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POLARIZATION PLANE ROTATOR FOR MICROWAVE ENERGY

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FIG. 1

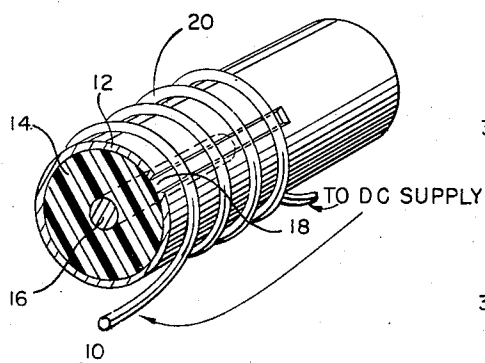


FIG. 2

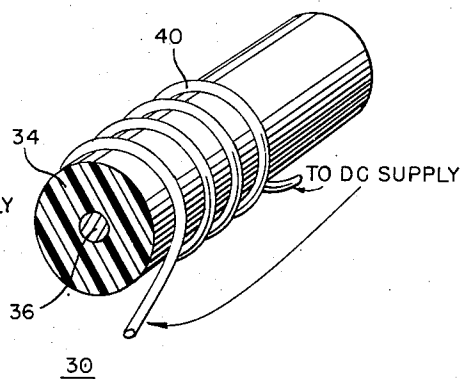
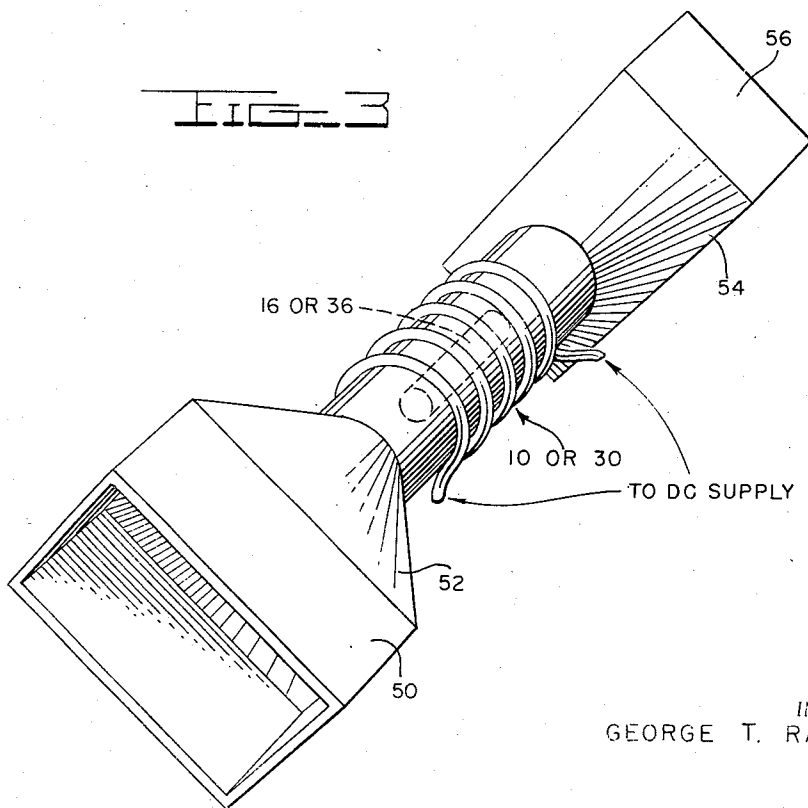


FIG. 3



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## POLARIZATION PLANE ROTATOR FOR MICROWAVE ENERGY

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This invention relates to improvements in a polarization plane rotator for electromagnetic waves. The device of the present invention utilizes the Faraday rotation principle and may be used as a high speed microwave switch for use as a transmitter-receiver switch in microwave frequency communication and radar circuits, in one-way transmission systems, microwave circulators and electrically controlled variable attenuators and modulators.

