

United States Patent [19]

Charlton et al.

[11] **3,787,869**[45] **Jan. 22, 1974****[54] INTEGRATED BEACON ANTENNA
POLARIZATION SWITCH****[75] Inventors:** Donald A. Charlton, Huntington Beach; James S. Ajioka, Fullerton, both of Calif.**[73] Assignee:** Hughes Aircraft Company, Culver City, Calif.**[22] Filed:** Oct. 11, 1972**[21] Appl. No.:** 296,702**[52] U.S. Cl.** 343/756, 343/781, 333/21 R, 333/21 A**[51] Int. Cl.** H01q 19/00**[58] Field of Search** 343/756, 773, 781, 786; 333/21 R, 21 A

[56]

References Cited**UNITED STATES PATENTS**

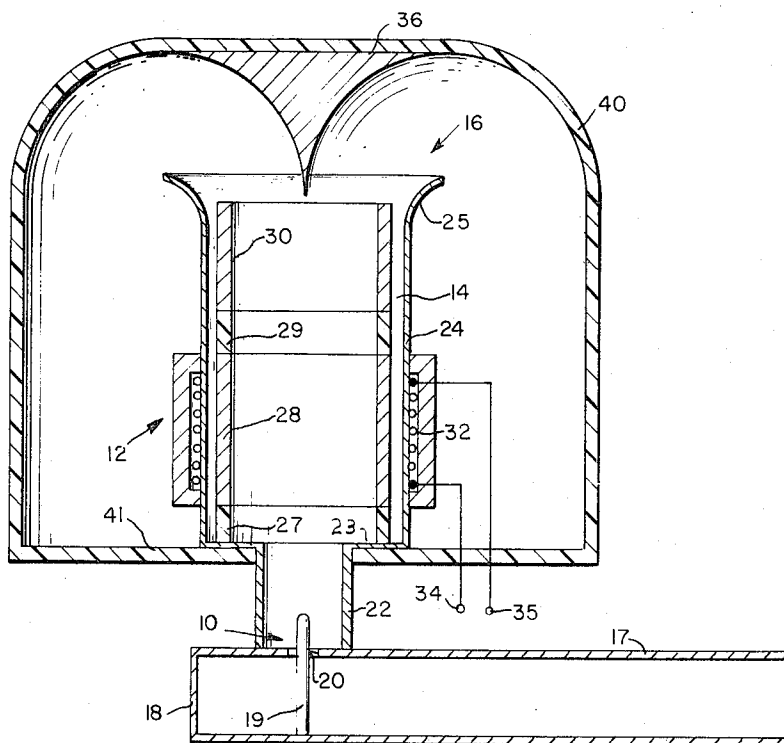
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[57]

ABSTRACT

This invention relates to a compact integrated beacon antenna polarization switch which may be designed to be fed by either coaxial line or circular waveguide and which provides a dual polarization radiating aperture having identical radiation beacon patterns for vertical and horizontal polarization and a ferrite mode switch capable of switching between the vertical, horizontal, right and left circular radiating mode.

10 Claims, 4 Drawing Figures

SHEET 1 OF 2

Fig. 1.

