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MICROWAVE FIELD ROTATOR

Original Filed Feb. 15, 1954

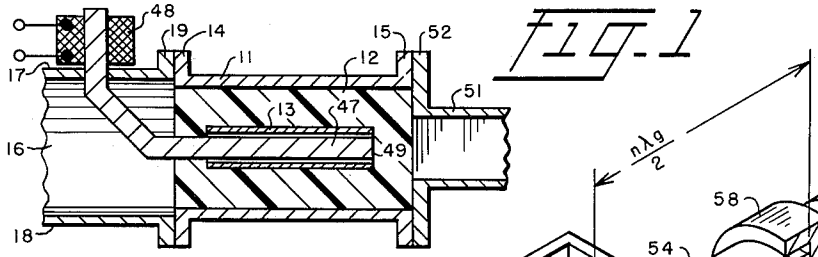


Fig. 1

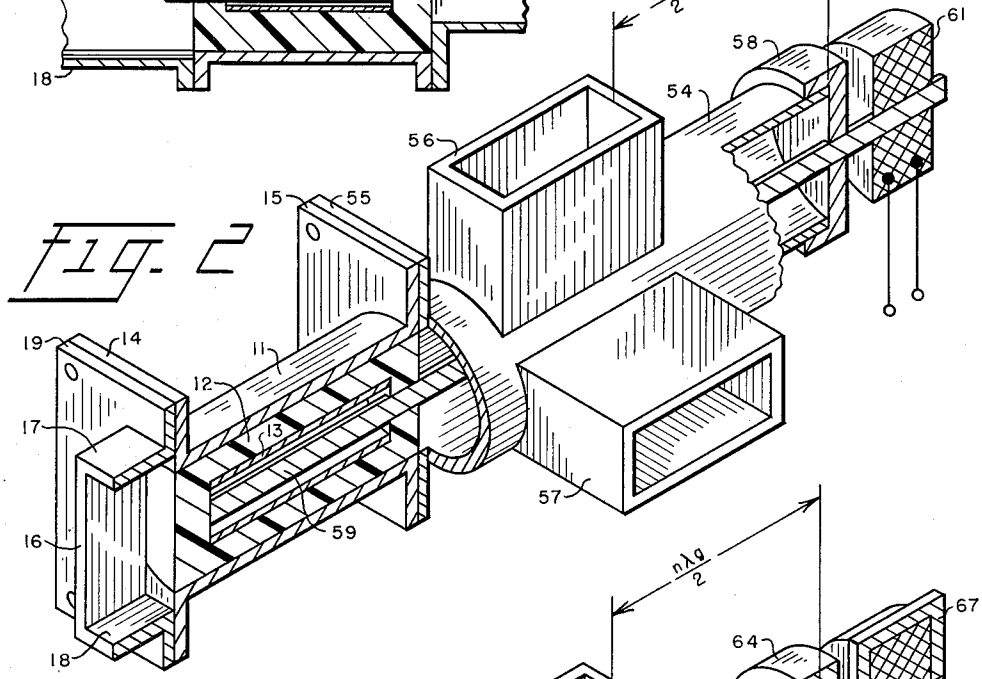


Fig. 2

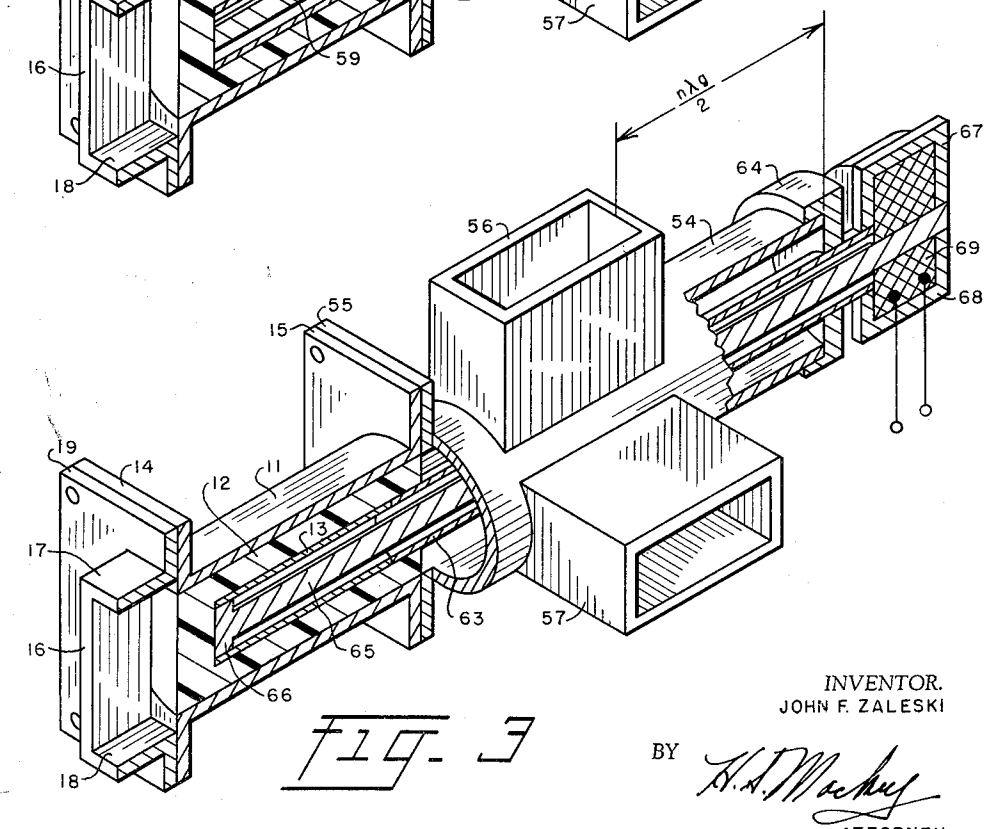


Fig. 3

INVENTOR.
JOHN F. ZALESKI

BY

ATTORNEY

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MICROWAVE FIELD ROTATOR

John F. Zaleski, Valhalla, N.Y., assignor to General Precision, Inc., a corporation of Delaware

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8 Claims. (Cl. 333—7)

This application is a division of my copending application Serial No. 410,154, filed February 15, 1954, and now abandoned, for "Microwave Field Rotator."

It has recently been discovered that, when linearly polarized microwave energy is transmitted through certain ferrites subjected to a magnetic field, the plane of polarization of the microwave energy is rotated. This discovery, which is more fully discussed in United States Patent No. 2,644,930 to Luhrs and Tull, has led to the development of polarization rotators useful as elements in microwave transmission systems. A typical model employs a rod or tube of ferrite positioned along the axis of a short section of standard circular waveguide and held in place by a low-loss dielectric material which completely fills the space between the rod and the waveguide walls. An axial magnetic field is applied to the rod by means of a permanent magnet or a solenoid on the outside surface of the waveguide. When microwave energy is propagated along the waveguide in the TE_{11} mode its plane of polarization is rotated, the direction and amount of rotation depending upon the polarity and intensity of the magnetic field applied to the ferrite rod but being independent of the direction of propagation of the microwave energy. Rotations of more than ninety degrees in each direction have been obtained.

Although a polarization rotator such as above described has a number of useful applications, it is subject to certain inherent limitations. The magnetic field developed by the solenoid is inefficiently coupled to the ferrite rod because of the large external flux leakage paths and the relatively great radial gap existing between the ferrite rod and the winding. Furthermore, if the solenoid be energized with alternating current, so as to "polarization modulate" the microwave energy within the guide, the metal waveguide constitutes a short circuited secondary winding which allows eddy currents to circulate in the wall of the guide. These factors make it necessary to use a large solenoid having a high inductance in order to obtain sufficient flux density within the ferrite rod. This requirement may be tolerable if the solenoid is to be energized with direct current, but imposes severe limitations on the frequency and waveforms of an alternating current excitation.

It is an object of this invention to provide a ferromagnetic microwave polarization rotator which may be excited with a high frequency alternating current.

Another object of the invention is to provide a polarization rotator having a low inductance exciting winding.

Another object of the invention is to provide a polarization rotator in which the available magnetomotive force is utilized efficiently.

