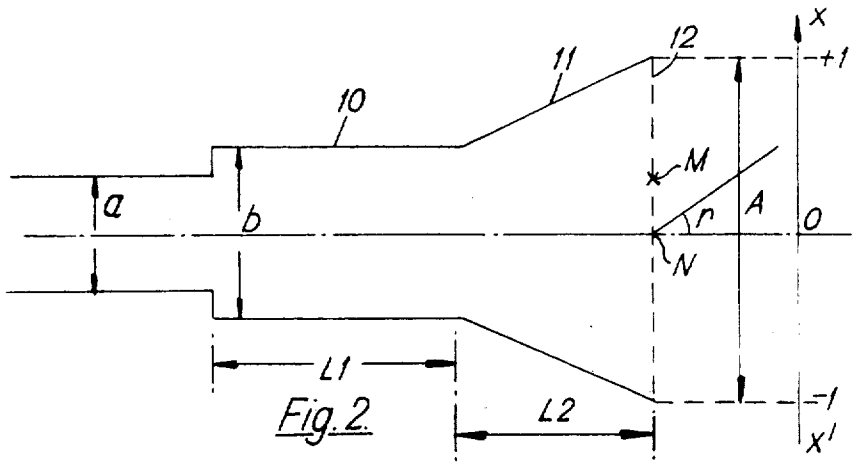


Fig. 2.

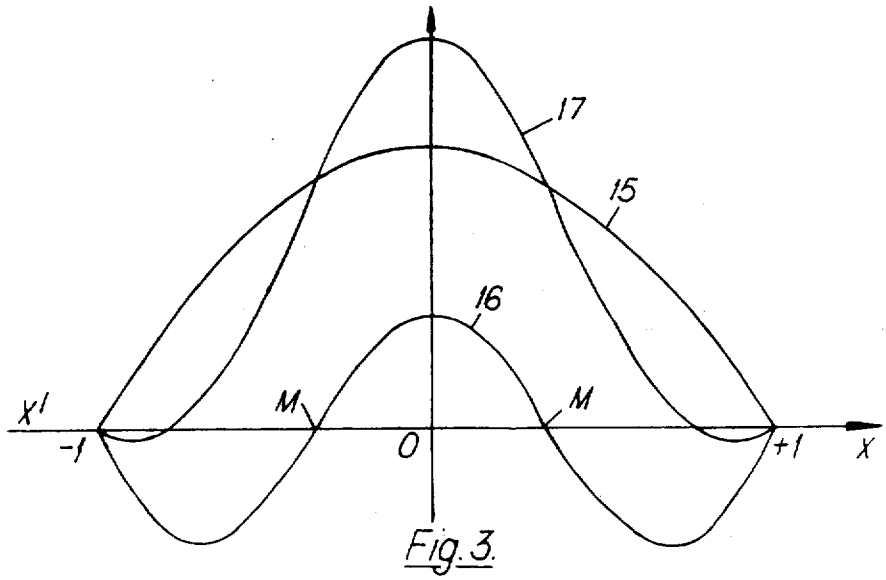


Fig. 3.

Inventor
Daniel Edmund Beguin

By William T. O'Neil
Agent

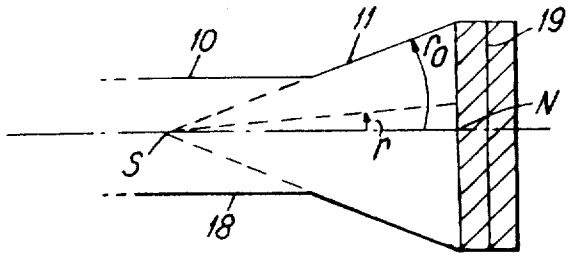


Fig. 4.

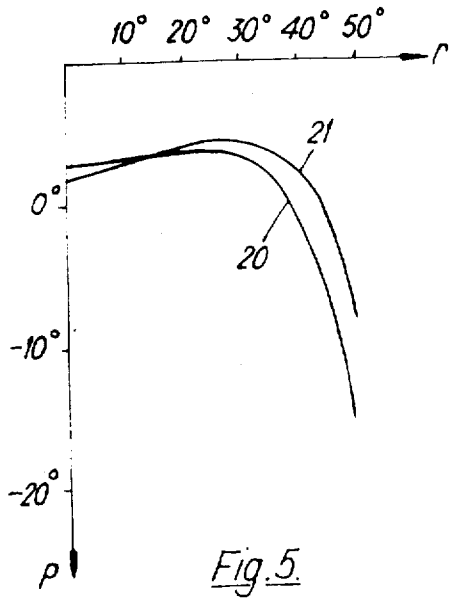


Fig. 5.

