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(71) Applicant: **Cook, Scott J.**
Woodstock, GA 30189 (US)

(72) Inventor: **Cook, Scott J.**
Woodstock, GA 30189 (US)

(74) Representative: **Gill, David Alan**
W.P. Thompson & Co.
55 Drury Lane
London WC2B 5SQ (GB)

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(54) Circular polarity elliptical horn antenna

(57) A relatively low cost, easy to install and aesthetically pleasing digital video broadcast from satellite (DVBS) elliptical horn antenna designed as part of a reflector antenna system (300) to receive satellite television broadcast signals with circular polarity. This type antenna may be implemented with a single antenna feed horn with multiple feed horns that may be arranged separately or in one or more integral fee horn blocks (304, 306). The antennas may be designed to achieve acceptable circular polarity performance over broad and multiple frequency bands through the use of oppositely sloped differential phase differential sections.

EP 2 131 446 A2

Description

REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to commonly-owned copending United States Provisional Patent Application Serial No. 60/572,080 entitled "Small Wave-Guide Radiators For Closely Spaced Feeds on Mufti-Beam Antennas" filed May 18, 2004, which is incorporated herein by reference; and United States Provisional Patent Application Serial No. 60/571,988 entitled "Circular Polarization Technique for Elliptical Horn Antennas" filed May 18, 2004, which is also incorporated herein by reference.

TECHNICAL HELD

[0002] The present invention is generally related to antenna systems designed to receive broadcast signals with circular polarity and, more particularly, is directed to digital video broadcast satellite (DVBS) antenna systems.

BACKGROUND OF THE INVENTION

[0003] An increasing number of applications, such as digital video satellite broadcast television systems, utilize elliptical antenna reflectors to improve gain and interference rejection in desired direction. This is particularly true for ground-based antenna systems designed to receive from and/or transmit to geo-stationary satellites when other potential interfering are closely for example on the order of two degrees away. Simply increasing a circular antenna's reception improve gain and interference rejection in all directions. Increasing the antenna size should also be balanced against cost and aesthetic tradeoffs. Elliptical antenna reflectors strike a better balance between these competing design objectives by the size of the antenna reflector more in the direction in which gain and interference rejection is most critical. The resulting elliptical antennas maintain a relative small reflector size (collection area) while providing improved of unwanted in the direction This is typically accomplished usually by the long axis of the antenna the geostationary arc. Elliptical can be designed to improve the antenna's performance when multiple feeds are used to receive from or transmit to multiple locations (such as multiple satellites).

[0004] In general, elliptical antenna feed horns should be used in connection with elliptical reflectors in order to achieve optimum performance on elliptical reflectors. Although elliptical antenna feed horns are somewhat more complex than ordinary circular feeds feed horns, there are a number of established design approaches for elliptical beam feeds. In addition many applications are now using circular polarity. This is where the challenge arises. It is difficult to achieve good circular polarity cross polarization isolation (also referred to as x-poiarization or x-pol isolation) when using an elliptical beam feed with circular polarity polarizer (also referred to as a CP polarizer) approaches. The problem arises because an elliptical horn (or most any non-axially symmetric horn) introduces a differential phase shift between orthogonal electric fields that are parallel (or near parallel) to either the wide or narrow sides of the horn. The result is that when circular polarity is received by an elliptical horn the asymmetries in the horn introduce a phase differential between the orthogonal fields, changing the circular polarity into elliptical polarity at the output of the horn. Simply attaching a conventional CP polarizer to a feed horn with an elliptical portion results in poor cross-polarization performance due to the differential phase and amplitude characteristics imparted by the elliptical portion of the feed horn.

[0005] The following additional background information will facilitate a more detailed discussion of CP polarizers and elliptical antenna feed horn. First it should be appreciated that that circular polarity can be expressed as the vector sum of two orthogonal linear components that are 90 degrees out of phase. For example, the orthogonal linear components can be referred to as +45FV0P (+45 degrees from vertical and 0 degrees phase reference) and -45FV+90P (-45 degrees from vertical and +90 degrees phase). A typical CP polarizer lined up with the -45LP+90P component and that 45FV±90P component by 90 degrees so that it in phase with the +45FV0P component. When this occurs the result is a theoretically lossless of the received power conversion from circular polarity to linear polarity (vertical polarity in this case). This linear can be easily picked up with simple linear or wave-guide slot etc. If both right hand circular polarity and left hand circular polarity LHCP beams are present, then the conversion produces both vertical and horizontal linear polarity components.

[0006] Now consider a theoretically perfect circular polarity beam impinging on an elliptically shaped receiving horn as shown in FIG. 1a. Again, recall that circular polarity can be expressed as the vector sum of 2 orthogonal linear components that are 90 degrees out of phase. For simplicity in this case, the orthogonal linear components will be taken to be H (horizontal) and V (vertical), where H is aligned (parallel) to the x-axis and V is aligned to the y-axis in a conventional Cartesian coordinate system. As the circular polarity beam enters the horn, the elliptical shape of the horn causes the H and V components to travel at different phase velocities through the horn so the H and V components are no longer 90 degrees out of phase when they reach the end of the horn (at the start of the polarizer section). So elliptical polarity now exists at the start of the polarizer section. So a polarizer designed to convert circular polarity to linear polarity will have poor CP cross polarization (cross polarization) performance as shown in FIG. 1b.

[0007] As a design compromise, many elliptical reflector systems simply use circular beam feeds with conventional CP polarizers in an attempt to preserve good circular polarity cross polarization isolation. This approach is easy to implement but results in significant compromise (degradations) in efficiency, gain noise temperature, beam width, and side lobe performance of the reflector system, because the circular beam feeds do not properly illuminate the elliptical reflector. This situation is shown in FIG. 2, in which the antenna horn illumination level along the short axis of the reflector is too high resulting in large amounts of wasted spillover energy that degrades gain, efficiency, and noise temperature. In addition, the antenna horn illumination level along the long axis of the reflector is too low resulting in degraded taper efficiency and gain. In addition, this improper illumination makes it very difficult to achieve desired beam width and side lobe performance. That is, the high illumination along the short axis of the antenna degrades (raises) side lobes while the low illumination along the long axis of the antenna degrades (widens) beam widths. In addition, for multi-beam applications where a single reflector is used to from multiple beam sources (typically satellites) that are closely spaced, use of a circular feed increases the physical spacing required between the feeds required to obtain acceptable gain and interference rejection characteristics.

[0008] There has been some work in the area of elliptical beam feed horns that provide circular polarization. U.S. Patent No. 6,570,542 gives a vague description of an antenna horn that includes a divided elliptical horn section including a phase compensator in the form an "arc structure metal" that spans the entire major axis of the elliptical horn. It is not clear whether or not the "arc structure metal" is used to remove the phase differential introduced by the horn such that a conventional CP polarizer can be attached to it or if the "arc structure metal" is used in conjunction with the horn to achieve the proper phase differentials needed for CP polarizer there by eliminating the need for a separate CP polarizer. Regardless, this metal structure complicates the manufacturability of the horn making it more difficult to die cast or machine. Also adding the arc through the middle of the horn might require the horn to be wider that desired for many applications.

[0009] Accordingly, there is an ongoing need for single and multi-beam elliptical antenna systems that exhibit improved efficiency, gain, interference rejection, gain noise temperature, beam width, side lobe, size and cost and other characteristics.

SUMMARY OF THE INVENTION

[0010] The present invention meets the needs described above in antenna feed horns and associated antenna systems for receiving circular polarity beams. This type of antenna system, which may be implemented with a single horn or one or more multiple-horn antenna feed blocks, are designed to achieve good circular polarity performance over broad and multiple frequency bands.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

FIG. 1a is a front view of a prior art antenna feed horn with an elliptical transition section and a conventional CP polarizer.

FIG. 1b is a perspective view of the antenna horn of FIG. 1a, which shows a Cartesian coordinate system that serves as a frame of reference .

FIG. 1c is a cross-sectional perspective view of the antenna horn of FIG. 1a.

FIG 1d is a graphical illustration of the circular polarity cross-polarization isolation characteristic of the antenna of FIG. 1a.

FIG. 2 is a graphical representation of a prior art configuration illustrating the improper illumination that results the use of a circular antenna feed horn with an elliptical reflector.

FIG. 3a is a top view of an antenna system including an elliptical deflector, a centrally located three-horn antenna feed block, and an off-center or outrigger two-horn antenna feed block.

FIG 3b is a front view of the antenna system of FIG. 3a.

FIG 3c is a perspective view of the feed horn structures of the antenna system of FIG. 3a.

FIG 3d is a rear perspective view of the antenna system of FIG. 3a.

FIG. 4a is a perspective view of an elliptical antenna feed horn that functions as a CP polarizer.

FIG. 4B is a cross-sectional perspective view of the antenna horn of FIG. 4a.

FIG 4c is a graphical illustration of the circular polarity cross-polarization isolation characteristic of the antenna horn of FIG. 4a.

FIG. 5a is front view of an antenna horn with an elliptical transition section and an additive phase differential section.

FIG. 5b is a perspective view of the antenna horn of FIG. 5a.

FIG. 5c is a cross-sectiohal perspective view of the antenna horn of FIG. 5a.

FIG 5d is a graphical illustration of the circular polarity cross-polarization isolation characteristic of the antenna horn of FIG. 5a.

FIG. 6a is perspective view of an antenna horn with an elliptical transition section and an oppositely sloped phase differential section.

FIG. 6b is a cross-sectional perspective view of the antenna horn of FIG. 6a.

FIG 6c is a graphical illustration of the circular polarity cross-polarization isolation characteristic of the antenna horn of FIG. 6a.

FIG. 7 is a phase differential versus frequency plot for a typical CP polarizer illustrating the a phase differential slope across a frequency band.

FIG. 8 is a phase differential versus frequency plot for the antenna horn shown in FIGS. 6a-c illustrating the broad band response improvement resulting form the oppositely sloped phase differential section.

FIG. 9a shows various of a multi-band, multi-port antenna feed horn with a circular reception section, an initial phase differential section, a frequency diplexer, and an second additive phase differential section.

FIG. 9b shows various views of a multi-band, multi-port antenna feed horn with an elliptical transition section, an initial oppositely sloped phase differential sections, a frequency diplexer, and a second additive phase differential section.

FIG. 9c shows various of a multi-band, multi-port antenna feed horn witch an integral elliptical reception cup polarizer section, a frequency diplexer, and an additive phase differential section.

FIG. 9d shows various views of a multi-band, multi-port antenna feed horn with an elliptical transition section, an initial additive phase differential section, a frequency diplexer, and a second additive phase differential section.

FIG. 9e shows various views of a multi-band, multi-port antenna feed horn with a circular transition section, an initial phase differential section, a frequency diplexer, and an second oppositely sloped phase differential section.

FIG. 9f shows various views of a multi-band, multi-port antenna feed horn with an elliptical transition section, an initial oppositely sloped phase differential section, a frequency diplexer, and a second oppositely sloped phase differential section.

FIG. 9g shows various views of a multi-band, multi-port antenna feed horn with an integral elliptical reception and CP polarizer, a frequency diplexer, and an oppositely sloped phase differential section.

FIG. 9h shows various views of a multi-band, multi-port antenna feed horn with an elliptical transition section, an initial additive phase differential section, a frequency diplexer, and an oppositely sloped phase differential section.

FIG. 10a shows a perspective of a three-horn antenna feed block.

FIG. 10b shows a cross-section of the perspective view of a three-horn antenna feed block of FIG. 10a.

FIG. 11a shows a cross-section of the perspective view of an antenna horn with an elliptical transition section, a CP polarizer, and phase compensation section.

FIG. 11b is a graphical illustration of the circular polarity cross-polarization isolation characteristic of the antenna horn of FIG. 11a.

FIG. 12a is a top of a three-horn antenna feed block with an elliptical feed horn located between two circular feed horns.

FIG. 12b is a perspective view of the three-horn antenna feed of FIG. 12a.

FIG. 12c is a front of the three-horn antenna feed of FIG. 12a.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] The present invention may be embodied in antenna feed norns and associated circular polarity antenna systems for or multiple-beam antennas designed to achieve good circular polarity performance over broad and multiple frequency bands. In general, several methods of introducing the needed phase differential between orthogonal linear components can be used in the opposite slop phase differential section described for embodiment 2 including but not limited to using sections of elliptical, rectangular or oblong waveguides, septums, irises, ridges, screws, dielectrics in circular, square, elliptical rectangular, or oblong waveguides. In addition the needed phase differential could be achieved by picking up or splitting off the orthogonal components via probes as in an LNBF or slots as in an OMT (or other means) and then delaying (via simple length or well establish phase shifting methods) one component the appropriate amount relative to the other component in order to achieve the nominal desired total 90° phase differential before recombining.

[0013] Elliptically shaped horn apertures are described in the examples in this disclosure, however this invention can be applied to any device that introduces phase differentials between orthogonal linear components that needs to be compensated for in order to achieve good CP conversion and cross polarization (Cross polarization) isolation including but not limited to any non-circular beam feed, rectangular feeds, oblong feeds, contoured corrugated feeds, feed radomes, specific reflector optics, reflector radomes, frequency selective surfaces etc.

[0014] To simplify the discussions, examples in this disclosure primarily refer to reception or signals and generally referred to a single circular polarity. However reciprocity applies to all of these embodiments given they are generally low loss passive structures. Furthermore the horns, CP polarizers and phase compensation sections obviously support both senses of CP (RHCP and LHCP). If both senses are impinging on the horn then they will be converted to 2 orthogonal linear polarities that can be easily picked up with 2 orthogonal probes and/or slots etc. So the approaches described in embodiments 1 and 2 can uses for systems transmitting and/or receiving in any of circular polarities: single CP or Dual CP for each band implemented including multiple widely spaced bands for embodiment 5.

[0015] It be pointed out four simplicity, specific phase values were often given in the examples, but the phase compensation concepts explained above are general.

[0016] For example, the following to embodiment #2: If the elliptical horn introduces X degrees phase differential then the opposite slop phase differential section should introduce 90-X degrees so that the total introduced phase differential is 90 degrees = X- (90-X).

[0017] For simplicity the inventor provides examples using a nominal 90 degrees phase differential between orthogonal linear components as the target for achieving CP conversion however it is understood that a nominal -90 degrees or any odd integer multiple of -90 or 90 degrees will also achieve good CP (...-630, -450, -270, -90, 90, 270, 450, 630 etc.) and this invention covers those cases as well. As an example for embodiment 2 the horn could introduce a 470 degrees phase differential and the opposite phase slop section could introduce a -200 degrees phase differential resulting in a total 270 degrees phase differential.