Prior art devices embodying the Faraday rotation principle for polarization plane rotation comprise metallic wave guides of circular cross-section containing cylindrically shaped ferromagnetic slugs within the wave guide and solenoidal windings encircling the wave guide walls in the vicinity of the slug. Provisions may be made to reduce reflections at the flat surfaces of the slug. When a direct current is passed through the windings encircling the wave guide walls, the ferromagnetic slug is magnetized in a direction substantially parallel to the axis of the guide. This causes a plane polarized wave propagated through the guide to split into positive and negative circularly polarized components having different refractive indices. This action causes the two circular components to travel with different velocities in the ferromagnetic medium and upon emerging from the medium, they are equivalent to a plane polarized wave whose plane of polarization has been rotated with respect to the incident polarization. Since the difference in velocities between the components is appreciable in the microwave region, the rotations produced are large even when the effective magnetic field is small. If the frequency is sufficiently high in comparison to certain characteristic values determined by the saturation magnetization and the applied field, then the energy loss is often quite small. The rotation obtained has been found to be directly proportional to the magnetization of the ferromagnetic material up to the point of saturation and approximately proportional to the length of ferromagnetic cylinder used. In addition, the rotation depends on the dielectric constant of the ferromagnetic medium.

Present microwave switches utilizing the Faraday rotation of the plane of polarization of microwaves are deficient in their operation when high speed switching is desired. This deficiency is due to the "switching-time-constant" of about 150 microseconds in present devices. Such a time interval is far too long for effective utilization of such a switch in radar and some microwave communication systems. We define the "switching-time-constant" as the time required for the R. F. power transmitted to decay to  $1/e$  of its "on" value when the switch is used as a turn-off device. An analogous definition is applied when the switch is used as a turn-on device.

Previous attempts to utilize the Faraday rotation effect in the realization of a high-speed microwave switch were abandoned due to the belief that the relatively long time delay in the switch operation was inherent in the ferromagnetic core used. The Applicant suggested that this delay was primarily due to the fact that the magnetic field pulse generated by a current pulse applied to a

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solenoid surrounding the conventional circular metallic wave guide cannot penetrate rapidly enough through the metallic wave guide into the ferromagnetic core contained within the guide.

5 The difficulties encountered with prior art devices of the above type were first determined by applicant to be due to eddy current shielding by the metallic wave guide walls. In other words, the transient skin effect prevents rapid penetration of the field through the metallic guide.

10 It is, therefore, an object of this invention to provide an improved polarization plane rotator for use with microwave energy that utilizes the Faraday rotation of the plane of polarization of microwaves.

It is another object of the invention to provide a microwave switch that has a "switching-time-constant" of the order of a microsecond or less.

Other objects and features of the present invention will become apparent upon consideration of the following detailed description taken in connection with the accompanying drawings which illustrate certain embodiments of the invention. It is to be expressly understood, however, that the drawings are designed for purposes of illustration only and not as a definition of the limits of the invention, reference for the latter purpose is to be had to the appended claims.

25 Figure 1 is a partial cross-section and partial perspective view of a portion of one embodiment of the present invention,

Figure 2 is a view similar to that of Figure 1 showing a different embodiment of the present invention,