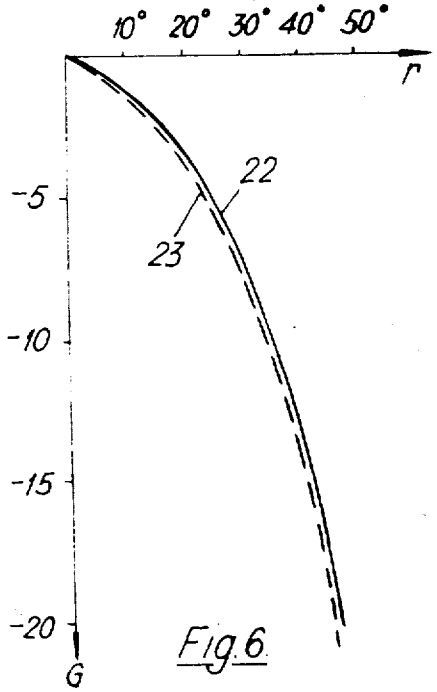


Fig. 6.

Inventor
Daniel Edmund Beguin

By William T. O'Neil
Agent

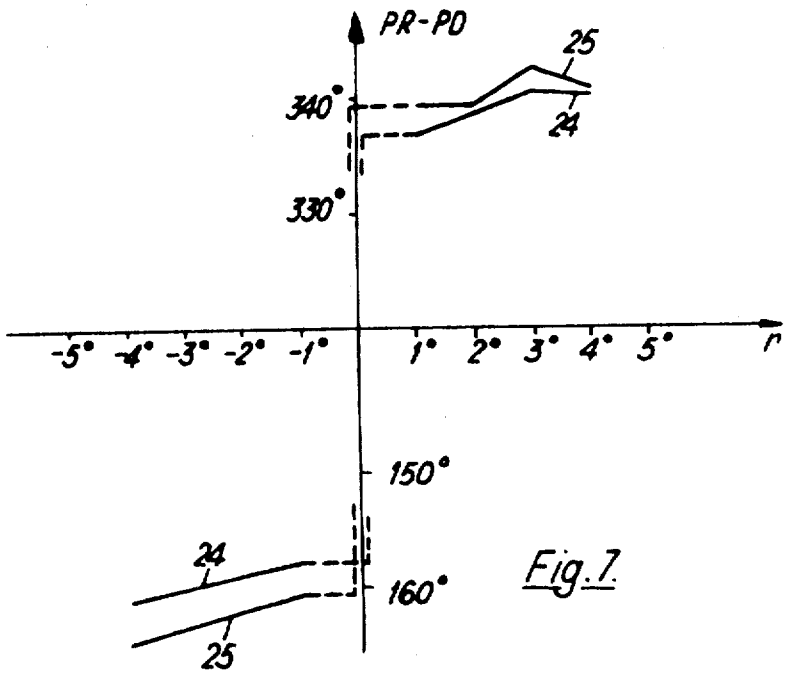


Fig. 7

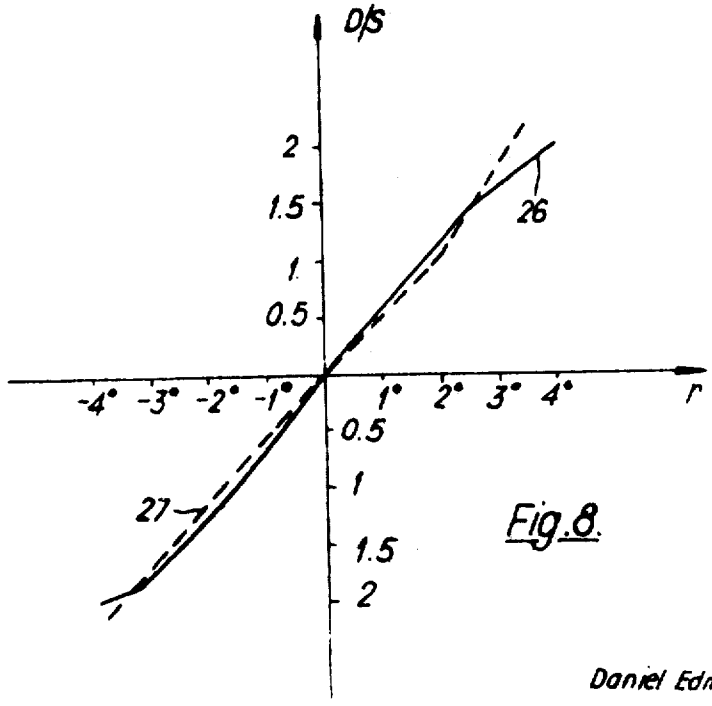


Fig. 8

Inventor
Daniel Edmund Beguin

By William T. O'Neil
Agent

PHASE CORRECTION APPARATUS FOR CIRCULAR POLARIZATION OPERATION MONOPULSE ANTENNA HORN

CROSS REFERENCE TO RELATED APPLICATIONS

This application is filed under the provisions of 35 U.S.C. 119 with claim for the benefit of the filing of an application covering the same invention filed July 28, 1970 Ser. No. 70 27747, in France.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to improvements to circular polarization antennas, particularly in relation to horn and polarizer combinations.

2. Description of The Prior Art

In the radar art, it is known that use of circularly polarized transmitted waves are advantageous in discriminating against hydrometeroic echo signals. Such circular polarization waves are, for example, obtained with a parallel metal plate device, called a polarizer, which is located in front of the horn opening from which linearly polarized waves are radiated. The polarizer is normally located with its plane parallel to the horn opening plane and oriented in such a manner that its plates are positioned at an angle of 45° (in a plane parallel to the plane of the aperture) with respect to the orthogonal polarization coordinates (i.e., horizontal and vertical). The radiated field component which is perpendicular to the plates is not affected by the polarizer, however, the component which is parallel to the said plates has its phase advanced by 90° and, consequently, the wave outgoing from the polarizer is circularly polarized.

Since reflection coefficients of a raindrop tend to be equal for the two circular polarization wave components, the waves reflected by raindrops are circularly polarized. When this reflected wave passes through the polarizer, the component which is parallel to the plates has its phase again advanced by 90° with the result that, after having been combined with the other component, the resulting linearly polarized waves are orthogonally oriented with respect to the initial transmitted waves before passage through the polarizer. Since the horn constitutes a filter for waves polarized perpendicular to the polarization for which it was designed, the waves reflected by raindrops result in little or no received energy propogation in the horn. Accordingly, rain echoes or the echoes produced by other hydrometeoric phenomena are discriminated against.