[0018] In addition, a skilled antenna designer will understand that the term "CP polarizer" is not limited to a device achieving a theoretically perfect conversion from circular polarity to linear polarity, but instead includes devices that achieves a conversion from circular polarity to linear polarity within acceptable design constraints for its intended application.

[0019] Referring now to the FIGS., FIGS. 1a-c is a front view of a prior art antenna feed horn **100** with an elliptical receiving cone and transition section **102** feeding into a conventional CP polarizer **104**. The transition section **102** extends from an aperture **106** at the from of the horn to the front of the front of the CP polarizer **104**, which extends to a waveguide port **108** where linear polarity pickups are located. As a result, this configuration is intended to produce a linear polarity signal at the waveguide port **108** but fails to take into account a 30 degree differential phase shift imparted by the transition section **102**. This results in poor cross-pole (x-pol) isolation, as shown FIG. 1d, which is graphical illustration **120** of the circular polarity cross-polarization isolation characteristic of the antenna horn **100**.

[0020] FIG. 2 is a graphical representation **200** of a prior art configuration illustrating the improper illumination that results from the use of a circular antenna feed horn with an elliptical reflector. The mismatched areas **202a-b** represent areas of wasted energy in the receive mode caused by under-illumination along the long axis of the elliptical reflector by the circular feed horn. Similarly, the mismatched areas **204a-b** represent areas of wasted illumination by the circular feed horn in areas the short axis of the elliptical reflector that extend beyond the physical of the reflector. This is also referred to as over-illumination spill-over energy.

[0021] FIG. is a top of an antenna system **300** including an elliptical reflector **302,** a centrally located three-horn antenna feed block **304,** and an off-center or outrigger two-horn antenna feed block **306.** Any of the horns described in this specification can be used in any of these locations. For example, the integral three-horn feed block **1600** described with reference to FIG 10a may serve as the centrally located three-horn antenna feed block **304,** and the outrigger horns **306** may be a conventional corrugated feed horn.

[0022] FIG. 4a-c show an elliptical antenna feed horn **400** that includes an elliptical reception cone and transition section **402** extending from the aperture **404** to a circular throat section **406**, which leads to the waveguide port **408,** where the linear polarity pickups are located. The transition section **402** functions as a 90 degree CP polarizer, whereas the throat section **406** does not impart any differential phase shift on the propagating signal. As a result, the feed horn **400** functions as a CP polarized without the need for any internal polarizing elements. This is accomplished by carefully selecting the height, width, length, flare angle and internal profile of the transition section **402.** Note that the flare angle need not be constant or smooth, and that the transition section could include flared or circular stages and other types of steps so long as the end result is a 90 degree differential phase shift as the incident CP bam travels through the transition section. FIG 4c is a graphical illustration **420** of the circular polarity cross-polarization isolation characteristic of the antenna horn **400.** Comparing this result to the graphical illustration **120** for the prior art antenna horn **100** shows the greatly improved x-pol isolation characteristic achieved by the horn **400**.

[0023] FIGS. 5a-c show an antenna horn **500** with an elliptical reception cone and transition section **502** from an aperture **504** to an additive phase differential section **506**, which leads to the waveguide port **508**, where the linear polarity pickups are located. In this embodiment, the transition section **502** imparts a less-than-need differential phase shift of 35 degrees and the additive phase differential section **506** imparts a differential phase of 55 in the same direction (i.e., +55 degrees additive) as the transition section.. Thus, the end result is a 90 degree differential phase shift through the horn **500,** which produces good x-pol isolation at the linear polarity pickups, as shown by the graphical illustration **520** shown in FIG. 5d. Again, comparing this result to the graphical illustration **120** for the prior art antenna horn **100** shows the greatly improved x-pol isolation characteristic achieved by the horn **500**.

[0024] FIGS. 6a-c show an antenna horn **600** with an elliptical reception cone and transition section **602** leading from an aperture **604** to an oppositely slopes phase differential section **606,** which leads to the waveguide port **608,** where the linear polarity pickups are located. In this embodiment, the transition section **602** imparts a greater-that needed differential phase shift of 130 degrees and the oppositely slopes phase differential section **606** imparts a differential phase shift of 40 degrees in the opposite direction (i.e., -40 degrees subtractive) as the transition section.. Thus, the end result is a 90 degree differential phase shift through the horn **600,** which produces good x-pol isolation at the linear polarity pickups, as shown by the graphical illustration **620** shown in FIG. 6c. Importantly, comparing this result to the graphical illustration **420** and **520** for the prior art antenna horns **400** and **500** show the greatly improved x-pol isolation characteristic achieved by the horn **600** over a much wider frequency bandwidth.

[0025] FIG. 7 is a phase differential versus frequency plot **700** for a typical CP polarizer illustrating its phase differential slope across its intended frequency band. FIG. 8 is a phase differential versus frequency plot **800** for the antenna feed horn **600**. The curve **802** represents the phase differential characteristic for the transition section **602** and the curve **804** represents the phase differential characteristic for the oppositely sloped phase differential section **606.** The combination of these two differential phase characteristics produces the total phase differential curve **806** through the horn **600,** shows the greatly improved CP polarization performance achieved by this horn (i.e., nearly 90 degrees differential phase shift) over a much wider frequency bandwidth.

[0026] FIG. 9a, which includes FIGS. 9a.1 through 9a.5, various views of a multi-band, multi-port antenna feed horn **900** with a circular reception section **902** feeding an initial phase differential section which in turn feeds a frequency diplexer **906** that separates low-band and high band signals propagating through the The frequency diplexer delivers the low-band signal to a first set of waveguide ports **908 a-b** (one for each linear polarity), and also the high-band to a second additive phase differential section **910**, which in turn delivers the high-band signal to a second waveguide port **912.** The low-band linear polarity pickups are located at the first set or waveguide port **908a-b** and the high-band linear polarity pickups are located at the second waveguide port **912.**

[0027] The circular reception section **902** does not impart any differential phase shift on the propagating signal. The initial phase differential section **904** imparts a low-band differential phase shift of 90 degrees and a high-band differential phase shift of 50 degrees. Then the second additive phase differential section **910** imparts an additive 40 degree differential phase shift to the high-band signal. As a result, low-band CP polarization is accomplished at the first set of waveguide port **908a-b,** whereas high-band CP polarization is accomplished at the second waveguide port **912.**

[0028] FIG. 9b, which includes FIGS. 9b.1 through 9a.4, show various views of a multi-band, multi-port antenna feed horn **920** with an elliptical reception section **922** feeding an initial phase differential section **924,** which in turn feeds a frequency diplexer **926** that separates low-band and high band signals propagating through the diplexer. The frequency diplexer delivers the low-band signal to a first set of waveguide ports **928 a-b** (one for each linear polarity), and also delivers the high-band signal to a second additive phase differential section **930,** which in turn delivers the high-band signal to a second waveguide port **932.** The low-band linear polarity pickups are located at the first set of waveguide port **928a-b** and the high-band linear polarity pickups are located at the second waveguide port **932.**

[0029] The elliptical reception section **922** imparts a low-band differential phase shift of 130 degrees and a high-band differential phase shift of 70 degrees. The initial phase differential section **924** imparts a tow-band differential phase shift of-40 degrees and a high-band differential phase shift of -25 degrees. Then the second additive phase differential section **910** an additive 45 degree differential phase shift to the high-band signal. As a result, low-band CP polarization is accomplished at the first set of waveguide part **928a-b,** whereas high-band CP polarization is accomplished at the second waveguide port **932**. In addition, improved x-pol isolation is accomplished for the low-band signal due to the -40 degrees oppositely slopped differential phase of the initial phase differential section **924.** Similarly, improved x-pol isolation is also for the high-band signal to the -25 degrees oppositely slopped phase differential characteristic of the initial phase differential section **924.**

[0030] FIG. 9c, which includes FIGS. 9c.1 through 9c.3, shows an antenna feed horn **940** with an integral elliptical reception and CP polarizer section **942,** a frequency diplexer **944,** and an additive phase differential section **948.** The frequency diplexer **944** separates low-band and high band signals propagating through the diplexer and delivers the low-band signal to a first set of waveguide ports **946a-b** (one for each linear polarity). The frequency diplexer **944** also delivers the high-band signal to the additive phase differential section **948,** which in turn delivers the high-band signal to a second waveguide port **949.** The low-band linear polarity pickups are located at the first set of waveguide port **948a-b** and the high-band linear polarity pickups are located at the second waveguide port **949.**

[0031] The elliptical reception section **942** imparts a low-band differential phase shift of 90 and a high-band differential phase shift 50 degrees. The additive phase differential section **948** imparts an additive 40 degree differential phase shift to the high-band signal. As a result, low-band CP polarization is accomplished at the first set of waveguide port **946a-b,** whereas high-band CP polarization is accomplished at the second waveguide port **949.**

[0032] FIG. 9d, which includes FIGS. 9d.1 through 9d.4, shows various views of a multi-band, multi-port antenna feed horn **950** with an elliptical transition section **952,** an initial additive phase differential section **954,** a frequency diplexer **956,** and a second additive phase differential section **958.** The frequency diplexer **956** separates low-band and high band signals propagating through the diplexer. The frequency diplexer delivers the low-band signal to a first set of waveguide ports **957 a-b** (one for each linear polarity), and also delivers the high-band signal to the second additive phase differential section **958**, which in turn delivers the high-band signal to a second port **359.** The low-band linear polarity pickups are located at the first set of waveguide port **957a-b** and the high-band linear polarity pickups are located at the second waveguide port **959**.

[0033] The elliptical reception section **952** a low-band differential phase shift of 60 degrees and a high-band differential phase shift of 35 degrees. The initial phase differential section **954** imparts a low-hand additive differential phase shift of 30 degrees and a high-band differential phase shift of 20 degrees, Then the second additive phase differential section **958** imparts an additive 35 degree differential phase shift to the high-band As a result, low-band CP polarization is accomplished at the first set of waveguide port **967a-b,** whereas high-band CP polarization is accomplished at the second waveguide port **959.**

[0034] FIG. 9e, which includes FIGS, 9e.1 through 9e.5, shows various views of a multi-band, multi-porfi antenna feed horn **960** with a circular reception section **961** feeding an initial phase differential section **962,** which in turn feeds a frequency diplexer **964** that separates low-band and high band signals propagating through the diplexer. The frequency diplexer delivers the low-band signal to a first set of waveguide ports **966a-b** (one for each linear polarity), and also delivers the high-band signal to an oppositely sloped phase differential section **968,** which in turn delivers the high-band signal to a second waveguide port **969**. The low-band linear polarity pickups are located at the first set of waveguide port **966a-b** and the high-band linear polarity pickups are located at the second waveguide port **969.**

[0035] The circular reception section **961** does not impart any differential phase shift on the propagating signal, The initial phase differential section **962** imparts a low-band differential phase shift of 90 degrees and a high-band differential phase shift of 50 degrees. Then the oppositely sloped differential section **968** imparts a -140 degree differential phase shift to the high-band signal. As a tow-band CP polarization is accomplished at the first set of waveguide port **966a-b,** whereas high-band CP polarization is accomplished at the second waveguide port **969.** In addition, improved x-pol isolation is accomplished for the high-band signal due to the -140 degrees oppositely slopped phase differential characteristic of the phase differential section **968**.

[0036] FIG. 9f, which includes FIGS. 9f.1 through 9f.4, shows various views of a multi-band, mufti-port antenna feed horn **970** with an elliptical transition section **971**, an initial oppositely sloped phase differential section **972,** a frequency diplexer **974**, and a second oppositely sloped phase differential section **The** frequency diplexer **974** separates low-band and high band signals propagating through the The frequency diplexer delivers the low-band signal to a first set of waveguide ports **976 a-b** (one for each linear polarity), and also delivers the high-band to to the second additive phase differential section **978**, which is turn delivers the high-band signal to a second waveguide port **979**. The low-band linear polarity pickups are located the first set of waveguide port **976a-b** and the high-band linear polarity pickups are located art the second waveguide port **979.**

[0037] The elliptical reception section **971** imparts a low-band differential phase shift of 130 degrees and a high-band differential phase shift of 70 degrees. The initial phase differential section **972** imparts a low-band differential phase shift of -40 degrees and a high-band differential phase shift of -25 degrees. Then the second phase differential section **978** imparts an oppositely sloped -135 degree differential phase shift to the high-band signal. As a result, low-band CP polarization is accomplished at the first set of waveguide port **976a-b,** whereas high-band CP polarization is accomplished at the second waveguide port **979.** In addition, improved x-pol isolation is accomplished for the low-band signal due to the -40 degrees oppositely slopped phase differential characteristic of the initial phase differential section **972.** Similarly, improved x-pol isolation is also accomplished for the high-band signal due to the -25 degrees oppositely slopped phase differential characteristic of the first phase differential section **972** and the -135 degrees oppositely slopped differential phase characteristic of the second phase differential section **978.**

[0038] FIG. 9g, which includes FIGS. 9g.1 through 9g.4, shows various views of a multi-band, mufti-port antenna feed horn **980** with art integral elliptical reception and CP polarizer **982,** a frequency diplexer **984,** and an oppositely sloped phase differential section. The frequency diplexer **984** separates low-band and high band signals propagating through the diplexer and delivers the low-band signal to a first set of waveguide ports **986a-b** (one for each linear polarity). The frequency diplexer **984** also delivers the high-band signal to the additive phase differential section **988**, which in turn delivers the high-band signal to the second waveguide port **989.** The low-band linear polarity pickups are located at the first set of waveguide port **986a-b** and the high-band linear polarity are at the second waveguide port **989**.

[0039] The elliptical reception sections **982** imparts a lovi-band differential phase shift of 90 and a high-band differential phase shift 50 The additive phase differential section **988** an oppositely sloped -160 degree differential phase shift to the high-band signals. As a result, low-band CP polarization is accomplished at the first set of waveguide port **986a-b**, whereas high-band CP polarization is accomplished at the second waveguide port **989**. In addition, improved x-pol is accomplished for the high-band signal due the -160 degrees oppositely slopped phase differential characteristic of the -135 degrees oppositely slopped differential phase characteristic of the phase differential section **988**.

