Sept. 27, 1955 C. H. LUHRS 2,719,274

MICRO WAVE SWITCHES

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Fig. 1.

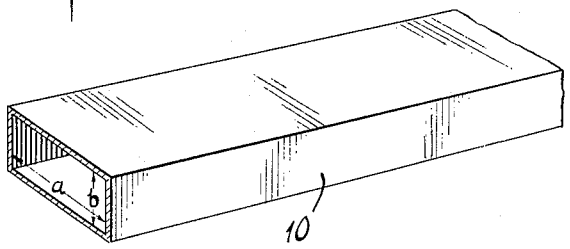


Fig. 2.

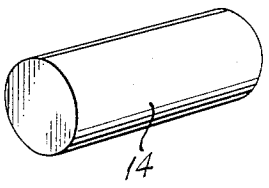


Fig. 3.

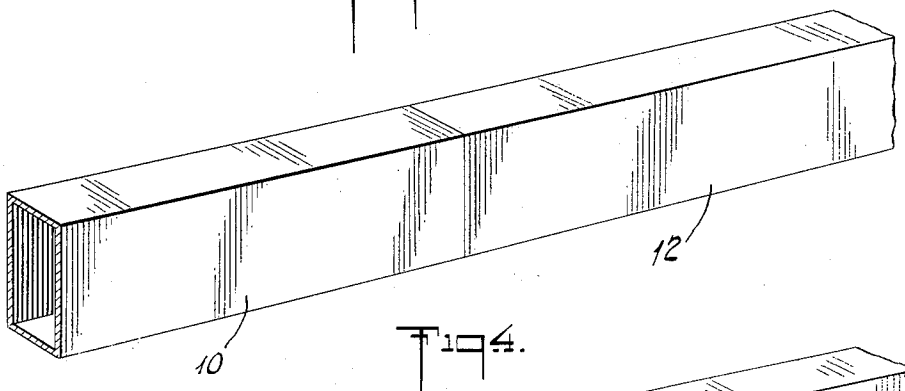


Fig. 4.

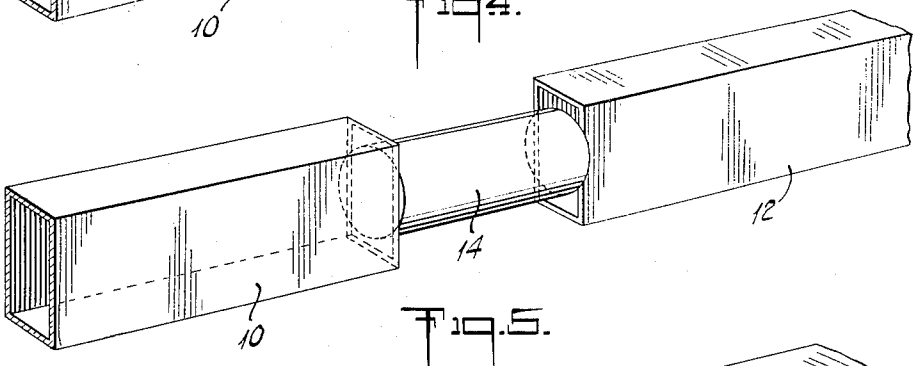
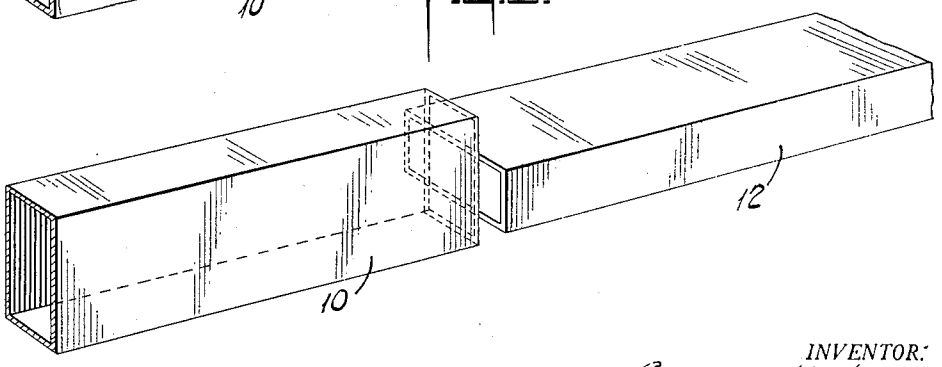


Fig. 5.



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Fig. 6.