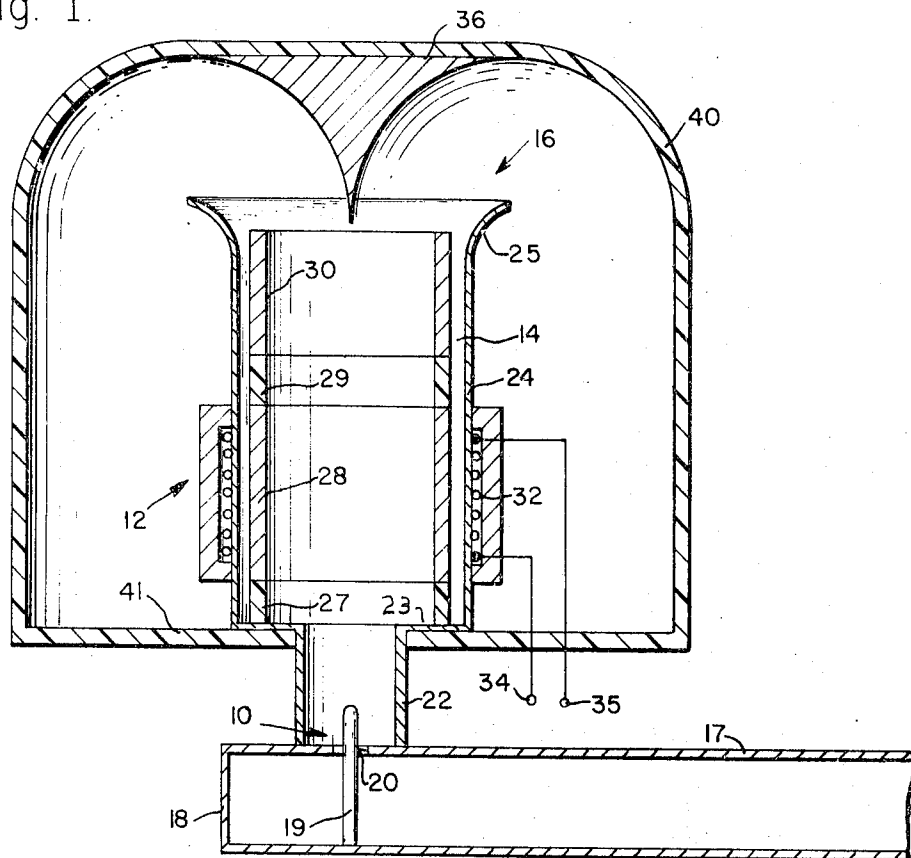


Fig. 3.

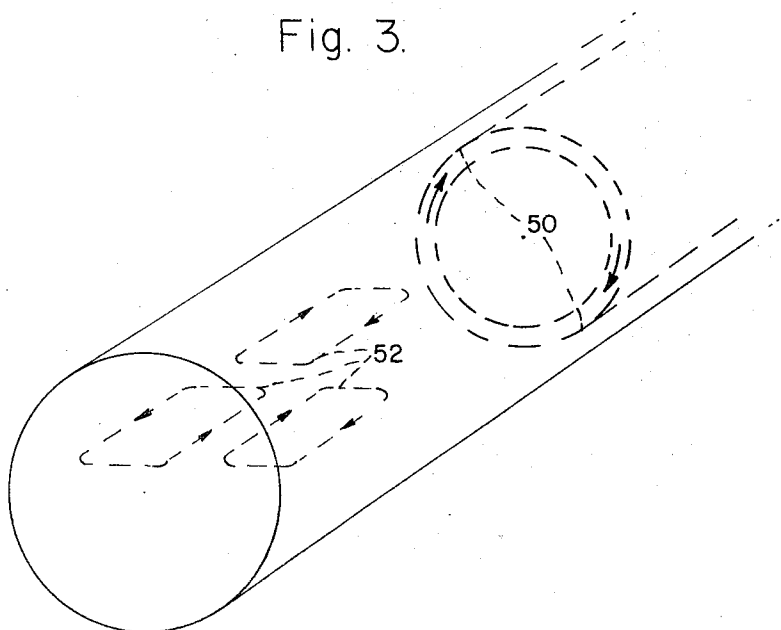


Fig. 2.