[0040] FIG. 9h, which includes FIGS. 9h.1 through 9h.4, shows various views of a multi-band, multi-port antenna feed horn **990** with an elliptical transition section **991,** an initial additive phase differential section **992,** a frequency diplexer **994,** and an oppositely sloped phase differential section **998.** The frequency diplexer **994** separates low-band and high band signals propagating through the diplexer, The frequency diplexer delivers the low-band signal to a first set of waveguide ports **996 a-b** (one for each linear polarity), and also delivers the high-band signal to the oppositely sloped phase differential section **998,** which in turn delivers the high-band signal to a second waveguide port **999.** The low-band linear polarity pickups are located at the first set of waveguide port **996a-b** and the high-band linear polarity pickups are located at the second waveguide port **999.**

[0041] The elliptical reception section **991** imparts a low-band differential phase shift of 60 degrees and a high-band differential phase shift of 35 degrees. The initial phase differential section **992** imparts a low-band additive differential phase shift of 30 degrees and a high-band additive differential phase shift of 20 degrees. Then the oppositely sloped phase differential section **998** imparts an oppositely sloped -145 degree differential phase shift to the high-band signal. As a result, low-band CP polarization is accomplished at the first set of waveguide port **996a-b,** whereas high-band CP ' polarization is accomplished at the second waveguide port **999**. In addition, improved x-pol isolation is accomplished for the high-band signal due to the -145 degrees oppositely slopped phase differential characteristic of the phase section **998**.

[0042] FIG. 10a-b shows a three-horn antenna feed block **1000** including a substantially rectangular center feed horn **1002** located between a first elliptical feed horn **1002** and a second elliptical feed horn **1004**. The feed block **1000** is an integral structure that includes the feed horns **1002**, **1003** and **1004** along with a composite LNB to form a three-horn integral LNBF within a single Any of the feed horns described in this specification, as potentially modified to a substantially rectangular feed horn profile for the center horn (or to any other profile for any of the horns) may be as alternative embodiments. In a particular embodiment, the center feed horn **1002** receives a beam in the frequency band of 12.7-12.7 GHz (Ku BSS band) from a satellite located at 101 degrees west longitude. The left feed horn **1004** receives a beam in the frequency band of 18.3-18.8 and 19.7-20.2 GHz (Ka band) from a satellite located at 102.8 degrees west longitude, The right feed horn **1006** receives a beam in the frequency band of 18.3-18.8 and 19.7-20.2 GHz (Ka band) from a satellite located at 99.2 degrees west longitude.

[0043] FIGS. 11a-b show an antenna horn **1100** with an elliptical transition section **1102**, a phase compensation section **1104**, and a CP polarizer **1106**, which delivers the propagating signal to a waveguide port **1108** where the linear polarity pickups are located. The elliptical reception section **1102** imparts a differential phase shift of 35 degrees, the phase compensation section **1104** imparts a differential phase shift of 35 degrees of -35 degrees, and the CP polarizer **1106** imparts a differential phase shift of 90 degrees, Thus, CP polarization is accomplished at waveguide port **1108** whereas high-band CP polarization is accomplished at the second waveguide port **999.** In addition, improved x-pol isolation is accomplished due to the -35 degrees oppositely slopped phase differential characteristic of the phase compensation section **1104**, as shown in FIG, 11b.

[0044] FIGS, 12a-c show a three-horn antenna feed structure **1200** with an elliptical feed horn **1202** located between two circular feed horns **1204** and **1206.** In this embodiment, each antenna horn feed block **1002**, **1204** and **1206** is an integral structure that includes an LNBF to form a single-horn integral LNBF within a single casting. All three horns are mounted on a common feed support bracket **1208.** Any of the feed horns described in this specification, as potentially modified to a substantivally to any other profile for any of the horns, may be used as alternative embodiments. In a particular embodiment, the center feed horn **1002** receives signals from two satellites that are located close together (from the perspective of the horn). The first satellite transmits in the frequency band of 12.7-12.7 GHz (Ku BSS band) from a location at 119 degrees west longitude, and the second satellite transmits in the frequency band of 11.7-12.2 (Ku BSS band) from a location at 118.7 degrees west longitude to produce an 11.7 to 12.2 CP broadband signal. Accordingly, the broad band antenna feed horn **600** described with reference to FIG. 6 is suitable for this application. The left feed horn **1004** receives a beam in the frequency band of 12.2-12.7 GHz (Ku BSS band) from a satellite at at 129 degrees west longitude, The right feed horn **1006** receives a beam in the frequency band of 112.2-12.7 GHz (Ku BSS band) from a satellite located at 110 degrees west longitude.

[0045] Additional description of the advantages, functions and configurations of the embodiments of the invention with reference to certain prior art configurations is set for the below.

<u>Current Compromised Approach #1 (CCA#1):</u>

[0046] FIGS. 1a-d illustrate a first current compromised approach (CCA#1). Many elliptical reflector systems simply use circular beam feeds with conventional CP polarizers in order to preserve good circular polarity cross polarization isolation. This approach is easy to implement but results in significant compromise (degradations) in efficiency, gain noise temperature, beam width, and side lobe performance of the reflector system, because the circular beam feeds do not properly illuminate the elliptical reflector.

[0047] As shown in FIG 2, the illumination level along the short axis of the reflector is to high resulting in large amounts of wasted spillover energy that degrades gain, efficiency, and noise temperature, and/or the illumination level along the long axis of the reflector is to low resulting in degraded taper efficiency and gain. In addition this improper illumination makes it very difficult to achieve desired beam width and side lobe performance. The high illumination along the short axis of the antenna degrades (raises) side lobes. The low illumination along the long axis of the antenna degrades (widens) beam widths. In addition for multi-beam applications where a single reflector is required to receive from and/or transmit to multiple sources (satellites) that are closely spaced a circular feeds are often to wide to allow the close physical spacing required between the feeds.

[0048] Several of embodiments of the invention (i.e., all embodiments except those shown on FIGS, 9a and 9e) solve the fundamental performance and implementation limitations of CCA#1 through the use of elliptical beam feed horns to optimize the elliptical reflector performance (efficiency, gain, noise temperature, side lobes, and beam width), while achieving good or excellent circular polarity performance including acceptable cross polarization isolation. Using an elliptical beam feed provides proper illumination of the entire elliptical reflector (along ails axis) reducing spillover while maintaining good taper effic-ency and gives the designer the freedom to illuminate the elliptical reflector in manor to best optimize performance for a application and customer requirements. In fact for some applications, this elliptical beam feed could be used on circular reflectors as a means of improving (narrowing) beam widths while maintaining reasonable efficiency, gain, and noise temperature. Specifically an elliptical illumination on circular reflector can the illumination only in the direction (typically along the satellite belt) needed to improve (narrow) the beam width in that direction while maintaining relatively low illumination in the orthogonal direction (perpendicular to the satellite belt) which helps maintain reasonable gain and noise temperature performance. In addition these elliptical feeds can be made considerably narrower than circular feeds which accommodates the closely spaced feed requirements for many multi-beam single reflector applications.

Current Compromised Approach #2 (CCA#2):

[0049] There have been other prior art approaches that use elliptical (or oblong) beam horns on elliptical (or oblong) reflectors. However, these prior art configurations result in poor x-pol isolation when a CP polarizer is simply attached to the elliptical feed horn section, as shown in FIGS 1a-d. Consider a perfect circular polarity beam impinging on an elliptically shaped receiving horn as shown in these FIGS.. Recall that circular polarity can be expressed as the vector sum of 2 orthogonal linear components that are 90 degrees out of phase. For simplicity these orthogonal linear components may be referred to as H (horizontal) and V(vertical), where H is aligned (parallel) to the x-axis and V is aligned to the y-axis. As the circular polarity enters the horn the elliptical shape of the horn causes the H and V components to travel at different phase velocities through out the horn so the H and V components are no longer 90 degrees out of phase when they reach the end of the horn (at the start of the polarizer section). The H and V components might now be for example either 60 or 120 degrees out of phase depending upon the CP polarizer orientation and if the initial CP was RHCP or LHCP. So elliptical polarity now exists at the start of the polarizer section. Simply using a circular polarity polarizer will result in poor cross polarization isolation as shown in figure 1b because conventional circular polarity polarizers are designed to convert perfect circular polarity (not elliptical polarity) to linear polarity by delaying one linear component 90 degrees relative to the other linear component.

[0050] Furthermore, as show in FIGS. 1a-c, many applications orient the CP polarizes at 45 degrees so that the linear probes or wave-guide slots are vertically and/or horizontally oriented in the or OMT that is connected to the polarizer. This is convenient for mechanical packaging. However, with an elliptical horn this presents a problem because the horn has already introduced a phase differential in the vectors aligned with the wide or narrow walls of the feed (not in the vectors oriented at 45 degrees where the CP polarizer is oriented). So the total phase differential from the horn and polarizer is more than the desired 90 degrees and the horns 30 phase differential is acting on orthogonal components that are not aligned with the orthogonal components that the polarizers 90 degrees phase differential is acting on. Both the improper amount and improper alignment of the phase differentials will seriously limit CP cross polarization performance.

Advantages of certain embodiments of this Invention over CCA#2:

[0051] All of the embodiments of the present invention overcome the fundamental performance shortcomings of CCA#2 caused by improper orientation and improper phase differential of the CP polarizer.

Current Compromised Approach #3 (CCA#3):

[0052] A third compromised approach referred to as CCA#3 is described in US Patent No. 6,570,542. The embodiments of the present invention include an undivided elliptical antenna feed horn section to improve over the divided elliptical horn section of CCA#3.

Advantages of certain embodiments of this Invention over CCA#3:

[0053] In particular, the first embodiment of the invention shown in FIGS. 4a-b includes an elliptical beam horn with integral CP polarizer functionality. To enable this embodiment, the inventor recognized that an elliptical antenna feed horn can be designed to receive circular polarity and provide good cross polarization isolation without the need for a separate polarizer section or a divided elliptical feed horn section, such as one including a septum that spans across elliptical horn section. This is monumental step forward because it greatly reduces the size and complexity of the elliptical horn polarizer, This is because the elliptical horn section and polarizer are now integrally formed into the same structure, which eliminates unnecessary components and thereby makes this embodiment easier and less costly to manufacture via die-casting, machining or other means. In addition, the internal dimensions of this embodiment can have angular drafts that are all in the same direction, meaning that the internal cross section gets larger from the input waveguide out towards the horn opening or aperture. This is very convenient for integrating the horn into a die-cast LNBF, OMT, diplexer or other device.

[0054] The horn transition section as shown in FIGS. 4a-b transitions smoothly, and in this particular example linearly, from an elliptical shape to a circular waveguide. However for all embodiments of this invention the horn transition section could be done non-linearly and/or in multiple sections that change (transition) at various rates, and in fact can include abrupt steps as well as a means to control performance and length of the horn. The inventor also recognized that if the dimensions of the sections and step are carefully chosen so that unwanted modes can be limited in order to maintain excellent illumination, match, and CP cross polarization performance.

[0055] The different height and width of an elliptical horn (major and minor axis) introduces a phase differential between the 2 orthogonal linear components as they propagate through the horn. The inventor recognized that by choosing the horn transition section dimensions (H, W and length) appropriately the phase differential "X" can be made almost exactly 90° or any odd integer multiple of 90° (... -630°, -450°,-270°, -90°, 90°, 270°, 450°. 630°) at a given frequency. So near center band the nominal phase differential "X" introduced by the horn transition section can simply be described by X= 90°*n where n is an odd integer. This results in excellent power conversion from CP to LP and excellent cross polarization isolation performance at a single frequency and good cross polarization isolation over a modest bandwidth.

[0056] This first embodiment shown in FIGS. 4a-b works best when the linear polarity probes, slots etc. are oriented at 45 deg. However the principles of the invention are also applicable to any alternative embodiment constructed by orienting the probes/slots at other angles.

[0057] The second as illustrated by the antenna feed horn **600** described with to FIGS, 6a-b is a broadband high performance elliptical beam circular polarity design that an elliptical beam horn deliberately designed to work in conjunction with an additional opposite slope phase differential section to greatly improve performance over very broad frequency bands as shown in FIG. 6C. To enable this embodiment, the inventor recognized that the phase differential introduced by most circular polarizers and the elliptical horn of embodiment 1 is not a constant over the desired bandwidth. It is generally sloped vs. frequency as shown in FIG. 7. So for the elliptical horn of embodiment 1 and for most circular polarity polarizers the desired 90 degrees total phase differential needed for complete CP conversion only occurs at a single frequency. This slope in phase differential vs. frequency fundamentally limits the CP Cross polarization performance over bandwidth.

[0058] For this embodiment, the inventor also recognized that an elliptical aperture receiving device can be designed consisting of an elliptical transition section and an oppositely sloped phase differential section that introduce phase differentials (between orthogonal linear modes) in the opposite direction of the elliptical transition section. Specifically if one of these components (transition section or opposite slope phase differential section) introduces a phase lag between orthogonal components, then the other can be designed to introduce a phase lead between those same orthogonal components. The sections are cooperatively designed so that the total phase differential is 90° or an odd integer multiple. The combination of leading and lagging phase differential components, imparting their opposing differential phase slope effects, allows the combined sections of the antenna horn to introduce a total phase differential between the orthogonal linear components is 90° over a wide frequency band. In other words, the resulting cross polarization isolation is better and more constant over the desired frequency band.

[0059] In this particular example, the horn transition section introduces a nominal phase differential "X" (X= 130 at center band for example) and an opposite slope phase differential section positioned after the transition section introduces an opposite phase differential "Y" (Y= -40° for example) at a desired nominal frequency, such that the resulting total phase differential through the horn transition section and opposite slope phase differential section is the desired 90° for CP polarization. This may be accomplished with any combination of oppositely sloped differential phase compensation (130°-40° in this example) or an odd integer multiple of 90° (e.g., -630°, - 450°, -270°, -90°, 90°, 270°, 450°, 630° etc.). In other words, near center band the phase differentials introduced by the 2 sections can be described by:

$$90*n = X+Y, \text{ where "n" is an odd integer}$$

[0060] In this equation, X is the nominal center band phase differential between orthogonal linear components introduced by of the horn transition section and Y is the nominal center band phase differential introduced by the opposite phase slope section, wherein Y and X have opposite slope (i.e., one is positive and the other is negative).

[0061] Importantly the phase differential vs. freq response for the "opposite slope phase differential section" is oppositely sloped from the phase differential vs. freq response of horn transition, so the resulting total (sum of) phase differential vs. frequency is relatively flat maintaining values close to 90° or an odd integer multiple of 90° over a much greater band width. As shown in FIG. 8 for example, at 11.2 GHz the phase differential is 93° = 149-56, at 12.2 GHz it is 90° =130-40, and at 13.2CHz it is 90° = 114-24). This results in excellent CP conversion and excellent CP cross polarization performance over a wide bandwidth as shown in FIG. 6c.

[0062] As another example the elliptical horn transition section could introduce a nominal 70 degrees of phase differential and the opposite phase slope section could introduce a nominal -160 degrees resulting in a nominal -90 degrees total phase differential. This also means the elliptical horn transition section could for example introduce a nominal 470 degrees of phase differential and the opposite phase slope section could introduce a nominal -200 degrees resulting in a nominal 270 degrees total phase differential.