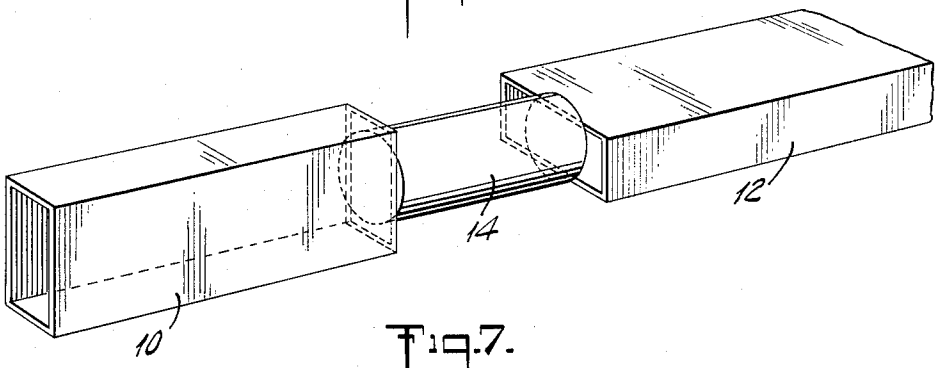


Fig. 7.

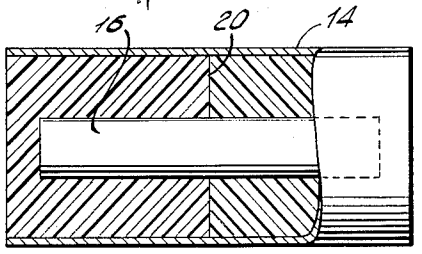


Fig. 8.

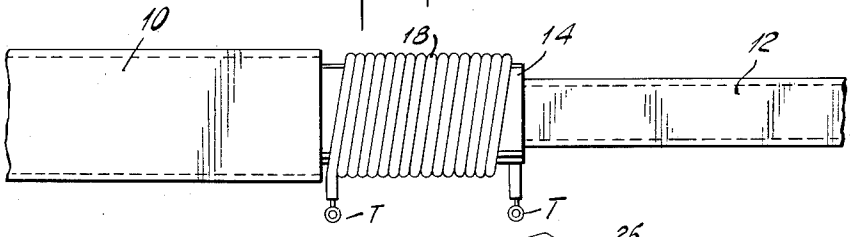
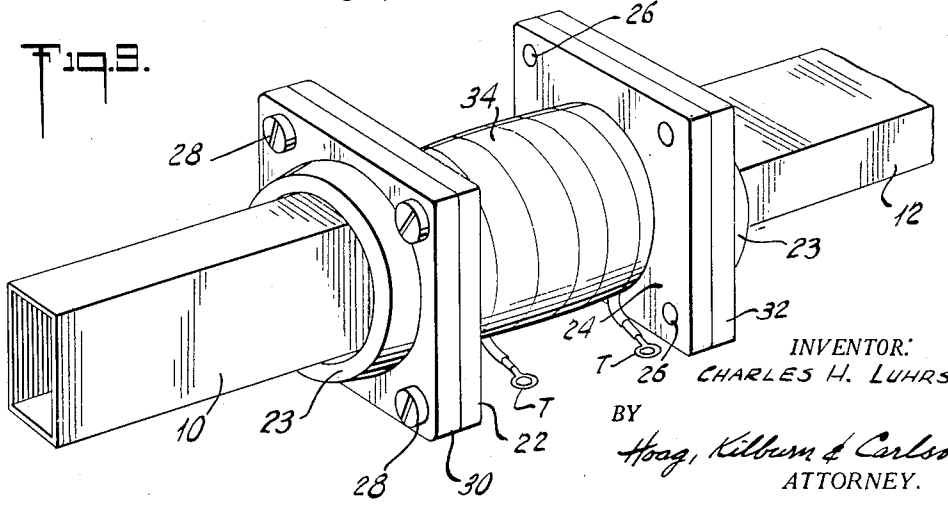


Fig. 9.



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Fig. 10.