30 Figure 3 shows an embodiment of the present invention utilized in practice as a microwave switch.

According to the principles of this invention, a polarization plane rotator of microwave energy is provided by utilizing a circular wave guide section in which a ferromagnetic slug, axially aligned with the section, is embedded concentrically within a dielectric filling medium. This section is encased within a solenoid. When a D. C. voltage pulse is applied across the solenoid windings, an axial magnetic field is produced. The plane of polarization of plane polarized microwaves within the section is caused to rotate for reasons stated above in the general theoretical discussion. This rotation can be controlled by varying the voltage applied to the solenoid, the magnetic characteristics and length of the ferromagnetic slug used and the dielectric constant of the ferromagnetic material. In order to decrease the delay time due to transient skin effects in the wall of the wave guide which effects prevent a rapid penetration of the magnetic field through the wave guide wall, it is proposed to provide a low eddy current loss support means for supporting the ferromagnetic slug within the solenoid and minimizing the eddy current loss in the guide member. Two solutions are proposed. The first embodies cutting a thin slot substantially parallel to the axis of the wave guide and at least equal in length to the ferromagnetic core within the wave guide thereby providing an open eddy current circuit. The other is to use the ferromagnetic core itself as the wave guide and space the core from the solenoid by means of a dielectric material.

60 With special reference to the drawings, Figure 1 shows a first embodiment of the present invention. The rotator represented in general by reference number 10 comprises a cylindrical, metallic wave guide wall 12, a low loss dielectric filling material 14, such as polystyrene or Teflon, within said wave guide, and a ferromagnetic core 16. This core 16 is of a ferromagnetic material of low conductivity to prevent eddy current losses. A typical family of substances used are the ferrites, which have the general formula  $MOFe_2O_3$ , where M stands for a divalent metal, such as, for example, nickel, manganese and magnesium.

A thin, longitudinal slot 18, having a width on the order of .01 inch and a minimum length equal to the axial length of the ferromagnetic core, is cut out of the wave guide wall along an axis substantially parallel to the wave guide axis. A solenoid 20 is wound around the periphery of the rotator. A representative prior art switch operating in the 3 cm. wavelength region which is adapted to be modified by the teachings of the present invention utilizes a solenoid of about 500 turns, having a length of  $1\frac{5}{16}$  inches and an inductance of the order of 1 millihenry and a magnetic core having a dielectric constant of about 10. Its dimensions include a core length of 1.26 inches and diameter of .23 inch, and an inside diameter of the wave guide of .681 inch. The core material is essentially magnesium ferrite, and the current through the solenoid is about 1 or 2 amperes or larger. Such a device causes a 90 degree rotation of the plane of polarization of microwave energy propagated through the switch.

Figure 2 shows another embodiment of the present invention. Rotator 30 comprises a dielectric material 34 encircling a ferromagnetic core 36. A solenoid 40 is wound around dielectric 34. The ferromagnetic material 36 itself is used as the wave guide. It is necessary to adjust the diameters of the core and the dielectric so that the solenoid is properly spaced from the core so that the wave propagation is almost completely confined to ferromagnetic core 36. Coil 40 should be a low inductance magnetizing coil concentric with ferromagnetic cylindrical core 36 and having a radius large compared to that of the ferromagnetic core 36. These characteristics assure a short time-constant coil producing a fairly uniform axial magnetic field, and prevent attenuation of the R. F. field by the metallic coil because the R. F. field decays exponentially outside the ferromagnetic cylinder if the latter acts as a wave guide.

The embodiment depicted in Figure 1 represents one extreme solution of the problem solved in this invention and the embodiment of Figure 2 represents the opposite extreme solution. It is understood that the elimination of any portion of the metallic wave guide walls between the two extremes shown also provides a solution to the problem of cutting down the delay time inherent in the operation of devices of the class claimed, provided the portion cut extends from a point transversely aligned with one end of the core at least to a point transversely aligned with the other end of the core so that no closed circumferential paths are available for the eddy currents produced.

Figure 3 shows how a device exemplifying the present invention may be used as a switch. Energy propagated via rectangular wave guide 50 from left to right is polarized so that its E-vector is parallel to the shortest dimension of the guide. Joint 52 couples rectangular wave guide 50 into the circular wave guide section which may be either embodiment 10 or 30 of this invention. Joint 54 couples circular wave guide section 10 or 30 into rectangular wave guide 56. This latter guide is oriented at right angles to guide 50. Thus, under normal conditions, the polarized energy propagated from left to right through guide 50, passes through joints 52 and 54 as well as rotator 10 or 30 but since guide 56 is oriented at 90 degrees to guide 50, extremely little energy passes into guide 56. Upon the initiation of a D. C. voltage pulse through solenoid 20 or 40, the E-vector of the energy propagated through guide 50 is rotated 90 degrees in circular guide 10 or 30, thereby enabling the energy to pass through wave guide 56 relatively unimpeded. The provision of either axially longitudinal slot 18 or a suitably thick dielectric medium and no metallic wave guide wall enables the switch to respond very rapidly.