In accordance with the invention, the above stated objectives are attained by providing a low reluctance magnetic path between the source of magnetomotive force and the active polarization rotating element. The polarization rotating element comprises a hollow cylindrical ferrite tube which is imbedded in a dielectric material and positioned along the axis of a short section of circular waveguide. The low reluctance path may be obtained by winding a solenoid about a soft iron core on the exterior of the waveguide and extending the core through the wall of the guide to the ferrite tube. The core extension is maintained at right angles to the lines of electric force of the microwave energy within the waveguide. The above construction provides a low reluctance path between the source of magnetomotive force and the ferrite tube resulting in efficient utilization of the available magnetomotive force.

For a clearer understanding of the invention reference may be made to the following detailed description and the accompanying drawing, in which:

Figure 1 is a sectional view of one embodiment of the invention; and

Figures 2 and 3 are isometric views of additional forms of the invention utilized as elements in power dividers.

Referring now to the drawing, there is shown in each figure a polarization rotator comprising a short section of circular waveguide **11** completely filled by a low-loss dielectric material **12**, except for a cylindrical space along the axis which is occupied by a hollow ferrite tube **13** and its associated elements. The dielectric material **12** is preferably a tetrafluoroethylene resin such as that sold under the trademark "Teflon," and serves to support the ferrite tube **13**. As is more fully explained in the aforementioned Patent No. 2,644,930, the tube **13** may consist of a number of different ferrites. For the sake of brevity, the term "ferrite" whenever used in this specification and the appended claims is intended to mean any of those ferrites which exhibit the polarization rotation properties herein referred to. One such ferrite which has been found satisfactory is known as Ferramic D and may be obtained from the General Ceramics and Steatite Corporation, Keasbey, New Jersey.

The circular waveguide **11** is provided with flanges **14** and **15** for connecting the polarization rotator to other microwave components. A rectangular input waveguide **16** having narrow sides **17** and **18** and a flange **19** is joined to the flange **14** of the circular guide **11**. It has been found that a circular guide having an internal diameter of 0.75 inch and filled with a dielectric material such as previously described has a characteristic impedance very nearly equal to that of an air-filled rectangular guide with internal dimensions of 0.9 x 0.4 inch. It is therefore possible to join the circular guide **11** directly to the rectangular guide **16** with negligible power loss. The input guide **16** is assumed to be propagating microwave energy in the dominant TE_{10} mode so that the lines of electric force are parallel to the narrow sides **17** and **18**. This wave energy will, of course, enter the circular guide **11** in the dominant TE_{11} mode.

Referring now to Fig. 1, there is shown within the ferrite tube **13** a ferromagnetic core **47** which extends axially for a short distance into the input waveguide **16**. The core **47** is then bent and, being kept parallel to the broad sides of the input guide **16**, is led to the exterior of guide **16** through an aperture in the narrow side **17**. The bend in the core may conveniently comprise two forty-five degree bends as shown, but other arrangements could be used, it only being necessary to keep the axis of the core in the median plane parallel to the broad sides of guide **16**. At the end where the core **47** emerges from the guide **16**, it has a solenoid **48** wound around it to provide the magnetic field necessary for operation of the device. A rectangular waveguide **51** is secured by means of its flange **52** to the flange **15** of the guide **11** and serves to receive the output energy. The guide **51** has been shown as making an angle of ninety degrees with the input guide **16**, but it will be understood that this angle is merely illustrative and

any other angle may be used to suit the particular application.

In operation, the lines of magnetic force generated by the solenoid 48 emerge from the end 49 of the core. In returning to the opposite end of the core, the lines of magnetic force will pass through the ferrite tube 13 thus providing a longitudinal magnetic field through the tube 13. It is obvious that the proximity of the core 47 and especially its end 49 to the tube 13 provides a magnetic path having a much lower reluctance than if the solenoid were wound on the outside of the circular guide 11.

Fig. 2 shows the use of a polarization rotator somewhat similar to that of Fig. 1 to form a microwave power divider. A section of circular waveguide 54 is joined by means of a flange 55 to the flange 15 of waveguide 11. A pair of rectangular waveguides 56 and 57 are secured to the periphery of the guide 54 with their broad sides parallel to the axis of guide 54 so as to form two mutually perpendicular H-plane junctions with the circular guide 54. The end of circular guide 54 is closed by means of a conductive plate 58 which is positioned an integral number of half guide wavelengths from the near narrow sides of the rectangular guides 56 and 57.