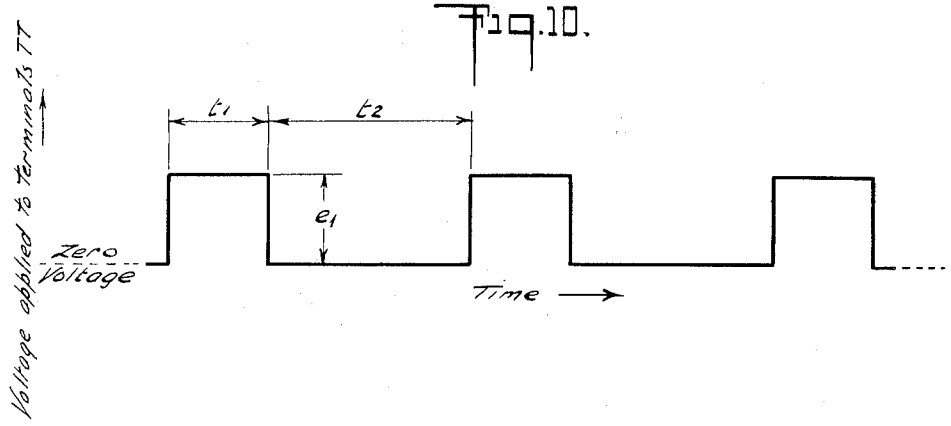
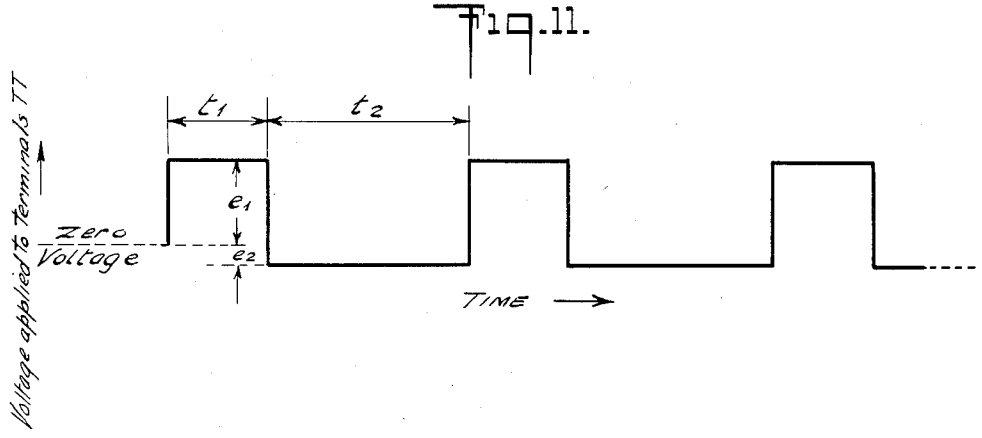


Fig. 11.



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United States Patent Office 2,719,274 Patented Sept. 27, 1955

2,719,274

MICROWAVE SWITCHES

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Application July 9, 1951, Serial No. 235,825

14 Claims. (Cl. 333—98)

This invention relates to a microwave switch.

It is often desirable to "cut off" and be able to again "turn on" a wave being propagated in a wave guide without disturbing the wave propagating source. Heretofore there has been no way of accomplishing this result except by means of inefficient mechanical devices and gas tubes of limited life.

Accordingly it is an object of this invention to provide method and means by which a wave may be "cut off," and "turned on" in a wave guide, as desired, without disturbing the propagating source.

Another object of the invention is to provide a simple, practical and effective microwave switch.

Other objects of the invention will be in part obvious or in part pointed out hereinafter.

The invention accordingly consists in the features of construction, combinations of elements, arrangements of parts, and in the several steps and relation and order of each of said steps to one or more of the others thereof, all as will be pointed out in the following description, and the scope of the application of which will be indicated in the following claims.

The invention will best be understood if the following description is read in connection with the drawings, in which:

Figure 1 is a perspective view of a portion of a rectangular wave guide section;

Figure 2 is a perspective view of a length of circular wave guide section;

Figure 3 is a perspective view illustrating two rectangular wave guide sections aligned end to end and disposed at the same radial angle;

Figure 4 is a perspective view illustrating two aligned rectangular wave guide sections disposed at the same radial angle, but spaced apart by a length of circular wave guide;

Figure 5 is a perspective view of two rectangular wave guide sections aligned end to end in abutting relation, but with the second section disposed at a radial angle of 90° with respect to the first section;

Figure 6 is a view similar to Figure 5 but showing the rectangular wave guide sections spaced apart but interconnected by a circular wave guide section;

Figure 7 is a front elevation partly in vertical cross section showing a circular wave guide section, such as is employed in the embodiment of the invention shown in Figures 8 and 9, and characterized by having a rod-like member positioned within it along its longitudinal median line;

Figure 8 is a view similar to Figure 6 showing an electrical conductor wound exteriorly on the circular wave guide section between two rectangular wave guide sections aligned but with one disposed at an angle of 90° to the other;

Figure 9 is a perspective view showing a completed embodiment of the invention with the intermediate circular wave guide section connected to the rectangular wave guide sections by coupling flanges and with a covering over the conductive winding shown in Figure 8.