It is understood that rotators 10 or 30 could also be used as an "on-off" switch rather than as an "off-on" switch by orienting rectangular guides 50 and 56 parallel to each other.

The invention described herein may be manufactured 75

and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

1. A high speed device for rotating the plane of polarization of propagated electromagnetic wave energy in a conductive wall waveguide system comprising a waveguide section capable of supporting two orthogonal dominant modes of a propagated wave and adapted for incorporation in said waveguide system; a ferromagnetic core element; said core element being active in the Faraday rotational sense and centrally disposed within said waveguide section; magnetic field producing means for producing a unidirectional axial field within said waveguide section; said field producing means being disposed outside said waveguide section such that lines of force of the axial field produced thereby intersect said core element; at least a portion of the wall of said waveguide section, which is disposed in the vicinity of said core element, being adapted to provide a substantially greater impedance to the flow of circumferential eddy currents with respect to the impedance presented to current flow in a circumferential direction by the conductive wall of said waveguide system.

2. A high speed device for rotating the plane of polarization of propagated electromagnetic wave energy in a conductive wall waveguide system comprising a waveguide section capable of supporting two orthogonal dominant modes of a propagated wave and adapted for incorporation in said waveguide system; an elongated ferromagnetic core element of predetermined length; said core element being active in the Faraday rotational sense and centrally disposed within said waveguide section; magnetic field producing means for producing a unidirectional axial field within said waveguide section; said field producing means being disposed outside said waveguide section such that lines of force of the axial field produced thereby intersect said core element; said waveguide section having at least a portion of the wall thereof, cutaway; said cutaway portion being coextensive in length with said core element such that said waveguide section provides a substantially greater impedance to the flow of circumferential eddy currents with respect to the impedance presented to current flow in a circumferential direction by the conductive wall of said waveguide system.

3. A high speed device for rotating the plane of polarization of propagated electromagnetic wave energy in a conductive wall waveguide system comprising a waveguide section capable of supporting two orthogonal dominant modes of a propagated wave and adapted for incorporation in said waveguide system; an elongated ferromagnetic core element of predetermined length; said core element being active in the Faraday rotational sense and centrally disposed within said waveguide section; magnetic field producing means for producing a unidirectional axial field within said waveguide section; said field producing means being disposed outside said waveguide section such that lines of force of the axial field produced thereby intersect said core element; said waveguide section having at least a portion of the wall in the vicinity of said core element, cutaway such that said waveguide section provides a substantially greater impedance to the flow of circumferential eddy currents with respect to the impedance presented to current flow in a circumferential direction by the conductive wall of said waveguide system.

4. A high speed device for rotating the plane of polarization of propagated electromagnetic wave energy in a conductive wall waveguide system comprising a waveguide section capable of supporting two orthogonal dominant modes of a propagated wave and adapted for incorporation in said waveguide system; a core element active in the Faraday rotational sense; said core element being centrally disposed within said waveguide section; magnetic field producing means for producing a unidirectional axial field within said waveguide section; said field pro-

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ducing means being disposed outside said waveguide section such that lines of force of the axial field produced thereby intersect said core element; at least a portion of the wall of said waveguide section, which is disposed in the vicinity of said core element, being adapted to provide a substantially greater impedance to the flow of circumferential eddy currents with respect to the impedance presented to current flow in a circumferential direction by the conductive wall of said waveguide system.

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