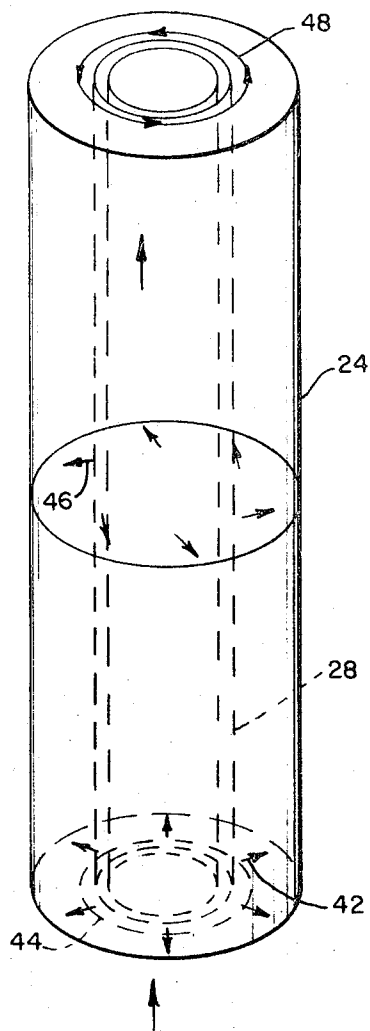
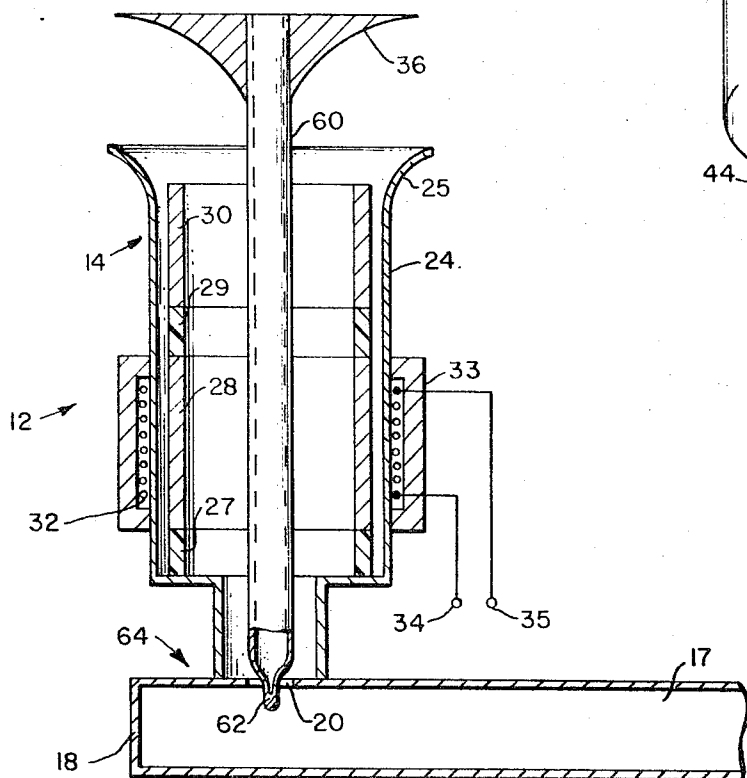


Fig. 4.



INTEGRATED BEACON ANTENNA POLARIZATION SWITCH

BACKGROUND OF THE INVENTION

The antenna polarization switch of the present invention offers advantages over contemporary switches which perform the same function such as reduced size, weight and complexity because the antenna and switch are integrated into one component. The disclosed switch also provides performance superior to that of contemporary switches primarily due to its circular symmetry.

SUMMARY OF THE INVENTION

The integrated beacon antenna polarization switch is a compact unit in circular waveguide or coaxial line which provides a beacon radiation pattern having vertical, horizontal, right circular, or left circular polarizations. The microwave structure constituting the switch includes four principal parts. For the circular waveguide version these parts are a TM_{01} mode launcher, a Faraday rotator section which includes a ferrite cylinder and a bias coil, a 90° fixed phase shift section and a radiating aperture. In the case of the coaxial line version, a TEM mode launcher is used in lieu of the TM_{01} mode launcher. The action of the bias magnetic field in the ferrite cylinder causes the radially oriented electric field of the TM_{01} or TEM mode to rotate in the transverse plane (clockwise or counterclockwise depending on direction of the bias field) thereby producing a component of electric field in the circumferential direction which is tantamount to exciting the TE_{01} mode. This rotation is followed by a quarter-wave phase shifter which acts only on the TE_{01} type energy. After this phase shift, the TE_{01} mode field either combines with the TM_{01} mode field to provide the circular polarizations or if alone provides the horizontal polarization. Thus, the bias current determines the amount of electric field rotation which, in turn, determines the ratio of the TM_{01} to TE_{01} modal content and the resulting polarization of the radiated field.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a cross-sectional view of the cylindrical waveguide version of the integrated beacon antenna polarization switch of the present invention;

FIG. 2 illustrates the mode conversion in the Faraday rotator in the device of FIG. 1;

FIG. 3 illustrates the operation of the TE_{01} mode phase shifter in the device of FIG. 1; and

FIG. 4 shows a cross-sectional view of the coaxial line version of the integrated beacon antenna polarization switch of the present invention.