Figure 10 is a schematic representation of one type of wave form; and

Figure 11 is a schematic representation of another type of wave form.

It is well known microwaves may be propagated and passed through a rectangular wave guide provided the dimension *a* (Figure 1) of said wave guide is great enough to permit propagation of a wave of given frequency, and dimension *b* is small enough to prohibit propagation of said wave under the condition that the E vector is perpendicular to *b*. It is thus known that a wave may be propagated and passed through a rectangular wave guide **10** of proper dimensions, such as is shown in Figure 1. It is also known that a wave propagated in a first section **10** of rectangular wave guide may be passed into a second section **12** of rectangular wave guide which is aligned in end to end relation with the first section and without any radial angle between them, as in Figure 3; and that a wave may be propagated and passed through a round length of wave guide **14**, such as is illustrated in Figure 2; that a wave propagated in a rectangular section **10** may not only be passed from section **10** into the round wave guide section **14** aligned with it as shown in Figure 4, but may be passed through the round wave guide section **14** and into and through the rectangular section **12** provided the latter is aligned with said first section **10** and not disposed at a radial angle to section **10**, even though sections **10** and **12** are separated and interconnected by said round section **14**.

It has heretofore been believed that no current whatsoever, propagated in rectangular section **10**, can be passed into rectangular section **12** if the latter, although aligned with section **10**, is disposed at a radial angle of 90° with respect to section **10**, as illustrated in Figure 5; and that although a wave propagated in section **10** can be passed into round section **14** if the latter is aligned with it as shown in Figure 6, it cannot be passed from section **14** into and through rectangular section **12** if the latter, although separated from section **10** by said round wave guide **14**, is disposed at a radial angle of 90° with respect to rectangular section **10**. I have found, however, that by the means disclosed herein a wave propagated in rectangular section **10** may be passed not only through round section **14** but also through rectangular section **12** even though the latter is disposed at a radial angle of 90°.

In accordance with my invention I couple a length of round wave guide **14** between two lengths of rectangular wave guide **10** and **12** disposed in end to end alignment, but with the second rectangular wave guide section at a radial angle of 90° with respect to the first rectangular wave guide section. Within the round length of wave guide section **14** I employ a dielectric material **20** and a rod **16** of greater length than its diameter and of material active in the Faraday magneto-optical sense. Rod **16** is supported within round wave guide section **14** along its longitudinal axis. The wave propagated in rectangular wave guide section **10** passes freely into round wave guide section **14** around which I create a magnetic field parallel to the axis of said round wave guide section, either by bringing a permanent magnet into close proximity to the said round wave guide section **14**, or preferably by providing around section **14** a conductor coil **18**, see Figure 8, and impressing a voltage across its terminals T, T. For coil **18** I prefer to use heating wire, to heat the interior of section **14** simultaneously with creating a magnetic field, to obtain increased energy output as pointed out hereafter.

I have found that when a voltage is impressed across said terminals T, T the plane of polarization of a wave

propagated in rectangular section **10** and passing through said round section **14** may be rotated through 90° and thus brought into proper alignment for propagation through said rectangular wave guide section **12**.

I have obtained very satisfactory results for waves within a frequency range of 8800 to 9800 magacycles using rectangular wave guide sections the *a* dimension of which is .9" and the *b* dimension of which is .4", with a wall thickness of .050", and a round wave guide section made of brass, having an outside diameter of 0.75 in. and an inside diameter of .686 in., which is 1.520 in. long and filled with polytetrafluoroethylene, the latter having within it, and supporting along its median line, a rod made of "Ferramic A," having a length of 1.256 in. and a diameter of .230 in.

For convenience in coupling a switch unit embodying my invention between two sections of rectangular wave guide I mount on the respective ends of a round wave guide section **14** the coupling flanges **22** and **24**, see Figure 9, provided with screw holes **26** for screws **28** by means of which coupling flanges **30** and **32** of standard kind, mounted on the adjacent ends of rectangular sections **10** and **12** respectively, may be readily joined to the end flanges **22** and **24** on the round section **14**, which, as shown in Figure 9, is covered with a winding of tape or the like **34**, extending around and over the coil **18**, but leaving the terminals T, T exposed. The coupling flanges **30** and **32** have rectangular openings to match the ends of the rectangular wave guide sections respectively, and projecting outwardly around said openings are the circular flanges **33** respectively into which the ends of the rectangular wave guide sections, are inserted in assembling the switch unit. If desired material such as soft putty may be packed in the space between the rectangular wave guide sections and the outwardly projecting flanges **33** on the coupling flanges **30** and **32**.