[0063] This embodiment **600** described with reference to FIGS. 6a-c is typically slightly longer than the first embodiment **400** described with reference to FIGS. 4a-c, but is still relatively easy and cost effective to manufacture (die-cast, machine, etc.) and integrate into an LNBF die cast housing. The embodiment **600** works best if the opposite slope phase differential section is aligned vertically with the ridges aligned with the long axis of the elliptical horn aperture and the linear polarity probes, slots etc. are oriented at 45 deg. However this patent should be construed to cover any alternative designed by orienting the polarizer and or probes/slots at other angles. The principles of the invention are also applicable to any alternative embodiment that breaks up the phase compensated polarizer function/section up further into multiple sections.

[0064] The 3rd embodiment 500 shown FIGS. 5a-c is a elliptical beam circular polarity design that employs an elliptical beam horn with an additive phase differential section to achieve CP polarization conversion over modest bandwidths. For this the inventor that the phase differential "X" introduced between orthogonal linear components by the elliptical horn is often something other than 90° (X = 35° for example) and that an additive phase differential section can be added to provide the additional phase differential Y (Y=55° in this example) to obtain a total phase differential of 90° or an odd integer multiple of 90° (...-630°, -450°, -270°, -90°, 90°, 270°, 450°, 630°....) near center band. The nominal phase differentials from the horn transition section and the additive phase differential section are indeed additive or in the same direction (if one introduces a phase lag between distinct orthogonal linear components the other also introduces a phase lag between those same components). So near center band the phase differentials introduced by the 2 sections can be described by:

$$90*n = X+Y, \text{ where "n" is an odd integer}$$

[0065] In this equation, X is the nominal center band phase differential between orthogonal linear components introduced by of the horn transition section and Y is the nominal center band phase differential introduced by the additive phase differential section, and Y must have the same sign as X.

[0066] Typically the phase differential vs. frequency from the horn transition section and the additive phase differential section are sloped in the same direction so the resulting total (sum) is sloped and the phase differential is not 90 degrees at the band edges. So this embodiment provides excellent CP conversion and CP cross polarization performance near center band and good performance at band edges. Although this embodiment #3 is not as broadband as embodiment #2 it can be used as an alternative and specifically for designs where there are limits on physical dimensions (length in particular) and bandwidth requirements are modest.

[0067] The third embodiment illustrated by the antenna feed horn **500** described with reference to FIGS. 5a-c, works best if the additive phase differential section is aligned horizontally with the ridges aligned with the short axis of the elliptical horn aperture as shown in FIGS. 5a-c, and the linear polarity probes, slots etc, are oriented at 45 deg, However the principles of the invention are also applicable to any alternative embodiment constructed by orienting the polarizer and or probes/slts at other angles, The principles of the invention are also applicable to any alternative embodiment constructed by breaking up the phase compensated polarizer function/section further into multiple sections.

[0068] Embodiment 4, including illustrative antenna feed horns **900-990** shown in FIGS 9a-h, employs multiple phase differential sections to achieve multi-band circular polarity performance in elliptical (or oblong), or circular beam receiving and/or transmitting devices. Many applications are requiring multiple frequency bands to be received and/or transmitted through the same feed horn on a reflector antenna system. For example the receive band might be at 19.7-20.2 Ghz while the transmit band might be at 29.5-30 GHz. Circular polarity polarizers that perform well over both bands are difficult to design, and if an elliptical illumination is also required of the horn the phase differential introduced by the horn (discussed above) adds to the difficulties. The methods used in embodiments 1, 2,3 can be employed to improve circular polarity performance with the elliptical feed, but for applications with multiple bands separated widely in frequency, even using embodiment #2 alone may not provide adequate performance.

[0069] To enable these embodiments, the inventor recognized that multiple stages of phase differential sections in combination with diplexing sections to extract and isolate bands, can be used in such cases. For simplicity the case of only 2 bands widely separated in frequency will be described here as an example (however the technique could be used for multiple bands). The inventor also recognized that phase differential sections or horn transition sections introduce more phase differential at lower frequencies than at higher frequencies and understood that this could be exploited to achieve excellent CP performance over multiple bands.

[0070] Specifically, for antenna feed horn **900** described with reference to FIG. 9a, the inventor recognized that the horn transition section (HTS) and initial phase differential section (IPDS) can be used to introduced the desired nominal 90 phase differential at the lowest frequency band (12.2-12.7 GHz for example), but not at the higher frequency band (only 50degrees nominally at 18.3-20.2 GHz for example) so the lower band (LB) has been completely converted from CP to LP (either single or dual polarities) and can be separated from the center wave-guide via a typical OMT or Co-polarity diplexer (or other means), allowing the upper band to pass through. The upper freq band continues on through another second phase differential section (SPDS) that the remaining additive phase differential (40 degrees nominally for this example) needed for high band so that the total phase differential is nominally 90 (50 +40) at the center of the upper frequency band. For this case the phase differential introduced at high band by the SPDS (40deg) is additive and the ridges in the SPDS are aligned with the ridges in the IPDS (unless the elliptical horn transition section introduces more phase differential than the IPDS). FIGS. 9b,c,d illustrates additional implementations of this concept for Elliptical Horns with the understanding that the elliptical horn transition section introduces part of the phase differential needed at both the high and low bands.

[0071] As another example, the antenna feed horn **920** described with reference to FIG, 9b includes an elliptical transition section that introduces a nominal 130° of low band phase differential and 70° of high band phase differential. The IPDS introduces a nominal -40° of low band opposite slop phase differential and -25° of high band phase differential. So at the input to the diplexer 90° (= 130°-40°) of phase differential has been introduced at low band providing excellent low band CP to LP conversion performance so that the diplexer can extract the resulting low band linear polarity signals into the side ports and pass the high band signals that only have 45° (= 70°-25°) of phase differential. The SPDS then introduces a nominal 45° of additive high band phase differential needed so that the total high band phase differential of 90° (= 70°-25°+45°) results and good CP to LP conversion occurs at high band as well

[0072] For the antenna feed horn **940** described with reference to FIG. 9c, the elliptical Horn introduces a nominal 90° of low band phase differential and 50° of high band phase differential. There is no need for an IPDS in this case because the elliptical horn introduced the entire nominal 90° of low band phase differential providing good low band CP to LP conversion performance so that the diplexer can extract the resulting low band linear polarity signals into the side ports and pass the high band signals that only have 50° of phase differential. The SPDS then introduces a nominal 40° of additive high band phase differential needed so that the total high band phase differential of 90° (= 50°-40°) results and good CP to LP conversion occurs at high band as well.

[0073] For the antenna feed horn **950** described with reference to FIG. 9d, the elliptical Horn introduces a nominal 60° of low band phase differential and 35° of high band phase differential. The IPDS introduces a nominal 30° of low band additive phase differentials and 20° of high band phase differential. So at the input to the diplexer 90° (= 60°+30°) of phase differential has been introduced at low band providing good low band CP to LP conversion performance so that the diplexer can extract the resulting low band linear polarity signals into the side ports and pass the high band signals that only have 55° (=35°+20°) of phase ditterential. The SPDS then introduces an nominal 35° of additive high band phase differential needed so that the total high band phase differential of 90° (= 35°+ 20°+35°) results and good CP to LP conversion occurs at high band as well

[0074] The antenna feed horn **960** described with reference to FIG. 9e provides an example where the SPDS introduces a nominal -140 degrees and is oppositely sloped from the phase differential introduced by the HTS and IPDS in the upper frequency band. So as in embodiment 2 this opposite slope results in a total phase differential of very close to -90 degrees across the entire upper band (for example: -92 = 60-152 at the bottom of the upper band, -90= 50-140 at center of the upper band, -88 = 40-128 at the top of the upper band) and improved CP cross polarization isolation performance over the entire upper band. For this case ridges in the SPDS or IPDS will be perpendicular to the ridges of the IPDS (unless the elliptical horn transition section introduces more phase differential than the IPDS). FIGS. 9f, g, h illustrates additional implementations of this concept for Elliptical Horns with the understanding that the elliptical horn transition section introduces part of the phase differential needed at both the high and low bands.

[0075] For antenna feed horn **970** described with reference to FIG. 9f, the elliptical transition section **971** introduces a nominal 130° of low band phase differential and 70° of high band phase differential. The IPDS introduces a nominal -40° of low band opposite slop phase differential and -25° of high band phase differential. So at the input to the diplexer 90° (= 130°-40°) of phase differential has been introduced at low band providing excellent low band CP to LP conversion performance so that the diplexer can extract the resulting low band linear polarity signals into the side ports and pass the high band signals that only have 45° (= 70°-25°) of phase differential. The SPDS then introduces a nominal -135°

of opposite slope high band phase differential needed so that the total high band phase differential of -90° (= 70°- 25°- 135°) results and good CP to LP conversion occurs at high band as well

[0076] For antenna feed horn **980** described with reference to FIG. 9g, the elliptical transition section **982** introduces a nominal 90° of low band phase differential and 50° of high band phase differential, There is no need for an IPDS in this case because the elliptical horn introduced the entire nominal 90° of low band phase differential providing good low band CP to LP conversion performance so that the diplexer can extract the resulting low band linear polarily signals into the side ports and pass the high band signals that only have 50° of phase differential. The SPDS then introduces a nominal - 160° of opposite slope high band phase differential needed so that the total high band phase differential of -90° (= 50°-160°) results and good CP to LP conversion occurs at high band as well.

[0077] For the antenna feed horn **990** described with reference to FIG. 9g the elliptical transition section **981** introduces a nominal 60° of low band phase differential and 35° of high band phase differential. The IPDS introduces a nominal 30° of low band additive phase differential and 20° of high band phase differential. So at the input to the diplexer 90° (= 60°+30°) of phase differential has been introduced at low band providing good low band CP to LP conversion performance so that the diplexer can extract the resulting low band linear polarity signals into the side ports and pass the high band signals that only have 55° (=35°+20°) of phase differential. The SPDS then introduces an nominal - 145° of opposite slope high band phase differential needed so that the total high band phase differential of
-90° (= 35°+ 20°-145°) results and good CP to LP conversion occurs at high band as well.

[0078] It should again be noted that the phase IPDS and SPDS can be designed such that the resulting nominal phase differentials for the low band and the high band are integer multiples of 90 deg. It is also easy to see how the same principles could continue on and on for improving performance not only across 2 bands but multiple frequency bands, by simply adding more phase compensation sections between each successive section where different bands are split off. Furthermore, it is also easy to see how any of these bands could be linear polarity by simply aligning the pick up probes, slots etc. with the polarizer and/or phase compensation section.

[0079] Embodiment 5, the antenna feed horn **1100** described with reference to FIG. 11 is an elliptical (or oblong) beam horn with phase compensation section for use with conventional CP Polarizers. Toe enable this embodiment, the inventor recognizes that a phase compensation section can be designed and placed between the elliptical horn and CP polarizer such that a conventional CP polarizer oriented in the more traditional 45 degrees plane as shown in FIGS. 11a-c can be used. This is convenient for mechanical packaging purposes for some applications because the pick up probes sand or slots (in OMTs and/or diplexing components) can be oriented vertically or horizontal.

[0080] The phase compensation section **1104** introduces a phase differential (30 degrees for example) between the 2 orthogonal components (H and V in this example) that is equal and opposite to the phase differential already introduced by the elliptical horn (30deg). So the total phase differential introduced by the horn and phase compensation section is 0 degrees = (30-30deg). In theory this re-establishes perfect CP between the phase compensation section and CP polarizer, so a conventional CP polarizer oriented at 45 degrees can be used and results in vertically or horizontally oriented linear polarity pick up probes slots, etc which is convenient for some LNBs, LNBF, OMTs and other waveguide or other feed assemblies etc. In fact the conventional CP can be oriented at any angle in order to orient the pick probes/ slots at any number of orientations.

[0081] This fifth embodiment **1100** works best if the phase compensation section is aligned vertically as shown in FIG. 11 a. However the principles of the invention are also applicable to any alternative embodiment constructed by orienting the phase compensation section at other angles. The principles of the invention are also applicable to any alternative embodiment constructed by breaking up the phase compensation section/function further into multiple sections or to brake up the CP polarizer into multiple sections/functions.

[0082] For this embodiment #5 the total length of the horn, phase compensation section and conventional polarizer will in general be slightly longer and more difficult to make than embodiment #1 and significantly longer and moderately more difficult to make than embodiment #2. However the phase compensation section of this third embodiment could be easily and cost effectively integrated into the horn casting.

[0083] Referring now to FIGS10a-b and 12a-c, all of thel embodiments can be used in single-feed or multi-feed reflector systems where the feeds are mounted separately or integrated in one or more housings that are mounted on an antenna dish to generate multiple receive and/or transmit beams for receiving from or transmitting to multiple nominal sources and/or receiver locations such as multiple satellite locations that can be separated by as little 1 degrees and as much as 180 deg. FIGS. 3a-d illustrate a system that has three of these feeds integrated into a LNBF housing (triple LNBF = Low Noise Block Down Converter with integrated Feeds) near the center of the reflector as well as two other more conventional feeds integrated into another LNBF housing (dual LNBF) that is significantly displaced from the reflector center. The horns on the triple LNBF are relatively tightly spaced to provide reflector beams to receive signals from three satellites that are spaced about 1.8 degrees apart. The dual LNBF feeds are spaced much further apart for receiving satellites spaced about nine degrees apart.

[0084] More specifically, for the centrally located triple-horn block, the LNBF the outer 2 feeds are for the Ka Satellite Band (downlink frequencies of 18.3-18.8 and 19.7-20.2 GHz) at nominal satellite locations of 99.2 and 102.8 west longitude. The center feed is for the Ku BSS (Broadcast Satellite Service) Band (downlink frequencies of 12.2-12.7GHz) at a nominal satellite location of 101degrees West longitude.

[0085] For the dual LNBF attached with the out rigger antenna feed block, the 2 feeds are for the Ku BSS (Broadcast Satellite Service) Band (downlink frequencies of 12.2-12.7GHz) at a nominal satellite location of 110 and 119 degrees West longitude.

[0086] FIG. 12 a,b,c illustrate a system that has 1 of these feeds (attached to an LNB and covered in a shroud) that is mounted near the center of the reflector as well as 2 other conventional circular feed LNBFs (low noise block down converters with integrated feed horns) that are significantly displaced from the reflector center. The center feed is designed to receive circular polarity from two satellites that are very close together. One satellite is for the Ku BSS band and is nominally located at 119° west longitude, and the other is for Ku FSS band is nominally located at 118.7° west longitude. The center feed is an elliptical beam circular polarity broadband feed as described in embodiment 2 and illustrated in FIG. 6. This maximize performance of the elliptical reflector system by improving gain, noise temperature, adjacent satellite rejection and cross polarity isolation over the required broad frequency range. The outer feeds are displaced with outrigger brackets to receive Ku BSS band services from 110° west longitude and 128° west longitude.