DESCRIPTION

Referring now to FIG. 1, there is shown a cross-sectional view of the cylindrical waveguide version of the integrated beacon antenna polarization switch in accordance with the invention. In general, the antenna polarization switch includes a TM_{01} mode launcher 10, a Faraday rotator 12, a 90° fixed phase shift section 14 and a circular radiating aperture 16. In particular, the TM_{01} mode launcher 10 includes by way of example a rectangular waveguide feed 17 which is terminated transversely across an extremity thereof by a conductive sheet 18. Along a center line of rectangular wave-

guide 17 approximately one-quarter guide wavelength from sheet 18, a probe 19 extends perpendicularly from the inside of one broad wall through an aperture 20 in the broad wall opposite therefrom for a distance not more than the height of rectangular waveguide 17. A vertically disposed cylindrical waveguide 22, as shown in the drawing, is symmetrically disposed about probe 19 and makes electrical connection to the outside of the broad sidewall of rectangular waveguide 17. Cylindrical waveguide 22 extends an arbitrary distance to an outward step 23 which provides a transition to an open-ended conductive cylinder 24 having an outward flare 25 at the top-most extremity thereof, as viewed in the drawing.

Commencing from the step 23 in the order named and symmetrically disposed within the cylinder 24, there is an annular dielectric ring 27, a ferrite cylinder 28, another annular dielectric ring 29 and another ferrite cylinder 30, all of substantially the same diameter and thickness. The dielectric rings 27, 29 and the ferrite cylinders 28, 30 are held in place within cylinder 24 by means of an appropriate low-loss potting compound or cement, not shown. Ferrite cylinder 30 is permanently magnetized in a circumferential direction and is of a length to constitute a non-reciprocal one-quarter wave plate thereby to provide the 90° fixed phase shifter 14.

Faraday rotator 12 intermediate the TM_{01} mode launcher 10 and the 90° fixed phase shifter 14 is provided by a direct-current coil 32 disposed around the cylinder 24 jacketed by an external shell 33 of ferrous material that is coextensive with the ferrite cylinder 28. Direct-current coil 32 has terminals 34, 35 for applying a direct current therethrough to produce a longitudinal magnetic field within ferrite cylinder 28 having a return path through the jacket of ferrous material 33. The annular dielectric rings 27, 29 separate the Faraday rotator 12 from the 90° fixed phase shifter 14.

Following the 90° fixed phase shifter 14 there is the circular radiating aperture 16 that is provided by a metallic reflector 36 which commences at a point from the center line of ferrite cylinder 30 near the top extremity thereof, as viewed in the drawing, and curves up and out in a surface of revolution until it approaches tangency to a horizontal plane at a diameter slightly larger than that of flare 25 on cylinder 24. The center of curvature may be substantially the same as that of flare 25. Reflector 36 may, for example, be supported by a dielectric radome 40 which envelopes the Faraday rotator 12 and 90° fixed phase shifter 14 and may be supported by a disc 41 attached to the outside of step 23.

In operation the probe 19 of the TM_{01} mode launcher 10 energizes the cylindrical waveguide 22 with an electric field which transforms into a radial electric field as it progresses along the waveguide 22. The concomitant magnetic field is orthogonal to the electric field which is circular thereby launching the TM_{01} mode in circular waveguide 22.