While my switch is operative even though the dielectric material within said round section **14** is air, and said rod **16** is mechanically supported along the longitudinal median line of section **14**, I prefer to fill section **14** with a lossless dielectric material, such, for example, as said polytetrafluoroethylene which is commercially available under the trade name "Teflon," polystyrene, foamy polystyrene, which is commercially available under the trade name "Polyfoam," or a copolymer of styrene, which is commercially available under the trade name "Rexolite #1422," which are themselves capable of acting as the support for rod **16**. For each dielectric material there is an optimum length for rod **16** but variations in length are slight and can be readily determined for each dielectric material by trial and error method and without affecting the requirement that the length of rod **16** must be greater than its diameter.

I have found that when the temperature within the round wave guide section **14** is increased the atenuation of the wave passing through the round section from rectangular section **10** into rectangular section **12** is decreased. In other words, by increasing the temperature within round wave guide **14**, and particularly the temperature of rod **16**, there is an increase in the energy transmitted when the switch is "on."

The temperature within round wave guide section **14** increases with increase of the R. F. energy flowing through it as of course the higher the energy the larger is the amount thereof dissipated in the form of heat. The temperature within the round wave guide may also be increased by selection of the wire comprising the coil **18**.

I have noticed a substantial increase in the energy output of the switch compared to the energy input when the temperature within the round wave guide is raised to a temperature substantially above room temperature, say on the order of 100° C.

This result of increased electrical energy output with increased temperature is of great importance. By heating the interior of the round wave guide section, and particularly rod **16**, the switch may be operated with little or no loss.

I have found that after the above described switch is energized the rod **16** becomes magnetized and when the switch is turned off by breaking the circunit between terminals T, T there is some residual magnetism within rod **16** which will prevent maximum attenuation, or the complete "turning off" of the wave. This hysteresis effect may be eliminated and complete attenuation obtained by demagnetizing rod **16** each time the switch is "turned off." The demagnetizing may be accomplished (1) by applying across terminals T, T a decaying A. C. voltage, or (2), a reversed voltage of the proper magnitude.

In Figure 10 the wave form illustrated is the type that one would expect to use in operating the switch were it not for the hysteresis effect. In Figure 1, e^1 represents the rise in voltage above the zero voltage line each time the switch is turned on; t^1 represents the time interval during the switch remains "on"; and t^2 represents the time interval during the switch is "off."

If after an interval t^1 the voltage is decreased or allowed to fall only to the zero voltage line there would be sufficient residual magnetism in rod **16** to prevent maximum attenuation of the wave when the switch is again turned "on," thus decreasing the efficiency of the switch.

In the wave form illustrated in Figure 11, e^2 represents negative or reversed voltage applied to terminals T, T each time the switch is turned off in order to "wipe out" the residual magnetism which the rod **16** would possess were the voltage, following switch operation, permitted to fall no lower than to zero volts. Other types of wave form may be used for overcoming the hysteresis effect and thereby fully realizing the maximum attenuation of the switch. Thus for example negative voltage may be applied for but a brief instant of time at the end of each time interval t^1. The application of negative voltage in this form may be referred to as a negative voltage pulse. Means for the generation of such a wave form and other wave forms to overcome hysteresis are well known to the art.

Rod **16** may be made of an oxide or mixture of oxides derived from magnetic oxide of iron, or having the formula AFe_2O_4 when A is any of a number of metals, such, for example, as nickel, cobalt or copper. The material from which rod **16** is formed is characterized in that right-handed-circularly-polarized wave travels through it at a velocity which is substantially different from the velocity for left-handed-circularly-polarized wave. Suitable material is available under the trade names "Ferramic A," "Ferramic D" and "Ferramic E," and in the form of polyiron, magnetite and various magnetic oxides of iron mixed with oxides of other metals.

If a microwave switch is desired for waves having a frequency outside of the range of 8800 to 9800 megacycles the dimensions of the round wave guide section **14** and of rod **16** should be increased or decreased as the case may be, keeping in mind the necessity for having the rod of greater length than its cross sectional diameter.