Other reflecting objects, including some which it is desired to observe, may present coefficients of reflection equal for the two components of the radiated wave, and therefore will be similarly suppressed. Accordingly, circular polarization is normally not used on a full time basis, but only during rain storms, etc. Therefore, the polarizer is normally mounted on a mechanical device which makes it possible to selectively emplace and remove it from the front of the horn opening at the radar operator's option.

When the antenna comprises a horn and reflector combination, there are several possible locations for the polarizer. For example, it may be located on the reflector and operated in reflection, or it may be at the reflector output behind the horn. As mentioned

hereabove, it may also be located between the horn and the reflector. The first two of the foregoing configurations have major drawbacks due to size and weight considerations and to difficulties in emplacing and removing the polarizer selectively.

In the third of the foregoing forms, it is possible to locate the polarizer at a distance of several wavelengths or more from the horn opening. At such a distance, the wave plane may be considered as spherical and this leads to use of a spherically shaped polarizer. The mechanical structure of such a polarizer is difficult to realize, moreover, such a polarizer acts as a mask which attenuates or partially blocks waves reflected by the reflector.

If, in the third configuration, the polarizer is located at a distance from the horn opening less than a few wavelengths, the indicated problems with that arrangement are not encountered, however, the successful construction of the polarizer is difficult because of the short distance from the horn. In the said near area, called the Fresnel zone, the amplitude and phase of the radiated field vary according to $1/r^n$ (r being the distance to the horn opening phase center and $n \geq 2$) so that the wave plane is not precise and, consequently, the polarizer is difficult to build. Germane background in respect to the invention is contained in U.S. Pat No. 3,510,875 and U.S. Pat. application Ser. No. 129,229 filed Mar. 29, 1971.

The manner in which the present invention overcomes these difficulties will be understood as this description proceeds.