The function of the Faraday rotator is to transform the TM_{01} mode into the TE_{01} mode to an extent determined by the bias current applied to coil 32. In particular, the magnitude and direction of the bias current applied at terminals 34, 35 through coil 32 determines the four modes of operation of the antenna polarization switch described herein, namely (1) zero bias current whereby energy propagates through Faraday rotator 12 in the TM_{01} mode without transformation; (2) full bias

current whereby substantially all of the TM_{01} mode is transformed to the TE_{01} mode; (3) one-half bias current in a first direction whereby one-half the energy propagating in the TM_{01} mode is transformed to the TE_{01} mode of a phase determined by the direction of the bias current; and (4) one-half bias current in a second direction opposite from the first direction whereby one-half the energy propagating in the TM_{01} mode is transformed to the TE_{01} mode of a phase that is 180° different from the phase of the TE_{01} mode in (3) above. Referring to FIG. 2, there is shown the manner of operation of the Faraday rotator 12 for the mode (2) above where substantially all of the TM_{01} mode is transformed to the TE_{01} mode. At the input of rotator 12 the E field 42 of the TM_{01} mode is radial and the associated H field 44 circular. The vectors of the E field 42 may be regarded as oppositely rotating vectors with concomitant H fields to indicate the change in magnitude and direction of the E field 42. The concomitant H fields being orthogonal to the bias field interact in a manner which increases the propagation constant of one and decreases the propagation constant of the other with corresponding changes in propagation constant of the oppositely rotating vectors representing the E field 42. This change in propagation constant of the oppositely rotating vectors representing the E field results in a net rotation of the E field 42 as illustrated by the E field 46. The direction of rotation is determined by the direction of the bias field in ferrite cylinder 28 which in turn is determined by the direction of the bias current through coil 32. During mode (2) above, the E field 42 is rotated 90° thereby forming the circular E field 48 typical of the TE_{01} mode. During mode (1) there is no rotation of E field 42 and thus no transformation into the TE_{01} mode. Lastly, during modes (3) and (4) above, the rotation of E field 42 is $\pm 45^\circ$ thus converting one-half the energy in the TM_{01} mode into the TE_{01} mode. The physical length of Faraday rotator 12 may vary depending on the type of ferrite, the frequency, the dimensions of ferrite cylinder 28 and the intensity of the bias field generated by current flow through coil 32.

Referring to FIG. 3 there is illustrated the operation of the 90° fixed phase shifter 14. The ferrite cylinder 30 of phase shifter 14 is permanently magnetized with a circular magnetic field 50 whereby there is no interaction with electromagnetic energy in the TM_{01} mode since the radio frequency magnetic field and the direct current magnetization are in the same direction. In the case of the TE_{01} mode, however, the magnetic field 52 thereof in propagating through the ferrite cylinder 30 rotates about the permanent bias field 50 to either slow the electromagnetic wave down or speed it up to produce a $\pm 90^\circ$ phase change depending on the direction of propagation of the TE_{01} mode relative to the direction of the permanent magnetic field 50. Because of this, the operation of the phase shifter 14 is said to be "non-reciprocal." This is of no consequence if the antenna polarization switch is to be used to transmit only or to receive only. In the present case, however, the non-reciprocal operation of phase shifter 14 is counteracted by the non-reciprocal operation of the Faraday rotator 12 whereby the device herein described can be used for transmitting and receiving without switching.

Referring again to FIG. 1, the radiating aperture 16 rotates the respective TM_{01} mode and TE_{01} modes from the center out through 90° . Thus in the case of mode (1) above, where the TM_{01} mode propagates through

the Faraday rotator 12 and the phase shifter 14 with no transformation, the radiating aperture 16 rotates the radial E field thereof into the upright position resulting in vertically polarized energy. In (2) above where the TM_{01} mode is transformed into the TE_{01} mode, the radiating aperture 16 allows the circular electric field of the TE_{01} mode to expand resulting in horizontally polarized energy. In modes (3) and (4) above, however, 50 percent of the energy reaching radiating aperture 16 is in the TM_{01} mode and the remaining 50 percent is in the TE_{01} mode and shifted in phase by 90° . When this energy is combined, the resulting electromagnetic wave has right-circular or left-circular polarization as determined by the direction of the bias field through the Faraday rotator 12.