Within the ferrite tube 13 is a cylindrical ferromagnetic core 59 which extends axially through the guide 54 and through an aperture in the conductive plate 58. At a point near its emergence from the plate 58, the core 59 has wound on it a solenoid 61 to produce the required magnetic field.

The operation of the polarization rotator is similar to that described in connection with Fig. 1. The end of the core 59 acts as a source of magnetic flux lines and these lines in returning to the solenoid provided a longitudinal magnetic field through the ferrite tube 13. The operation of the power divider is believed to be obvious from the drawing. If no current flows through the winding 61, energy from the input guide 16 will pass through the rotator with no change in polarization and will be coupled to the rectangular guide 56. If sufficient current flows through winding 61, the plane of polarization can be rotated through ninety degrees and all of the input power will appear in guide 57. At intermediate values of current through solenoid 61, the power will divide between guides 56 and 57.

Referring now to Fig. 3, there is shown a device similar to that shown in Fig. 2. The circular guide 11, the input guide 16, the circular waveguide 54 with its associated rectangular guides 56 and 57 are the same as in Fig. 2. Abutting the ferrite tube 13 is a tubular ferromagnetic core 63 having approximately the same diameter and thickness as the tube 13. The core 63 extends axially through the circular guide 54 and through an aperture in a conductive plate 64 which closes the open end of waveguide 54 at a distance which is approximately an integral number of half guide wavelengths from the near narrow sides of rectangular guides 56 and 57. Within the tube 13 and the core 63 is a cylindrical ferromagnetic core 65, the enlarged end 66 of which touches the inside of tube 13 at one end. The cylindrical core 65 extends coaxially through the core 63, the circular guide 54 and the conductive plate 64 to the exterior of the system. A pair of U-shaped ferromagnetic members 67 and 68 have one leg of each joined to the end of tubular core 63 while their other legs are joined to the cylindrical core 65. A solenoid 69 is wound around the core 65 between the legs of the U-shaped members 67 and 68.

The operation of the embodiment of Fig. 3 is similar to that of the embodiment of Fig. 2. The advantage of the construction shown in Fig. 3 is the completely closed ferromagnetic path of very low reluctance which extends from each end of the tube 13 to the solenoid. By this construction, there is a maximum concentration of magnetic flux through the tube 13 where it is needed.

Although the invention has been described with respect to several specific embodiments many modifications may be made within the scope of the invention. Although a tubular shape is at present preferred for the ferrite member, other shapes, such as a solid rod or bar, could be used. Many other modifications will occur to those skilled in the art.

What is claimed is:

1. A microwave polarization rotator comprising, a circular waveguide, said waveguide comprising a hollow cylindrical conductive pipe open at both ends and capable of transmitting microwave energy therethrough in the axial direction, a ferrite tube within said waveguide and coaxial therewith, a solenoid located outside said waveguide, and a ferromagnetic rod projecting into the interior of said solenoid and extending into but substantially magnetically insulated from said tube for substantially the entire length thereof.

2. A microwave polarization rotator comprising, a circular waveguide, said waveguide comprising a hollow cylindrical conductive pipe open at both ends, a hollow cylindrical ferrite tube positioned coaxially within said waveguide, a solenoid outside of said waveguide, and a ferromagnetic rod projecting into the interior of said solenoid and extending into but substantially magnetically insulated from said ferrite tube for substantially the entire length thereof, the axis of said rod being at right angles to the lines of electric force of any microwave energy transmitted through said waveguide in the dominant mode.

3. A microwave polarization rotator comprising, a circular waveguide, said waveguide comprising a hollow cylindrical conductive pipe open at both ends and capable of transmitting microwave energy therethrough in the axial direction, a hollow cylindrical ferrite tube within said circular waveguide and coaxial therewith, a rectangular waveguide joined coaxially to said circular waveguide for introducing linearly polarized microwave energy into said circular waveguide, a ferromagnetic rod the axis of which lies in the median plane parallel to the broad sides of said rectangular waveguide, said rod containing a bend, one end of said rod projecting through a narrow side of said rectangular waveguide to the exterior thereof and the other end extending into but substantially magnetically insulated from said tube for substantially the entire length thereof, and a solenoid on said one end of said rod.