SUMMARY OF THE INVENTION

In view of the aforementioned prior art problems and disadvantages, it may be said to have been the general object of the present invention to provide a horn-polarizer combination which exhibits little variation in the amplitude and phase of radiated energy between the conditions of "polarizer on" and "polarizer off."

A circular polarized antenna arrangement according to the present invention comprises a horn followed by a polarizer located in the horn opening so that the front face of the said polarizer lies in the horn output (aperture) plane. The horn with which the polarizer is associated in the present invention is a multimode horn, the phasing section length of which is selected so as to obtain a radiation pattern having a substantially stationary phase characteristic within a broad range of radiation angle values.

When the antenna is used as a monopulse radar antenna, the phasing section length is selected so as to obtain a small amount of intentional phase shift between the Reference channel and the Difference channel over a broad range of radiation angle values.

Other objects, features and advantages of the present invention will be evident from the following description of a specific embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a rectangular wave guide for explanation purposes.

FIG. 2 shows a cross-section of a multimode horn, for explanatory purposes.

FIG. 3 shows electric field curves for two types of mode and their sum, for explanatory purposes.

FIG. 4 shows an antenna constituted with a multimode horn and polarizer, according to the invention.

FIG. 5 shows phase curves of the field radiated by the horn, with or without polarizer, as a function of radiation angle.

FIG. 6 shows the amplitude curves of the field radiated by the horn, with or without polarizer, as a function of radiation angle.

FIG. 7 shows curves of phase shift between the Reference and the Difference channel of a monopulse radar as related to radiation angle.

FIG. 8 depicts amplitude ratio curves for Reference and Difference channels.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, a rectangular wave guide 2, having a width a and a height c is viewed from the open end 1. When a and c, with respect to the free space wavelength d, are such that $d/2 < a < d$ and $c < d/2$, the only mode which is significantly propagated by the wave guide is a transverse electric field mode, i.e., a mode having an electric field vector perpendicular to the propagation direction Cz. In the plane of opening 1, the electric field distribution has the shape of the curve 3, representing the envelope of the electric field vectors 4. Such a mode is called mode TE_{10} or H_{10}, the indicia 1 and 0 meaning that there is an electric field maximum along the axis Ox and no electric field maximum along the axis Oy. For the same free space wavelength d, if the dimension a of the wave guide 2 is increased, other modes appear which may be called mode TE_{m0} or H_{m0}. More generally, if the wave guide sizes a and c are increased, other modes appear which may be transverse electric field modes, TE_{mn} (H_{mn}), or may be transverse magnetic field modes, $TM_{m'n'}$ ($E_{m'n'}$). It will be noted that in the case of the modes $E_{m'n'}$, indicia m' and n' are always different from zero.

Based on FIG. 1, it is possible to define an electric plane E as the plane containing Oy and Oz, and a magnetic plane H as the plane containing Ox and Oz, the latter perpendicular to the electric plane E.

In order to provide a transition between the wave guide and the free space, the wave guide is enlarged, across one or both dimensions to form a sectoral or pyramidal horn, respectively. In principal, such an enlargement is defined with respect to the electric plane E and the magnetic plane H and a horn is said to be enlarged in the magnetic plane H when the side walls perpendicular to this plane have been flared. Thus, in the case of the FIG. 1, an enlargement in the magnetic plane H corresponds to flaring the wave guide side walls 5 and 6 outward.

In modifying a horn radiation pattern, sometimes it is of interest to cause several modes to appear simultaneously in the horn opening, each of these modes having a determined amplitude. It is clear that, in a horn, the various modes are established successively as the opening sizes increase, however relative amplitudes of each of these modes are not precisely determined. For obtaining modes with precise relative amplitudes, step-by-step enlargements are used, then, when the desired modes are obtained, the transition between the last wave guide and the free space is made through a horn. In the antenna art, a so-called "multimode horn" means the assembly formed by the various wave guide step segments (sometimes referred to as a mode separator) having increasing cross-section, and by the horn.

FIG. 2 shows a cross-section of a multimode horn, obtained from the wave guide of FIG. 1, the dimensions a and c of this guide being such that only the mode H_{10} or main mode is propagated. The larger dimension has been increased up to a value b such that the mode H_{30} will appear, i.e., $3d/2 < b < 2d$. The ratio k of the mode H_{30} and H_{10} amplitudes depends on the values a and b, for a given frequency, that ratio being called the harmonic rate. The wave guide 10, with the side dimension b, is then larger in the magnetic plane H to form a sectoral horn 11 of which the opening 12 has width A. Thus it will be seen that FIG. 2 shows a cross-section of a multimode horn in the magnetic plane.