Referring to FIG. 4 wherein like reference numerals indicate like elements, there is illustrated a coaxial line version of the integrated beacon antenna polarization switch of the present invention. A coaxial center conductor 60 extends through conductive cylinders 22, 24 and supports the metallic reflector 36 obviating the need for the support radome 40. At the extremity of coaxial center conductor 60 nearest the rectangular waveguide 17, the conductor 60 tapers to a probe 62 and extends into the rectangular waveguide 17 through the aperture 20, thus providing a TEM mode launcher 64 into the Faraday rotator 12. A coaxial line could be used without the transition from rectangular waveguide 17, thus obviating the need for the TEM mode launcher in that the TEM mode propagates normally in coaxial line. The center conductor 60 may be supported by low-loss dielectric or dielectric wafers in a conventional manner, not shown. Inasmuch as the electric and magnetic fields of the TEM mode is substantially identical to the TM_{01} mode in cylindrical waveguide with the exception that the fields surround the center conductor 60, the operation of the coaxial line version of the antenna polarization switch of FIG. 4 is the same as the cylindrical waveguide version of the antenna polarization switch of FIG. 1. The TE_{01} mode is normally not a practical operating mode of most coaxial lines because there are many lower order modes which the coaxial line will support. In this case, however, due to the dielectric or ferrite cylinder within the coax and a larger than average inside diameter of outer conductor to outside diameter of inner conductor ratio, the order of the modes is changed and the TE_{01} mode is made to have a lower cut-off frequency than all but the TEM mode.

What is claimed is:

1. An integrated antenna polarization switch capable of operating in vertical, horizontal, left-circular and right-circular polarization modes, said switch comprising means for guiding electromagnetic energy along a predetermined path having an input and an output, said path being symmetrical about a center line; means for launching electromagnetic energy along said path in a first mode having a transverse radial electric field and a transverse magnetic field about said center line; means disposed along a first section of said path for controllably rotating said radial electric field in a plane transverse to said center line thereby to transform a controllable portion of said electromagnetic energy from said first mode into a second mode having an electric field disposed around said center line; means disposed along a second section of said path subsequent to said first section for shifting the phase of said elec-

tromagnetic energy in said second mode by substantially 90° without affecting the relative phase of said electromagnetic energy in said first mode; and means for directing electromagnetic energy in said first and second modes outwards from said center line in a direction substantially transverse thereto.

2. The integrated antenna polarization switch capable of operating in vertical, horizontal, left-circular and right-circular modes as defined in claim 1 wherein said predetermined path is oriented in a selected direction and none of said electromagnetic energy in said first mode is transformed into said second mode whereby said electromagnetic energy directed outwards from said center line is polarized in said selected direction.

3. The integrated antenna polarization switch capable of operating in vertical, horizontal, left-circular and right-circular modes as defined in claim 1 wherein said predetermined path is oriented in a selected direction and substantially all of said electromagnetic energy in said first mode is transformed into said second mode whereby said electromagnetic energy directed outwards from said center line is polarized in a direction normal to said selected direction.

4. The integrated antenna polarization switch capable of operating in vertical, horizontal, left-circular and right-circular modes as defined in claim 1 wherein said predetermined path is oriented in a selected direction and approximately one-half of said electromagnetic energy in said first mode is transformed into said second mode whereby said electromagnetic energy directed outwards from said center line is left-circularly polarized for a 45° rotation of said radial electric field in one direction and is right-circularly polarized for a 45° rotation of said radial electric field in a direction opposite from said one direction.

5. An integrated antenna polarization switch capable of operating in vertical, horizontal, left-circular and right-circular polarization modes, said switch comprising a predetermined length of cylindrical waveguide; means for launching electromagnetic energy in the TM_{01} mode into one extremity of said cylindrical waveguide; a Faraday rotator disposed along a first portion of the length of said cylindrical waveguide, said Faraday rotator having a bias current for controllably rotating the electric field of said TM_{01} mode in plane transverse to the center line of said cylindrical waveguide thereby to progressively transform said TM_{01} mode to the TE_{01} mode; a non-reciprocal one-quarter wave plate disposed along a second portion of the length of said cylindrical waveguide; and means disposed at the extremity opposite from said one extremity of said cylindrical waveguide for directing electromagnetic energy propagated thereby from said center line thereof outwards in an outwardly direction thereby providing said vertical, horizontal, left-circular and right-circular polarization modes as determined by the magnitude and direction of said bias current.