4. A microwave power divider comprising, a first circular waveguide, said first circular waveguide comprising a hollow cylindrical conductive pipe open at both ends and capable of transmitting microwave energy therethrough in the axial direction, a hollow cylindrical ferrite tube within said waveguide coaxial therewith, a second circular waveguide having one end joined coaxially to said first circular waveguide, a plurality of rectangular waveguides coupled to and spaced around the periphery of said second waveguide, a conductive plate closing the other end of said second circular waveguide, a ferromagnetic rod along the axis of said circular waveguides, one end of said rod projecting into but substantially magnetically insulated from said tube for substantially the entire length thereof and the other end of said rod protruding through an aperture in said plate, and a solenoid around said other end of said rod.

5. A microwave power divider comprising, a first circular waveguide, said first circular waveguide comprising a hollow cylindrical conductive pipe open at both ends and capable of transmitting microwave energy therethrough in the axial direction, a hollow cylindrical ferrite tube within said waveguide and coaxial therewith, a second circular waveguide having one end joined coaxially to said first circular waveguide, a plurality of rectangular waveguides coupled to and spaced around the periphery of said second waveguide, a conductive

plate closing the other end of said second waveguide, a hollow cylindrical ferromagnetic tube along the axis of said waveguides one end of which abuts said ferrite tube and the other end of which projects through an aperture in said plate, a ferromagnetic rod positioned coaxially within both said ferrite tube and said ferromagnetic tube, said rod extending into but substantially magnetically insulated from said ferrite tube for substantially the entire length thereof, said rod also protruding beyond said other end of said ferromagnetic tube, a solenoid wound around the protruding portion of said rod, and a ferromagnetic path connecting said rod and said ferromagnetic tube.

6. A microwave polarization rotator comprising, a hollow conductive pipe wave transmission means including a section of waveguide having a circular cross section and being open at both ends, said section of waveguide being capable of transmitting microwave energy therethrough in the axial direction, a hollow cylindrical ferrite tube positioned coaxially within said section of waveguide, a ferromagnetic rod having its first end extending within and substantially magnetically insulated from said tube for substantially the entire length thereof and its second end extending to the exterior of said wave transmission means, said rod being so positioned relative to the walls of said transmission means that the lines of electric force of any wave energy being transmitted through said wave transmission means in the dominant mode are perpendicular to the axis of said rod, and a solenoid wound on said second end of said rod.

7. A microwave polarization rotator comprising, a first circular waveguide, said first circular waveguide comprising a hollow cylindrical conductive pipe open at both ends and capable of transmitting microwave energy therethrough in the axial direction, a hollow cylindrical ferrite tube within said waveguide coaxial therewith, a second circular waveguide having one end joined coaxially to said first circular waveguide, a conductive plate closing the other end of said second circular waveguide, a ferromagnetic rod along the axis of said circular waveguides, one end of said rod extending within but substantially magnetically insulated from said tube for substantially the entire length thereof and the other end of said rod protruding through an aperture in said plate, and a solenoid around said other end of said rod.

8. A microwave polarization rotator comprising, a first

circular waveguide, said first circular waveguide comprising a hollow cylindrical conductive pipe open at both ends and capable of transmitting microwave energy therethrough in the axial direction, a hollow cylindrical ferrite tube within said waveguide and coaxial therewith, a second circular waveguide having one end joined coaxially to said first circular waveguide, a conductive plate closing the other end of said second waveguide, a hollow cylindrical ferromagnetic tube along the axis of said waveguides one end of which abuts said ferrite tube and the other end of which projects through an aperture in said plate, a ferromagnetic rod within both said ferrite tube and said ferromagnetic tube, said rod extending into and substantially magnetically insulated from said ferrite tube for substantially the entire length thereof, said rod also protruding beyond said other end of said ferromagnetic tube, a solenoid wound around the protruding end of said rod, and a ferromagnetic path connecting said rod and said ferromagnetic tube.

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