It is understood that within the concept of this invention a switch may be made to operate in the reverse fashion from that described above, that is to say with the two rectangular wave guide sections aligned end to end, without any radial angle between them, and the wave rotated 90° within the round wave guide length to turn off the switch instead of to turn it on.

It will thus be seen that there has been provided by this invention a method and apparatus in which the various objects hereinabove set forth together with many thoroughly practical advantages are successfully achieved. As various possible embodiments might be made of the mechanical features of the above invention and as the art herein described might be varied in various parts, all without departing from the scope of the invention, it is to be understood that all matter hereinbefore set forth

or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

What I claim is:

1. A microwave switch comprising two sections of rectangular wave guide aligned longitudinally but with one rotated through 90° relative to the other, separated and interconnected by a section of round wave guide, means for subjecting said round section to a magnetic field parallel to the wave guide axis, and a rod of material active in the Faraday magneto-optical sense having a length exceeding its diameter supported longitudinally within said round section in substantial spaced relation as respects the interior wall thereof.

2. The device claimed in claim 1 in which the means for creating said magnetic field is an electrically conductive coil wound externally around said length of round wave guide and having terminals for connection in an electrical circuit.

3. A microwave switch comprising two sections of rectangular wave guide aligned longitudinally but with one rotated through 90° relative to the other, separated and interconnected by a section of round wave guide, means for subjecting said round section to a magnetic field parallel to the wave guide axis, and a rod of material for which the velocity for right-handed-circularly-polarized wave is substantially different from the velocity for left-handed-circularly-polarized wave, said rod having a greater length than diameter and supported longitudinally within said round section in substantial spaced relation as respects the interior wall thereof.

4. The device claimed in claim 3 wherein said round section is filled with a substantially lossless dielectric material, and said rod is supported by and within said dielectric material.

5. The device as claimed in claim 3 in which the said rod comprises an oxide derived from magnetic oxide of iron.

6. A microwave switch comprising two sections of rectangular wave guide aligned longitudinally but with one rotated through 90° relative to the other, separated and interconnected by a section of round wave guide, a coil wound externally around said length of round wave guide and having terminals for connection in an electrical circuit, means for subjecting said round section to a magnetic field parallel to the wave guide axis, and a rod of material active in the Faraday magneto-optical sense supported within said round section along its longitudinal median line, said coil comprising resistance wire, for heating the interior of said round section simultaneously with creating said magnetic field.

7. A device of the class described comprising, a waveguide section capable of supporting a non-circular field mode in orientation displaced by 90°, a body of material having a length greater than its transverse dimensions longitudinally supported in said waveguide section with its external periphery substantially spaced from the internal wall surface of said waveguide section, and means for impressing a magnetic field on said body of material in a direction parallel to the longitudinal axis thereof.

8. A device as set forth in claim 7 having a dielectric material supporting said body of material and filling the space between the external periphery of said body and the internal wall surface of said waveguide section.

9. A device of the class described comprising, a waveguide member capable of supporting a non-circular field mode in orientations displaced by 90°, a rod of ferrite material whose length exceeds its transverse dimensions and any transverse dimension of which is materially less than any corresponding transverse dimension of said waveguide member positioned internally of said waveguide member longitudinally with respect thereto, and means for impressing a magnetic field on said rod in a direction along its longitudinal axis.

10. A device as set forth in claim 9 having a dielectric material supporting said rod and completely filling the space between said rod and the internal surface of said waveguide member.

11. A device of the class described comprising, a waveguide section capable of supporting a non-circular field mode in orientations displaced by 90°, an elongated body of material active in the Faraday magneto-optical sense whose length exceeds its transverse dimensions positioned with its longitudinal axis lying along the longitudinal axis of said waveguide section and having its external periphery materially spaced from the internal wall surface of said waveguide section, and means for impressing a magnetic field on said body in a direction parallel to the longitudinal axis thereof.

12. A device as set forth in claim 11 having a dielectric material supporting said elongated body and filling the space between its external periphery and the internal surface of said waveguide section.

13. A device of the class described comprising, a waveguide member capable of supporting a non-circular field mode in orientations displaced by 90°, a body of material active in the Faraday magneto-optical sense having a length exceeding its diameter positioned interiorly of said waveguide member longitudinally with respect thereto, said body having a diameter less than one half the internal diameter of said waveguide member, and means for impressing a magnetic field on said body in a direction parallel with respect to the longitudinal axis thereof.

14. A device as set forth in claim 13 having a a dielectric material supporting said body and completely filling the space between the external surface of said body and the internal surface of said waveguide member.

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