[0087] All of these services require and feeds support both Right Hand Circular Polarity and Left Hand Circular Polarity simultaneously. Of course this a specific geometry but as discussed in the disclosures the invention can be used for many combinations of frequencies, polarities and satellite locations.

[0088] For single polarity applications it is worth noting that the transition section could simply transition from an elliptical radiating aperture to a rectangular or other oblong waveguide (including ridged waveguide) instead of circular or square waveguide, The rectangular waveguide would typically be oriented at 45 degrees relative to the major or minor axis of the elliptical radiating aperture.

[0089] The inventor further recognized that all embodiments discussed above could also include additional metal or plastic ridges, slabs, posts or other structures protruding out of or placed against the major axis walls and/or the minor axis walls such that they protrude into the throat of the horn transition section. This is done to better control the physical lengths for general product size requirements/ constraints and/or for ease of integration into single die cast parts of multi-feed LNBF assemblies and possibly. This could also be employed to better control the specific amount and slope of the phase differential vs. frequency of the transition section. As an example the center feed in FIG. 10 illustrates an embodiment with a square antenna feed horn with, in this example ridges in the top and bottom walls. Adding the ridges in these wall forces the horn transition section (from oblong to square waveguide) to become longer in order to provide the desired amount of phase differential (somewhat greater than 90° in this case) which in turn caused the opposite slope phase differential section to lengthen as well so that the resulting total phase differential is 90°. It was necessary to make this center feed longer in order to match the length of the outer feeds so that they could be easily die-cast as a single unit. If ridges are placed in the two side walls, or in all four walls, instead of only in the top and bottom walls, then the feed can be shorter.

[0090] Therefore, it will be understood that various embodiments of the invention have the features and exhibit the advantages described below,

1. An elliptical (or other oblong) beam circular polarity receiving and/or transmitting device comprising either detachable or integrated electronics (such as low noise block down converters, amplifiers, transmitters, or transceivers), any necessary waveguide interface components and a simple horn that transitions abruptly and/or smoothly in one or more sections from a circular, or square waveguide to an elliptical, rectangular or other elongated radiating aperture where the aperture size (height and width), circular waveguide and transition section dimensions (lengths, heights, widths, flare angles and step are chosen to achieve good circular polarity performance (match and cross polarization isolation), and the desired radiation pattern characteristics without using cumbersome metal or dielectric septums or structures stretching across the inside of the horn for phase compensation. These dimensions are chosen to achieve a phase differential between orthogonal linear modes that are lined up with the wide (major) and narrow (minor) axis of the oblong horn. The phase differential is typically designed to be either +90 degrees or -90 degrees at a nominally frequency and varies across the frequency band to some degree, but can be any odd integer multiple of 90°, such as -630°, -450°, -270°, -90°, 90°, 270°, 450°, 630° and so forth.

2. An elliptical (or other oblong) circular polarity receiving and/or transmitting device comprising of either detachable or integrated electronics (low noise block down converters, amplifiers, transmitters, or transceivers), any necessary waveguide interface components, a simple horn that transitions abruptly and/or smoothly in one or more sections from a circular, or square waveguide to an elliptical, rectangular or other elongated radiating aperture, and an opposite slope phase differential section.

3. An elliptical (or other oblong) beam circular polarity receiving and/or transmitting device comprising of either detachable or integrated electronics (low noise block down converters, amplifiers, transmitters, or transceivers), any

necessary waveguide interface components, a simple horn that transitions abruptly and/or smoothly in one or more sections from a circular, or square waveguide to an elliptical, rectangular or other elongated radiating aperture, and an additive phase differential section.

4. An elliptical (or other oblong) beam circular polarity receiving and/or transmitting device of that includes additional metal or plastic ridges, slabs, posts or other structures protruding out of or placed against the side walls of major axis and/or the side walls of the minor axis such that they protrude into the throat of the horn transition section for the purpose of

a) better controlling the physical lengths for general product size requirements/constraints and/or for ease of integration into single die cast parts of multi-Teed LNBF assemblies, and
b) and better controlling the specific amount and slope of the phase differential vs. frequency of the transition section.

5. The elliptical (or other oblong) beam circular polarity receiving and/or transmitting device mounted on an antenna dish to generate a receive beam and/or transmit beam for receiving from or transmitting to a nominal source and/or receiver location such as a nominal geostationary satellite location that has several satellites at that location, where in one or more frequency bands and/or one or more polarities can be received from and/or transmitted to the location.

6. Multiple elliptical (or other oblong) beam circular polarity receiving and/or transmitting devices mounted separately or integrated in one or more housings that are mounted on an antenna dish to generate multiple receive and/or transmit beams for receiving from or transmitting to multiple nominal sources and/or receiver locations such as multiple satellite locations, where in the locations can be separated by as little 1 degrees and as much as 180 deg. and where in one or more frequency bands and/or one or more polarities can be received from and/or transmitted to each location.

7. One or more elliptical (or other oblong) beam circular polarity receiving and/or transmitting devices of the type described in advantages 1 and/or 2 and/or 3 and/or 4 as described above with one or more circular and/or linear polarity circular aperture receiving devices and/or one or more linear polarity elliptical (or other oblong) linear polarity devices mounted on an antenna dish to generate multiple receive and/or transmit beams for receiving from or transmitting to multiple nominal source and/or receiver locations such as multiple satellite locations, where in the locations can be separated by as little 1 degrees and as much as 180 deg.

Claims

1. An antenna feed horn (400,600) extending in a signal propagation direction, comprising: a reception end defined by an undivided, oblong input aperture (404);
an output aperture spaced apart from the input aperture in the signal propagation direction;
a phase adjustment structure extending from the input aperture to the output aperture comprising an interior surface defining an oblong, undivided cross-section perpendicular to the signal propagation direction over a substantial portion of the phase adjustment structure in the signal propagation direction, and for a signal propagating at a desired frequency and exhibiting circular polarity expressed by orthogonal linear components when incident at the input aperture, the interior surface of the phase adjustment structure configured to differentially phase shift the linear components by approximately 90 degrees to convert the signal from circular polarity to linearly polarity as the signal propagates through the phase adjustment structure.

2. The antenna feed horn of claim 1, wherein the phase adjustment structure (402) comprises a transition section that differentially phase shifts the linear components in a first direction by an initial amount less than 90 degrees and an additive phase differential section that differentially phase shifts the linear components by an additive amount in the first direction to impart a total differential phase shift through the phase adjustment structure of approximately 90 degrees, or optionally wherein the phase adjustment structure comprises a transition section (402) that differentially phase shifts the linear components in a first direction by an initial amount greater that 90 degrees and an oppositely sloped phase differential section that differentially phase shifts the linear components by a subtractive amount in a second direction opposing the first direction to impart a total differential phase shift through the phase adjustment structure of approximately 90 degrees.

3. The antenna feed horn of claim 3, wherein:

the transition section (402) exhibits a phase differential versus frequency transfer function that slopes in a first direction across an operational frequency band of the antenna feed horn; and
the oppositely sloped phase differential section exhibits a phase differential versus frequency transfer function that slopes in a direction opposing the first direction across the operational frequency band of the antenna feed horn.

4. The antenna feed horn of claim 1, wherein the oblong, undivided cross-section of the interior surface (400) of the phase adjustment structure is substantially elliptical or substantially rectangular.

5. The antenna feed horn of claim 1, wherein the interior surface (406) of the phase adjustment structure is smooth-walled, comprises one or more ridges extending in the signal propagation direction, or comprises a smooth-walled first portion and a second portion comprising one or more ridges extending in the propagation direction.

6. The antenna feed horn (400,600) of claim 1, further comprising two additional antenna feed horns (1004,1006) as described in claim 1, disposed within a common integral housing, and wherein each antenna feed horn is positioned to receive signals from an associated satellite, and the satellites are located approximately within a four degree longitudinal zone.

7. An antenna feed horn (400, 600) extending in a signal propagation direction and, for a signal propagating through the antenna feed horn at a desired frequency and exhibiting a polarity expressed by linear components, the phase adjustment structure comprising:

a transition section (402) that differentially phase shifts the linear components in a first direction; and an oppositely sloped phase differential section that differentially phase shifts the linear components by a subtractive amount in a second direction opposing the first direction.

8. The antenna feed horn (400,600) of claim 7, wherein:

the transition section (402) exhibits a phase differential versus frequency transfer function that slopes in a first direction across an operational frequency band of the antenna feed horn;
the oppositely sloped phase differential section exhibits a phase differential versus frequency transfer function that slopes in a second direction opposing the first direction across the operational frequency band of the antenna feed horn.

9. The antenna feed horn (400,600) of claim 3 or 8, wherein, for an operational frequency band between a low-end frequency of 18.3 GHz and a high-end frequency 20.2 GHz, the differential phase shift through the antenna feed horn differs from 90 degrees by no more than ten degrees over the operational frequency band, or optionally wherein, for an operational frequency band between a low-end frequency of 11.7 GHz and a high-end frequency 12.7GHz, the differential phase shift through the antenna feed horn differs from 90 degrees by no more than ten degrees over the operational frequency band.

10. An antenna feed horn (400, 600) comprising a phase adjustment structure extending in a signal propagation direction, the phase adjustment structure comprising:

a non-corrugated interior surface extending in the signal propagation direction and defining an oblong, undivided cross-section perpendicular to the signal propagation direction over a substantial portion of the phase adjustment structure in the signal propagation direction; and
for a signal propagating at a desired frequency and exhibiting circular polarity expressed by orthogonal linear components when incident at the input aperture, the interior surface of the phase adjustment structure configured to deliver the signal to the output aperture exhibiting circular polarity.

11. The antenna feed horn (400, 600) of claim 10, wherein the interior surface of the phase adjustment structure is smooth-walled, comprises one or more ridges extending in the signal propagation direction, or comprises a smooth-walled first portion and a second portion comprising one or more ridges extending in the propagation direction.

12. An antenna (300) comprising an oblong reflector (302) and an antenna feed horn (306) positioned and configured to illuminate substantially all of the oblong reflector, the antenna feed horn comprising:

a reception end defined by an undivided, oblong input aperture;
an output aperture spaced apart from the input aperture in the signal propagation direction;
a phase adjustment structure extending from the input aperture to the output aperture comprising a interior surface defining an oblong, undivided cross-section perpendicular to the signal propagation over a substantial portion of the phase adjustment structure in the signal propagation direction; and for a signal propagating at a desired frequency and exhibiting circular polarity expressed by orthogonal linear components when incident at the input aperture, the interior surface of the phase adjustment structure configured to differentially phase shift the linear components by approximately 90 degrees to convert the signal from circular polarity to linearly polarity as the signal propagates through the phase adjustment structure.

13. The antenna (300) of claim 12, further comprising two additional antenna feed horns (1O04,1006 as described in claim 16, disposed within a common integral housing, and wherein:

each feed horn is positioned to receive signals from an associated satellite; and the satellites are located approximately within a four degree longitudinal zone.

14. The antenna (300) of claim 13, wherein, for each antenna feed horn (1004,1006) the phase adjustment structure of comprises a transition section (402) that differentially phase shifts the linear components in a first direction by an initial amount greater than 90 degrees and an oppositely sloped phase differential section that differentially phase shifts the linear components by a subtractive amount in a second direction opposing the first direction to impart a total differential phase shift through the phase adjustment structure of approximately 90 degrees.

15. The antenna (300) of claim 14, wherein, for each antenna feed horn (1004,1006):

the transition section (402) exhibits a phase differential versus frequency transfer function that slopes in a first direction across an operational frequency band of the antenna feed horn; and
the oppositely sloped phase differential section exhibits a phase differential versus frequency transfer function that slopes in a direction opposing the first direction across the operational frequency band of the antenna feed horn.

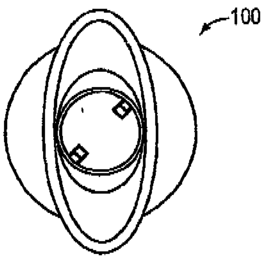


FIG. 1A

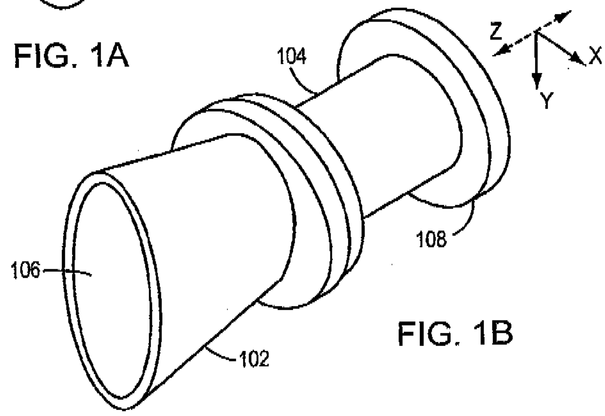


FIG. 1B

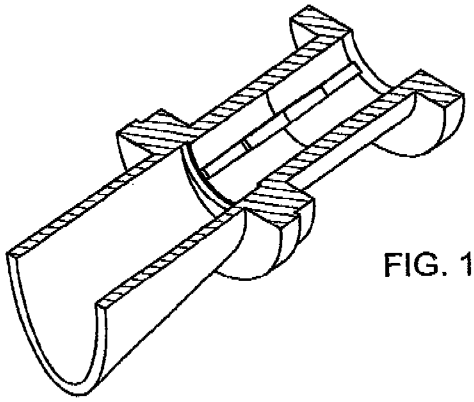
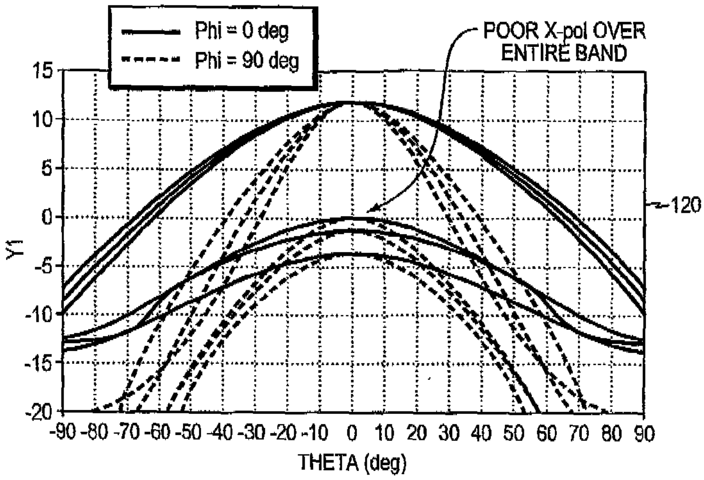


FIG. 1C



Phi = 0 deg
Phi = 90 deg
POOR X-pol OVER ENTIRE BAND
15
10
5
0
-5
-10
-15
-20
Y1
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
THETA (deg)
120

FIG. 1D

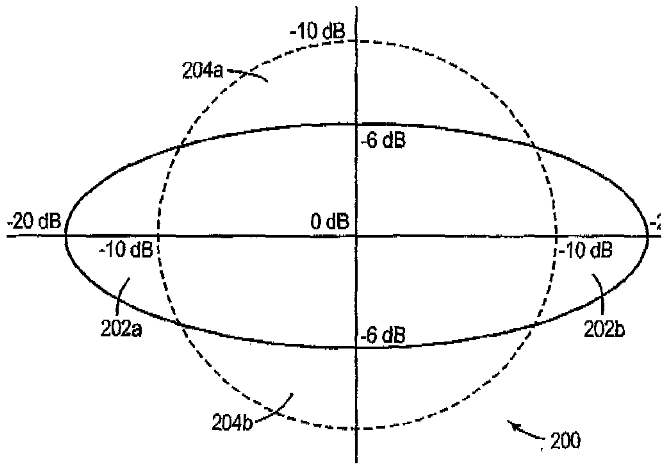


FIG. 2
PRIOR ART

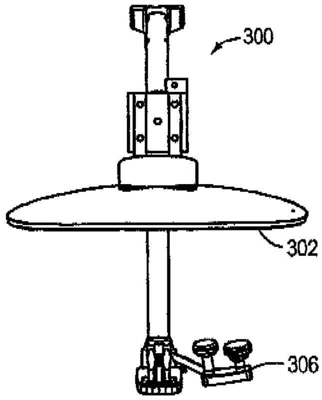


FIG. 3A

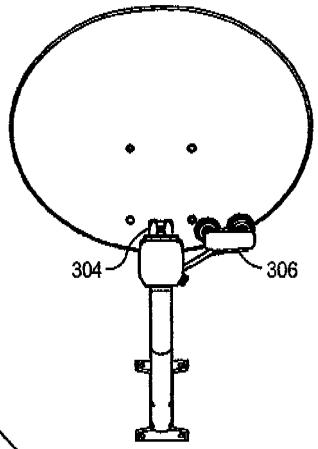


FIG. 3B

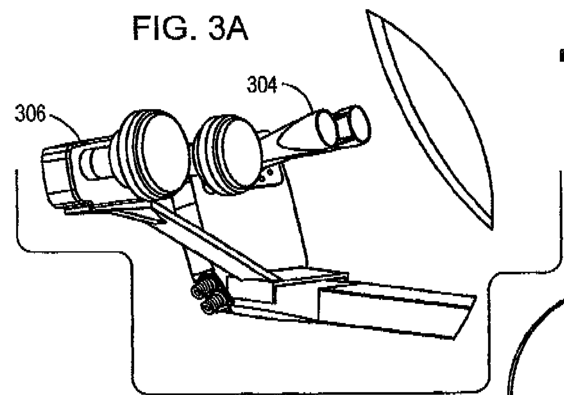


FIG. 3C

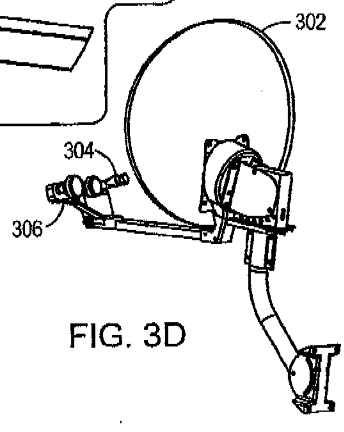


FIG. 3D

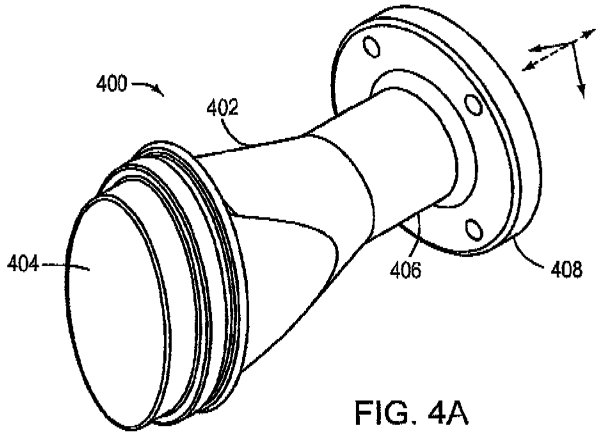


FIG. 4A

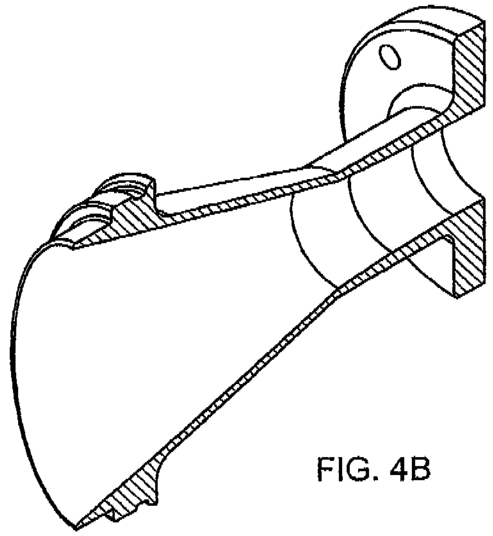


FIG. 4B

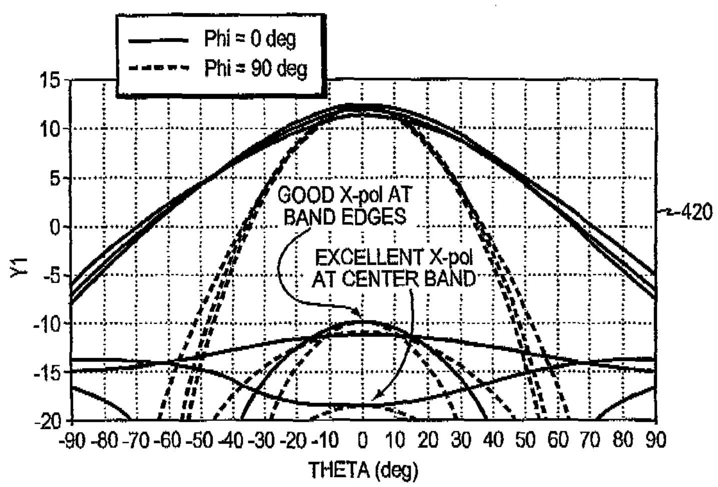

Phi = 0 deg
Phi = 90 deg
15
10
5
0
-5
-10
-15
-20
Y1
GOOD X-pol AT BAND EDGES
EXCELLENT X-pol AT CENTER BAND
420
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
THETA (deg)

FIG. 4C

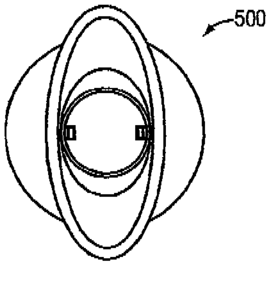


FIG. 5A

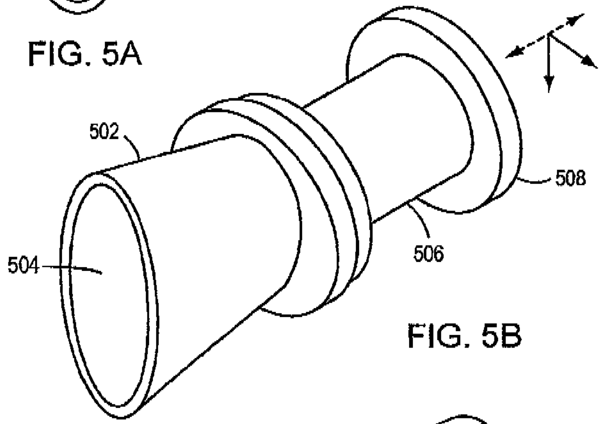


FIG. 5B

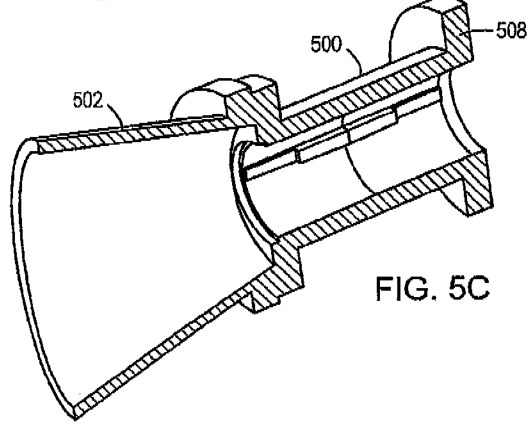


FIG. 5C

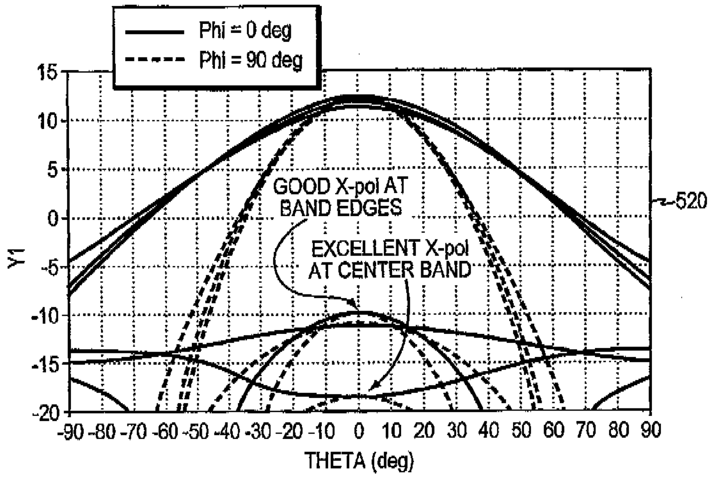

Phi = 0 deg
Phi = 90 deg
15
10
5
0
-5
-10
-15
-20
Y1
GOOD X-pol AT
BAND EDGES
EXCELLENT X-pol
AT CENTER BAND
520
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
THETA (deg)

FIG. 5D

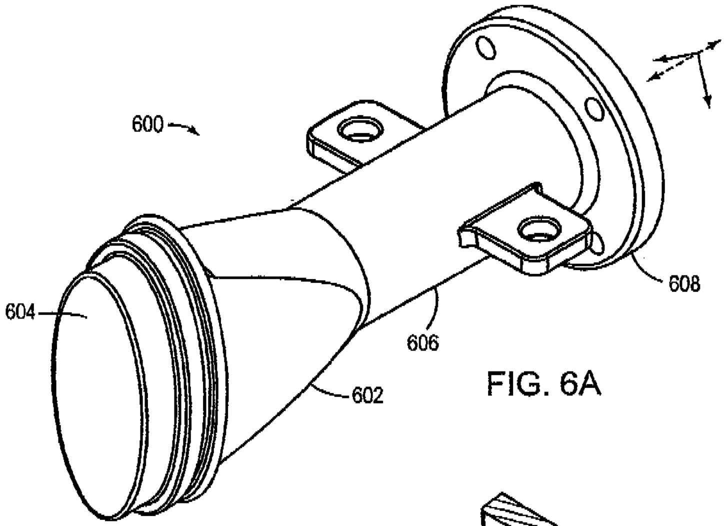


FIG. 6A

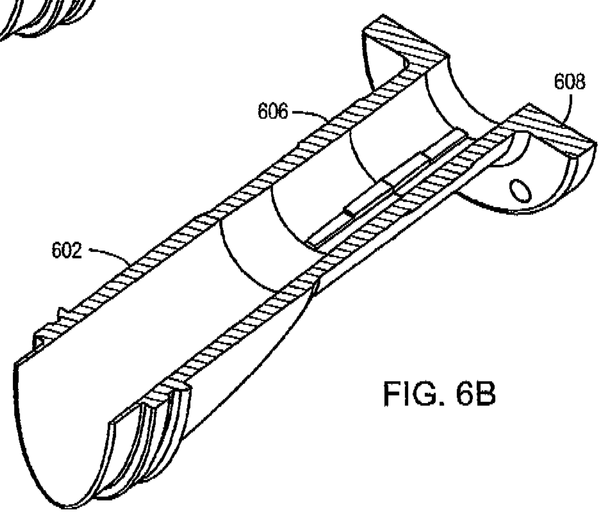


FIG. 6B

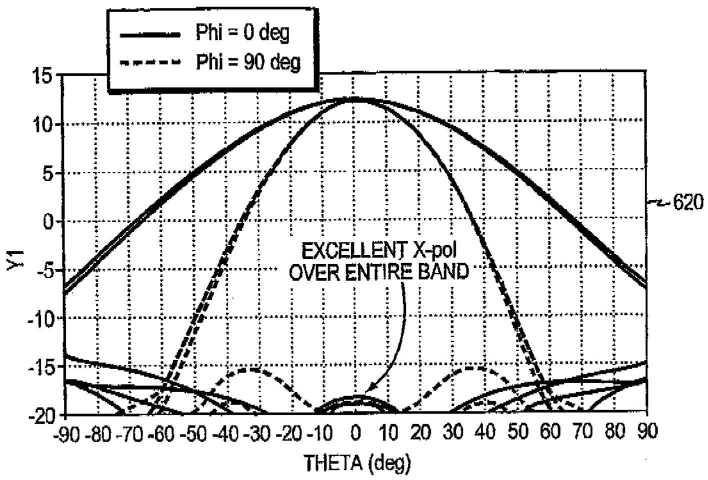

Phi = 0 deg
Phi = 90 deg
15
10
5
0
-5
-10
-15
-20
Y1
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
THETA (deg)
EXCELLENT X-pol
OVER ENTIRE BAND
620

FIG. 6C

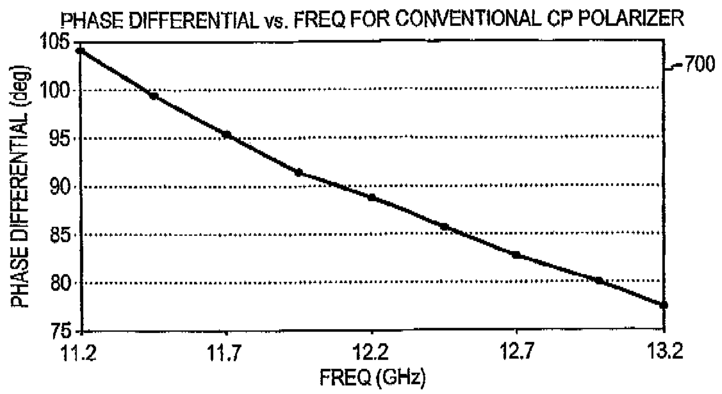

PHASE DIFFERENTIAL vs. FREQ FOR CONVENTIONAL CP POLARIZER
PHASE DIFFERENTIAL (deg)
105
100
95
90
85
80
75
11.2
11.7
12.2
12.7
13.2
FREQ (GHz)
700

FIG. 7

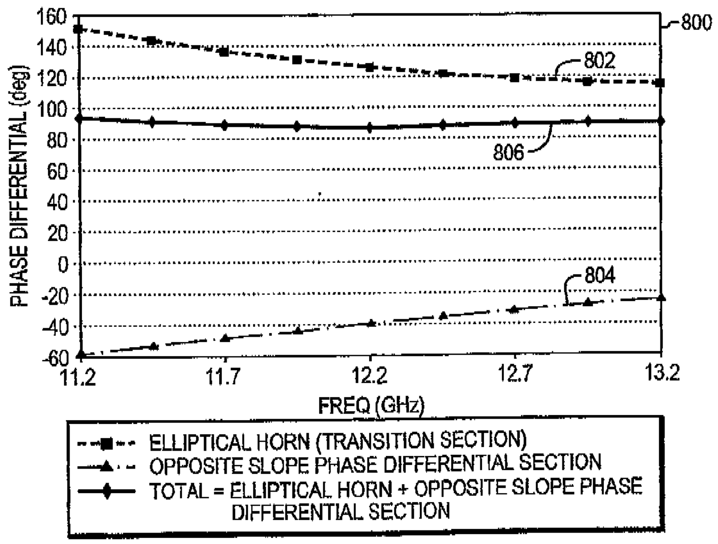

PHASE DIFFERENTIAL (deg)
160
140
120
100
80
60
40
20
0
-20
-40
-60
11.2
11.7
12.2
12.7
13.2
FREQ (GHz)
800
802
804
806
ELLIPTICAL HORN (TRANSITION SECTION)
OPPOSITE SLOPE PHASE DIFFERENTIAL SECTION
TOTAL = ELLIPTICAL HORN + OPPOSITE SLOPE PHASE DIFFERENTIAL SECTION

FIG. 8

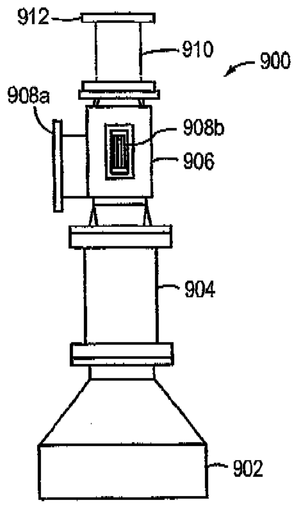


FIG. 9A.1

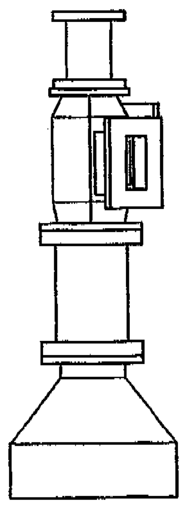


FIG. 9A.2

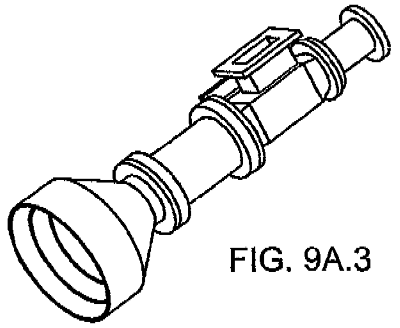


FIG. 9A.3

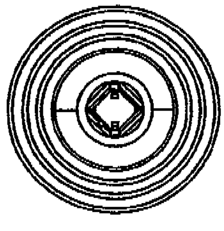


FIG. 9A.4

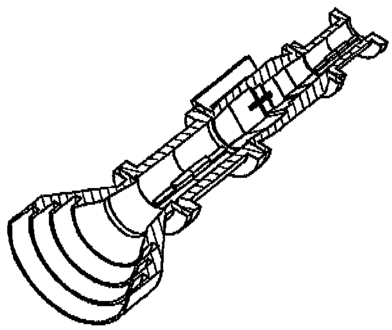


FIG. 9A.5

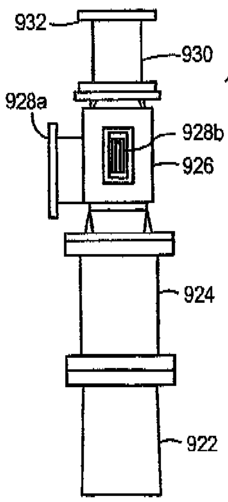


FIG. 9B.1

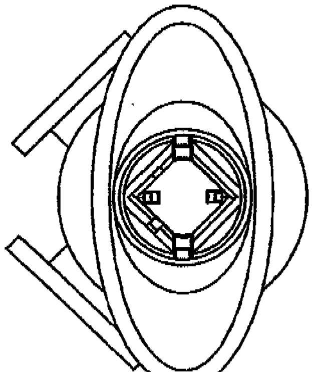


FIG. 9B.2

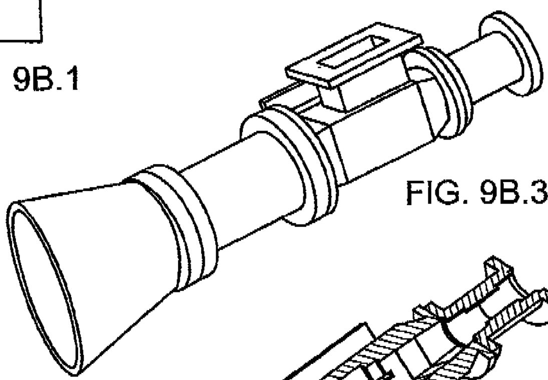


FIG. 9B.3

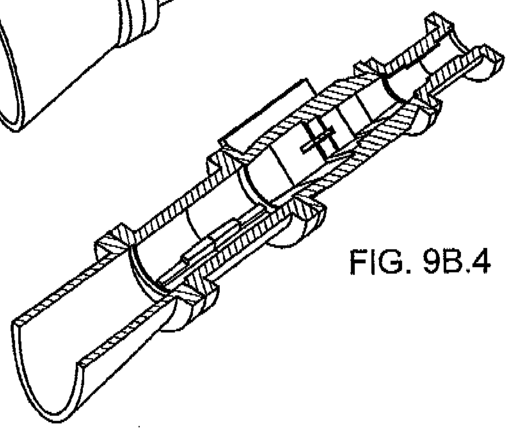


FIG. 9B.4

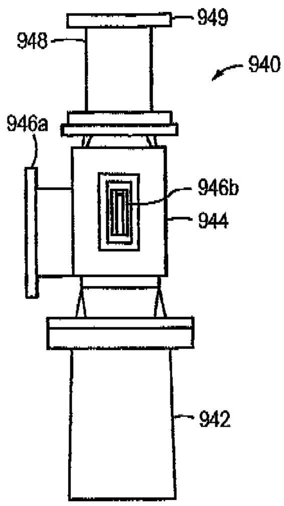


FIG. 9C.1

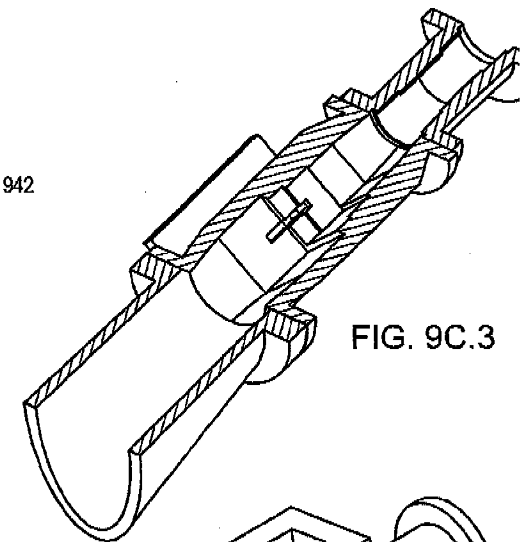


FIG. 9C.3

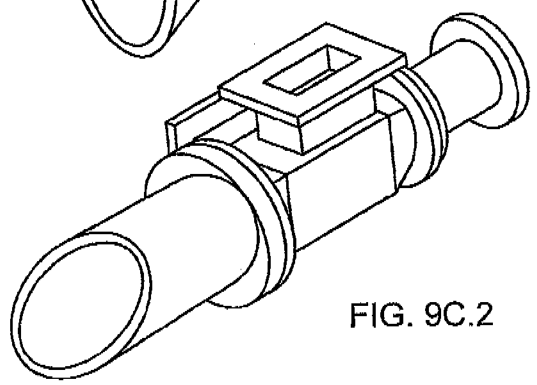


FIG. 9C.2

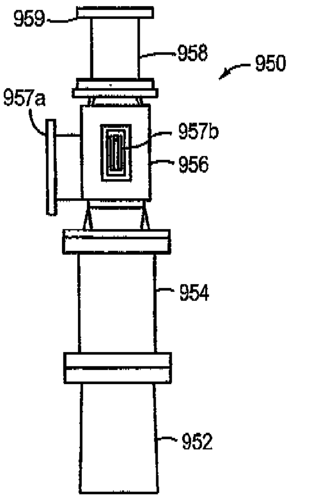


FIG. 9D.1

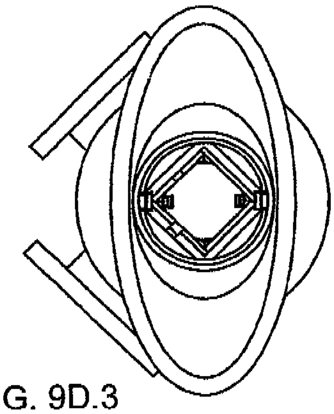


FIG. 9D.3

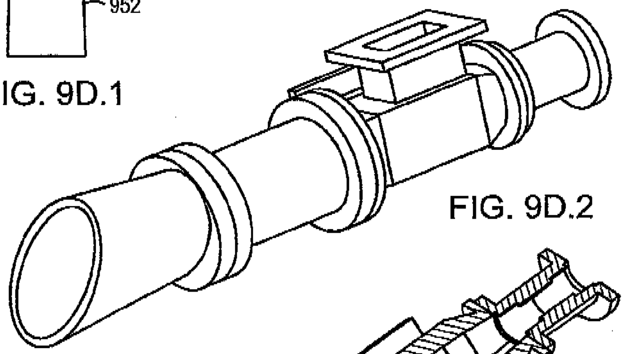


FIG. 9D.2

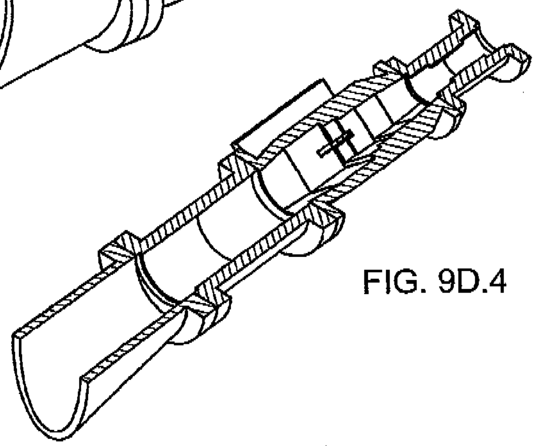


FIG. 9D.4

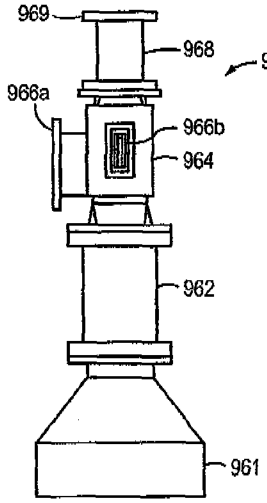


FIG. 9E.1

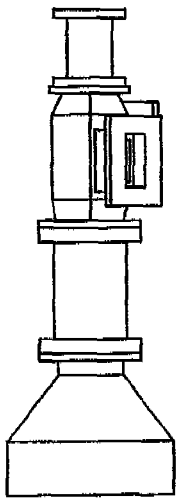


FIG. 9E.2

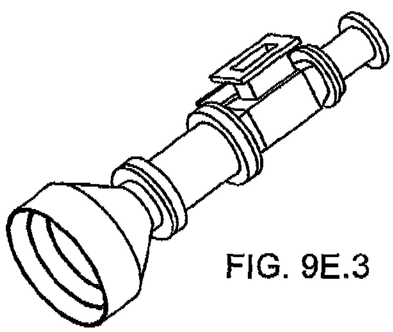


FIG. 9E.3

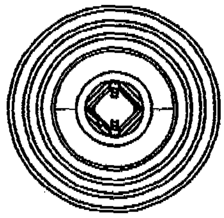


FIG. 9E.4

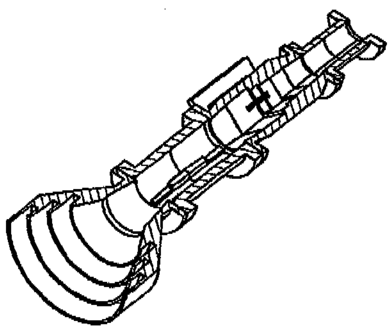


FIG. 9E.5

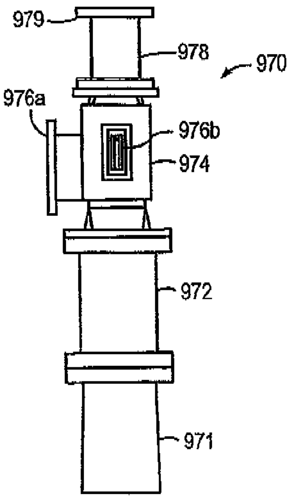


FIG. 9F.1

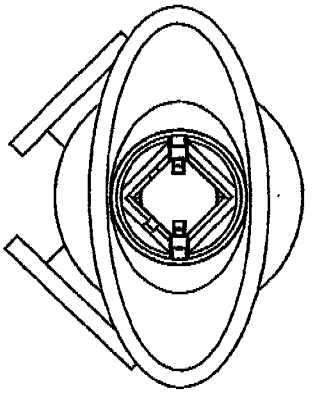


FIG. 9F.2

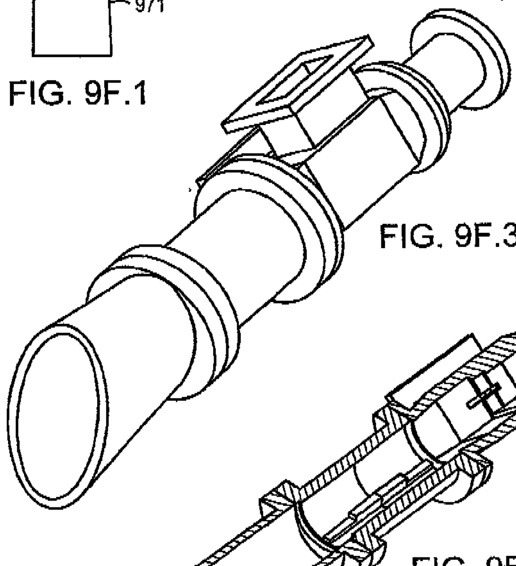


FIG. 9F.3

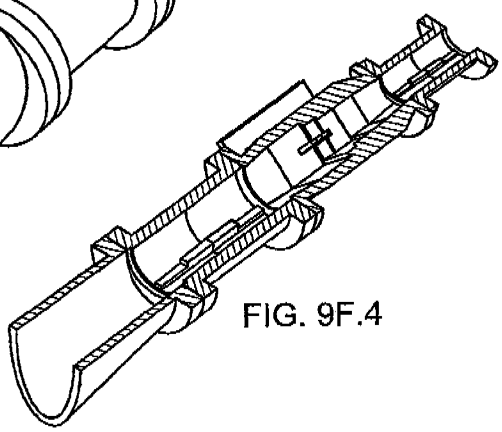
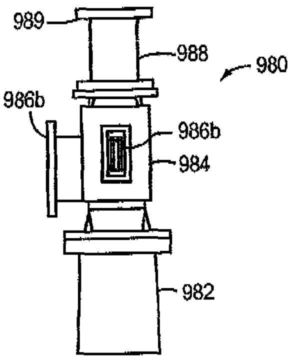