Throughout 11 of the multimode horn, other modes than the modes H_{10} and H_{30} are produced, but those other modes have low amplitudes and their effects on the electromagnetic field distribution in the horn opening, and consequently on the radiation patter, may be regarded as negligible. Thus the horn aperture electric field distribution may be practically obtained by adding electric fields of the modes H_{10} and H_{30}, these electric fields being represented by their amplitudes and phases.

FIG. 3 shows the amplitude curves of the modes H_{10} (curve 15), H_{30} (curve 16) and addition curve 17 for horn aperture 12, assuming that the said modes are in phase at the aperture mid point. The axis X'OX is scaled according to values of ratio between abscissa measured from opening center and half-width $A/2$ of the opening, this ratio being called the standard abscissa X.

In the multimode horn art, the said modes are usually phased at the center point N of the horn opening, such phasing being generally obtained by varying the length LI (phasing section 10).

In the horn opening, transmission may be through of as coming from a point S (FIG. 4) and it is understood that, due to different transmission paths, waves arriving at different points of the aperture do not have the same phase. It may be demonstrated that, in the horn aperture, the phase shifts of modes H_{10} and H_{30} are respectively expressed by BX^2 and CX^2, B and C being the maximum phase shifts appearing at the horn outer perimeter. If a polarizer 19 is located in the opening of the horn 18, each wave propagated on modes H_{10} and H_{30} has an angle-of-incidence varying from 0 to r_0. In a polarizer, the intended 90° phase shift between the two electric field components actually will be seen to vary with the angle of incidence so that an additional aberational phase shift results producing a certain ellipticity rate. It may be demonstrated that the additional phase shift or phase error is defined by KX^2, K being small compared with B and C and being either negative or positive depending on the polarizer type. Practically, it is negative (advance of phase) for a guided propagation polarizer (grating) made with conductor strips, and positive (delay of phase) for a dielectric polarizer.

French Pat. No. 1,537,063 (corresponding U.S. Pat. Application Ser. No. 129,229 filed Mar. 29, 1971) describes a horn antenna without polarizer wherein a plane wave was obtained over the aperture of the said

horn by varying the length LI (FIG. 2) of the phasing section so that there exists a phase shift PO at the point N between the modes H_{10} and H_{30}. It is then shown by calculation and experiments that the phase P(r) of the field radiated by the horn varies but little within a broad range of values for the angle r.

As the phase shift introduced by the polarizer varies according to a square law, it is possible to compensate the polarizer effect by modifying PO, by modifying the length LI. In practice, in a multimode horn wherein modes H_{10} and H_{30} are propagated, PO is selected so that the phase of the overall field is the same at the point N as at the point M where the mode H_{30} amplitude is null ($X = 1/3$). Accordingly, $PO = (1 + 1/k)$, $P(M) = (1 + 1/k)\ B/9$, i.e., PO is proportional to B. Therefore, the value P of the modification applied to PO is (with the polarizer in place) given by $P/PO = K/B$ (Equation I). This last equation may be applied only if the polarizer is permanently in place. When it is intended to use it selectively, the value p' of the modification must be half as much (a compromise valve). Accordingly, the phase of the field radiated by the horn is little influenced by the presence or the absence of said polarizer, i.e., $p'/PO = 1/2\ K/B$. (Equation II).

By applying the modification p (or p'), the phase error produced by the polarizer is compensated, and, accordingly, phase error has the effect of only determining the ellipticity rate, the latter being kept low and relatively constant over a broad range of radiation angles r.

It will be noted that the ellipticity rate also depends on the difference of the amplitudes of the two electric field components, but that such an amplitude error has negligible effect compared to the effect of phase error.

FIG. 5 shows the phase curves P(r) of the field radiated by the horn along (curve 20) and by the horn with polarizer (curve 21) for $K = -9°$, $k = 0.4$, $PO + 10$ and $p = 0°$. The curves are closely related and their similarity it may be further improved in having for p the value given by the Equation I or II, depending on the situation.

FIG. 6 shows the amplitude curves G(r) of the field radiated by the horn along (curve 22) and by the horn with polarizer (curve 23) under the same conditions as above. The deviation between the two curves is less than 1 db for attenuations on the order of 20 db.