6. The integrated antenna polarization switch as defined in claim 5 wherein the operation of said Faraday rotator is non-reciprocal thereby making the operation of said switch reciprocal.

7. An integrated antenna polarization switch capable of operating in vertical, horizontal, left-circular and right-circular polarization modes, said switch comprising a predetermined length of coaxial line; means for launching electromagnetic energy in the TEM mode into one extremity of said coaxial line; a Faraday rota-

tor disposed along a first portion of the length of said coaxial line, said Faraday rotator having a bias current for controllably rotating the electric field of said TEM mode in a plane transverse to the center field of said coaxial line thereby to progressively transform said TEM mode to a circular transverse electric mode; a non-reciprocal one-quarter wave plate disposed along a second portion of the length of said coaxial line; and means disposed at the extremity opposite from said one extremity of said coaxial line for directing electromagnetic energy propagated thereby from said center line thereof outwards in an outwardly direction thereby providing said vertical, horizontal, left-circular and right-circular polarization modes as determined by the magnitude and direction of said bias current.

8. The integrated antenna polarization switch as defined in claim 5 wherein the operation of said Faraday rotator is non-reciprocal thereby making the operation of said switch reciprocal.

9. A reciprocal integrated antenna polarization switch capable of operating in vertical, horizontal, left-circular and right-circular polarization modes, said switch comprising a predetermined length of cylindrical waveguide having an axis of rotation; means for launching electromagnetic energy in the TM_{01} mode into one extremity of said cylindrical waveguide; a first ferrite cylinder disposed within said cylindrical waveguide along a first portion of said predetermined length adjacent said one extremity symmetrically about said axis of rotation thereof; means for producing a longitudinal magnetic field through said ferrite cylinder that is controllable both in direction and intensity; a second ferrite cylinder disposed symmetrically about said axis of rotation along a second portion of said predetermined length subsequent to said first portion, said second ferrite cylinder being circumferentially magnetized for changing the phase of electromagnetic energy in the TE_{01} mode by 90°; and means disposed at the extremity opposite said one extremity of said cylindrical waveguide for directing electromagnetic energy propagated thereby from said axis of rotation outwards in an outwardly direction thereby providing said vertical, horizontal, left-circular and right-circular polarization modes as determined by the direction and intensity of said longitudinal magnetic field through said first ferrite cylinder.

10. A reciprocal integrated antenna polarization switch capable of operating in vertical, horizontal, left-circular and right-circular polarization modes, said switch comprising a predetermined length of coaxial line having an axis of rotation; means for launching electromagnetic energy in the TEM mode into one extremity of said coaxial line; a first ferrite cylinder disposed within said coaxial line along a first portion of said predetermined length adjacent said one extremity symmetrically about said axis of rotation thereof; means for producing a longitudinal magnetic field through said ferrite cylinder that is controllable both in direction and intensity for rotating the radial electric field of said TEM mode in a plane transverse to said axis of rotation to produce a circumferential mode, said coaxial line having an outside to inside diameter ratio capable of supporting said circumferential mode; a second ferrite cylinder disposed symmetrically about said axis of rotation along a second portion of said predetermined length subsequent to said first portion, said second ferrite cylinder being circumferentially magnetized

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for changing the phase of electrical energy in said circumferential mode by 90°; and means disposed at the extremity opposite said one extremity of said coaxial line for directing electromagnetic energy propagated thereby from said axis of rotation outwards in an outwardly direction thereby providing said vertical, hori-

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zontal, left-circular and right-circular polarization modes as determined by the direction and intensity of said longitudinal magnetic field through said first ferrite cylinder.

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