FIG. 9F.4



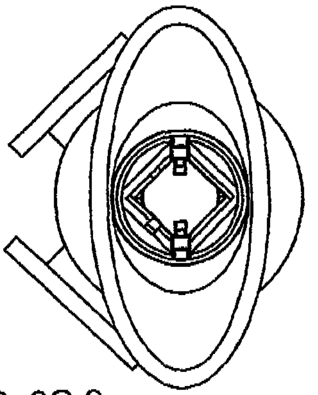


FIG. 9G.2

FIG. 9G.1

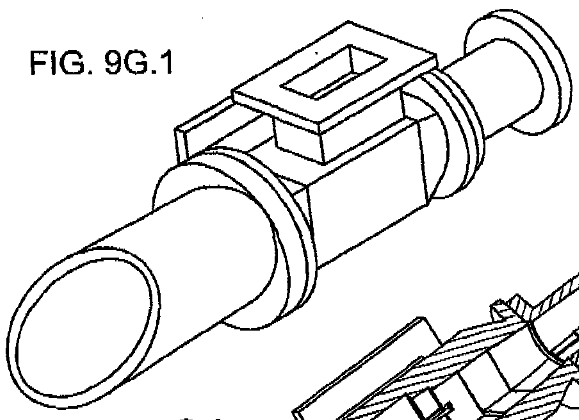


FIG. 9G.3

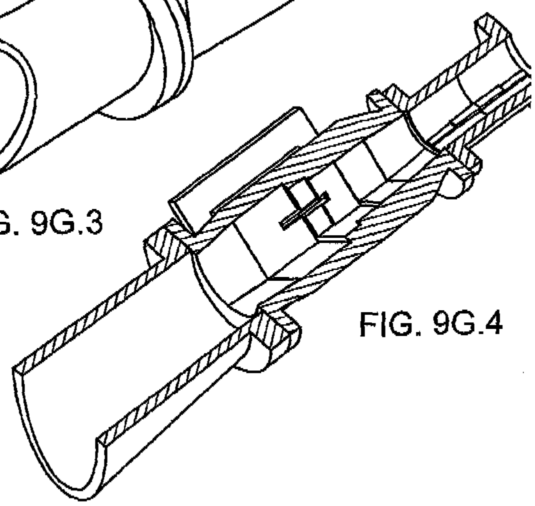


FIG. 9G.4

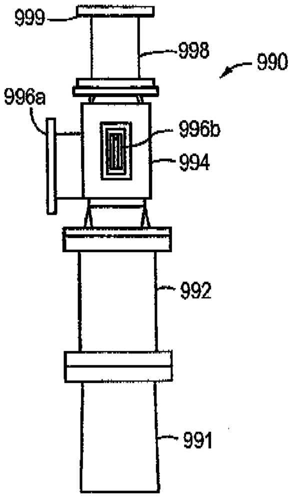


FIG. 9H.1

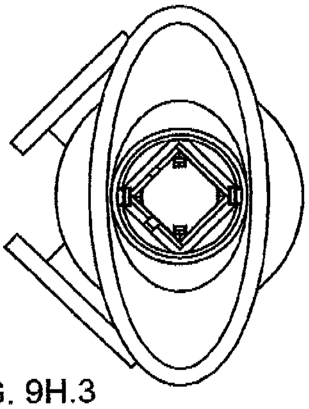


FIG. 9H.3

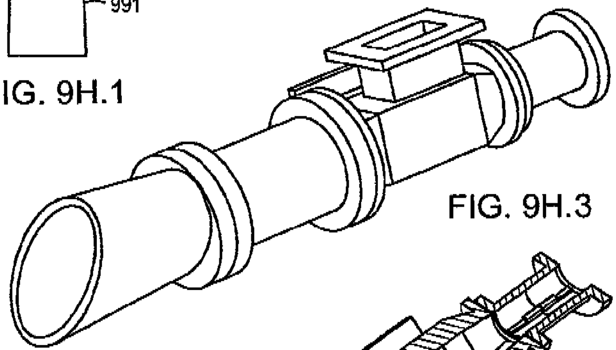


FIG. 9H.3

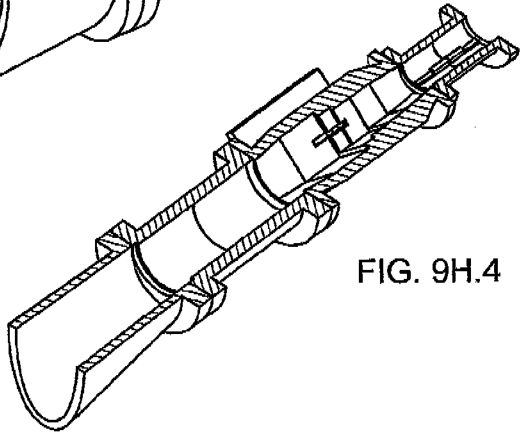


FIG. 9H.4

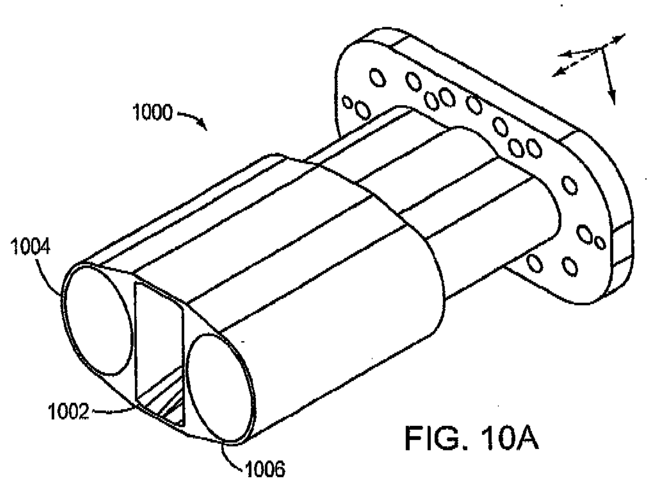


FIG. 10A

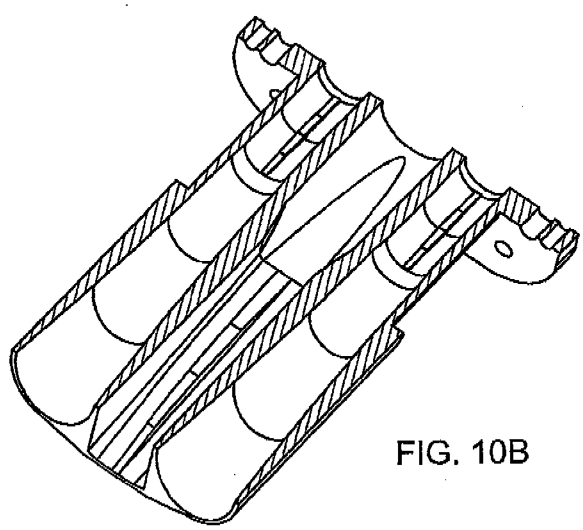


FIG. 10B

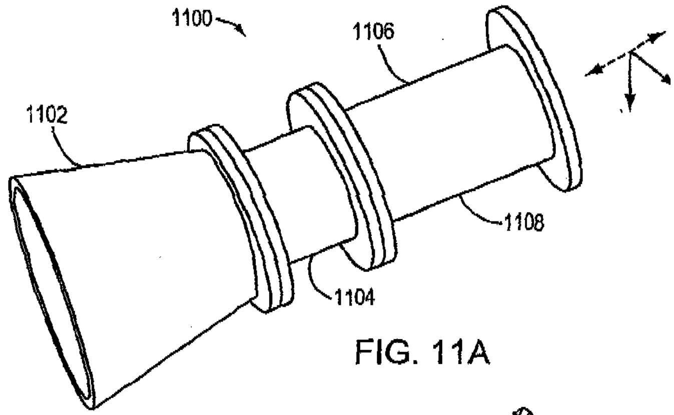


FIG. 11A

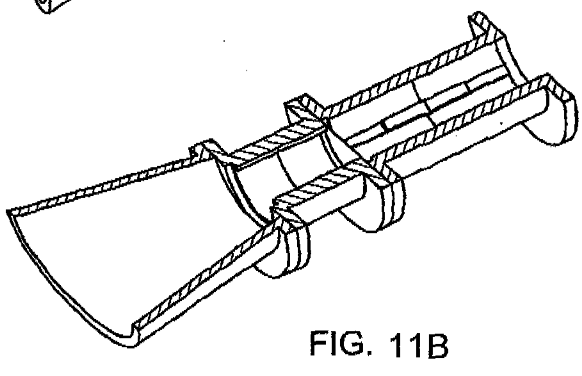


FIG. 11B

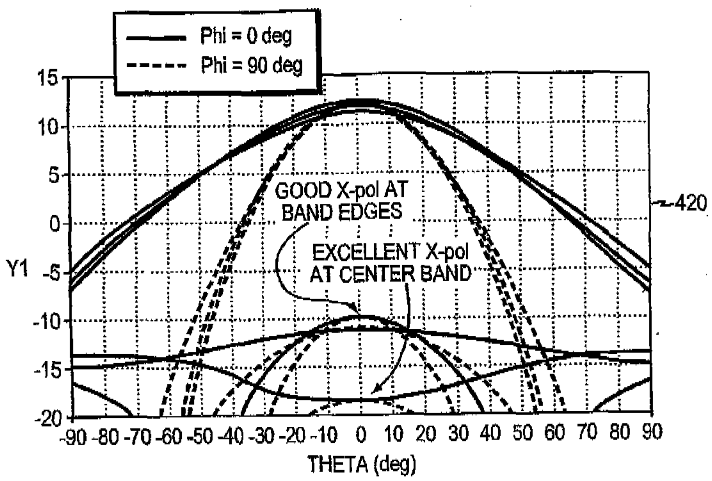

Phi = 0 deg
Phi = 90 deg
15
10
5
0
-5
-10
-15
-20
Y1
GOOD X-pol AT
BAND EDGES
EXCELLENT X-pol
AT CENTER BAND
420
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
THETA (deg)

FIG. 11C

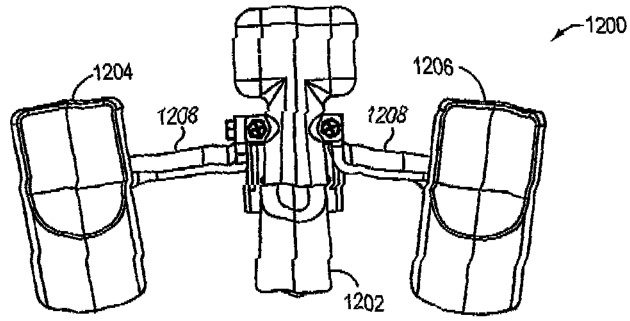


FIG. 12A

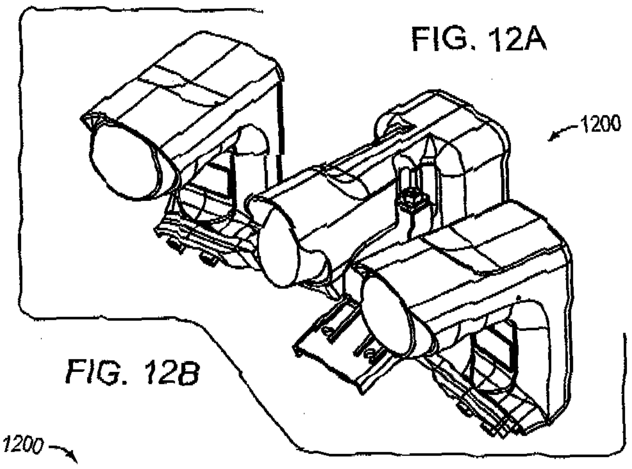


FIG. 12B

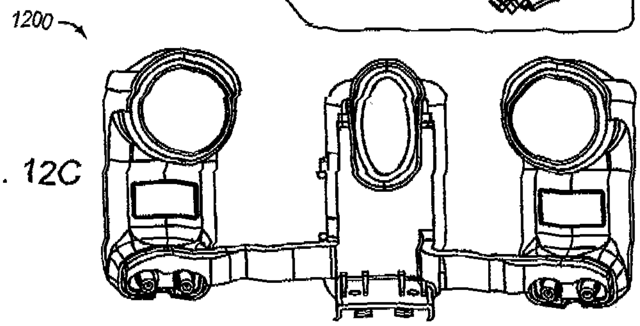


FIG. 12C

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- US 60571988 B **[0001]**
- US 6570542 B **[0008] [0052]**