The present invention may also be used when the horn is associated with a reflector in a combination constituting the antenna of a simultaneous overlapping-beam radar, commonly known as monopulse radar.

It will be recalled that a monopulse radar makes it possible to make deviation measurements, for example, azimuthal deviation, between a main target and a secondary target constituted, for example, by a shell explosion or tracking missile.

In a monopulse radar, the antenna is commonly constructed with a focusing system (lens or reflector) located in front of a primary source consisting of a rectangular cross-section horn. In a standard monopulse antenna, the horn whose largest dimension referenced a is horizontal, includes a vertical media partition effectively breaking the aperture into two horns, and both the outputs are connected to a hybrid junction (magic T, for example) for providing signals respectively equal to the sum and to the difference of energies received at the two openings. The sum signal and the difference signal are applied to two reception channels which constitute the sum channel S and the difference channel D. The sum channel is also called Reference channel.

It is also possible to use, as a primary source for a monopulse radar antenna system, a horn without partition forming a multimode source as outlined in published technical papers, entitled "Optimum feeds for all three modes of a multimode antenna" published in the September 1961 issue of "IRE Transactions on Antennas and Propagation", Pages 444—453 and 454—460. Such a multimode source utilizes the property according to which several modes and their harmonics may be propagated simultaneously in a wave guide up to a maximum order determined by the guide-cut-off frequency. By combining several propagation modes in the same guide, it is possible to generate, at the horn opening, the illumination patterns required for the reference channel S and the difference channel D. Information corresponding to each of the patterns corresponding to these channels is then separable on the basis of modes is a so-called mode separator, as is well known in this art.

In monopulse radars, and particularly in those of the coherent Doppler type, one of the most important problems to be solved is to obtain a null or constant phase shift between the reference channel and the difference channel over the whole useful angular range of the radiation pattern. Moreover, it is to be understood that the angular extent of this useful range closely depends on phase shift variations in the reference and difference channels in relation with the radiation angle.

The presence of the polarizer in the horn aperture produces a phase error which is compensatable by varying the phasing section length according to the hereinabove Equations I or II. Such a compensation must be made so that the phase difference variation curves in linear polarization and in circular polarization are parallel.

FIG. 7 illustrates the variation curves for the phase difference PR - PD between the Reference channel and the Difference channel for the horn along (curve 24) and for the horn with polarizer (curve 25) in the case when the Reference channel includes the modes H_{10} and H_{30} and the Difference channel includes the mode H_{20} and in having $K = -9°$, $k = 0.2$, $PO = +15°$ and $p = 0°$.

FIG. 8 shows the amplitude quotient (ratio) curve for the signals of the reference and difference channels versus angle r, for the horn alone (curve 26) and for the horn with polarizer (curve 27) with other conditions as hereinbefore described.

The invention is applicable to any antenna comprising a horn and a polarizer combination.

Various modifications within the spirit of the invention will suggest themselves to those skilled in the art. Accordingly, it is not intended that the scope of the invention should be considered limited by the drawings and this description, these being typical and illustrative only.

What is claimed is:

1. An antenna system for radiating and receiving circularly polarized energy, comprising the combination of:

a multimode horn having an aperture;

a polarizer inserted substantially within the plane of said aperture, said polarizer having the characteristic of introducing a phase error between the electric field components of mode energy at said aperture, said error varying as a quadratic function of the angle of radiation and reception with respect to the axis of said horn;

means included between the flared section of said multimode horn including at least one phasing section, the axial length of said phasing section being selected such that a phase variation in a compensatory sense as compared to said polarizer phase error is introduced as a function of said angle of radiation and reception.

2. Apparatus according to claim 1 in which said horn propogates H_{10} and H_{30} modes, and said phasing section length is selected so that the relative phase shift between energy components of said modes at the center of said aperture is equal to that at least at two predetermined points removed from said center but within said aperture.

3. Apparatus according to claim 1 in which said horn propogates at least H_{10} and H_{30} modes and said phasing section length is selected to cause the relative phase shift at the center of said aperture to be substantially the same as at points within said aperture where the H_{30} mode energy is substantially zero.

* * * * *

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,699,583 Dated October 17, 1972

Inventor(s) Daniel Edmund Beguin

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the Title Page add the following:

[30] Foreign Application Priority Data

July 28, 1970 France 70 27747

Signed and sealed this 14th day of May 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents