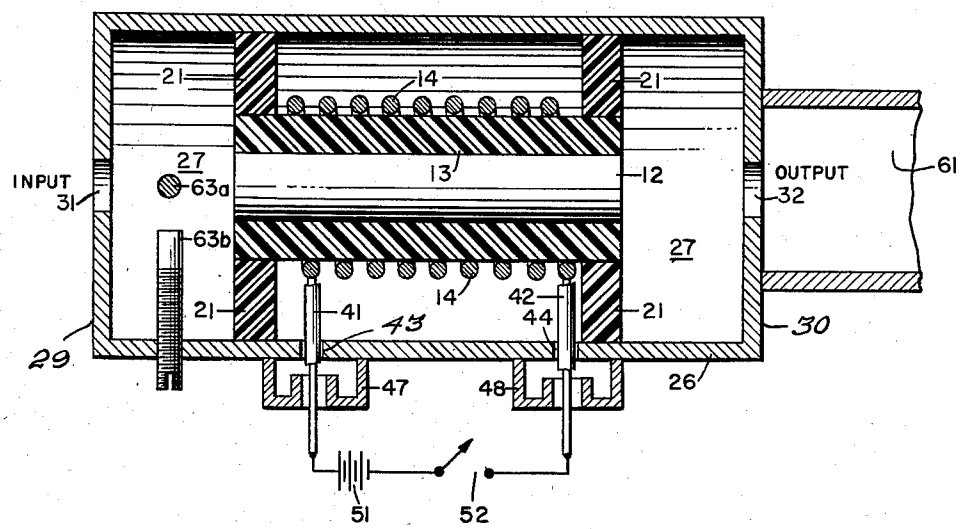
Oct. 13, 1959 R. F. SULLIVAN ET AL 2,908,878

MICROWAVE SWITCHING DEVICE

Filed May 27, 1955



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United States Patent Office 2,908,878
Patented Oct. 13, 1959

2,908,878

MICROWAVE SWITCHING DEVICE

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Application May 27, 1955, Serial No. 511,816

1 Claim. (Cl. 333—98)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment to us of any royalty thereon.

This invention relates to devices for the substantially non-dissipative attenuation of microwave energy. In a typical application of the invention a ferrite rod surrounded by a coil of wire is mounted in a cavity. At one end of the cavity, which may be cylindrical, input means is provided for receiving microwave energy having a certain plane of polarization. At the other end of the cavity output means is provided, preferably responsive to energy having the same plane of polarization as the energy at the input end, for withdrawing energy from the other end. The geometry is preferably such that (1) the wave in the region of the ferrite rod is equivalent to the resultant of two circularly polarized components, (2) the cavity will propagate each circular component independently, (3) a large part of the energy that reaches the output end from the input end passes through the ferrite rod, and (4) with no current applied to the coil the cavity has a resonant mode at or near the frequency of the injected energy. Under these no-current conditions energy leaves the output end at a relatively high rate. But when current is applied to the coil the effective permeability of the ferrite is changed, and this change of permeability causes attenuation of the output wave in two distinct ways: first, by detuning the cavity from resonance; and second, by causing rotation of the plane of polarization of the wave reaching the output end. High attenuations can be obtained as a result of these two effects. The attenuation may be switched off and on at high speeds.

An object of the invention is to provide a device for controllably attenuating a microwave signal.

Another object is to provide a microwave attenuator having high attenuation.

Still another object is to provide a fast-acting microwave switch having high attenuation.

Other objects, aspects, uses and advantages will become apparent from the following description and from the accompanying drawing, which shows a longitudinal section of a microwave attenuator in accordance with the invention.

In the drawing, a ferrite rod **12** is preferably surrounded by a tube **13** of polystyrene, Teflon, or other low-loss material having a dielectric constant greater than air but lower than that of the ferrite. A coil **14** of wire is wound around tube **13**. The assembly comprising rod **12**, tube **13**, and coil **14** is supported axially in a cylindrical waveguide cavity structure **26** having an inner cylindrical cavity **27** by means of supports **21** which are preferably of foamed polystyrene or other low-loss material. Cavity structure **26** is provided with an axial input aperture **31** at input end **29**, adapted to admit microwave energy from an external source into cavity **27**. Another axial aperture **32** at the output end **30** of cavity structure **26** is adapted to permit microwave energy to flow out of cavity **27**. Radial wire leads **41** and **42** are connected electrically to the respective ends of coil **14** and extend insulatedly

through apertures **43** and **44** in cavity structure **26**. Choke structures **47** and **48** associated with apertures **43** and **44** are preferably provided, to inhibit the flow of microwave energy through apertures **43** and **44**. Leads **41** and **42** are connected through a switch **52** to a battery or other power source **51**.

With switch **52** open—no current applied to coil **14**—cavity **27** is resonant in the TE_{11} mode at a certain microwave frequency f_0. Let microwave energy of frequency f_0 and and having a certain plane of polarization be introduced through input aperture **31** into input end **29** of cavity **27**. Let output aperture **32** at output end **30** be coupled to a section of rectangular waveguide **61** or other structure adapted to accept microwave energy of frequency f_0 having the same plane of polarization as the energy introduced into input aperture **31** and to discriminate against waves having other planes of polarization. It will be understood that under these conditions cavity **27** will function as a relatively effective coupling device and that energy will flow out of output aperture **32** at a relatively high rate P_0.

It is a known characteristic of cylindrical waveguide excited in the TE_{11} mode that the wave along the axis of the guide may be broken down into two circular polarized components. It is also known that if a ferrite rod is placed axially in such a waveguide, and if an axial magnetic field is applied to the ferrite, the ferrite will have different effective permeabilities for each circular polarized wave. (See C. L. Hogan, Bell System Tech. Jour., XXXI, No. 1 (1952).) It is known that as the wave progresses axially along the ferrite rod under such conditions the positive and negative circular polarized components are phase-shifted oppositely, and that the plane of polarization of the resultant wave becomes progressively rotated. Furthermore, the energy density of the TE_{11} mode in cylindrical waveguide is maximum along the axis and falls off toward the walls; and in addition, because of the high dielectric constant of ferrites, the axial ferrite rod **12**—referring to the figure—further concentrates in the axial region the energy in cavity **27**. The dielectric tube **13** also contributes to the concentration of energy.

Accordingly it will be understood that, if we now apply current to coil **14** by closing switch **52**, an axial magnetic field will be applied to ferrite rod **12** and the plane of the TE_{11} wave passing axially through rod **12** will be rotated. Furthermore, because the input wave entering input aperture **31** effectively traverses cavity **27** longitudinally a number of times before leaving cavity **27** through output aperture **32**, the rotation occurring in cavity **27** when switch **52** is closed is cumulative.

Moreover, it will be understood that, because the effective permeability of rod **12** is changed for each circular component when switch **52** is closed, cavity **27** becomes detuned from the frequency f_0 of the input wave.

Closing switch **52** thus has the dual effect of (1) reducing the amplitude and (2) rotating the plane of polarization, of the wave at output aperture **32**. Accordingly, closing switch **52** reduces the energy flow from output aperture **32** into rectangular waveguide **61**.

It will be understood that various mechanical and electronic equivalents for battery **51** and switch **52** may be utilized to apply current to coil **14**, and that rapid switching of the microwave energy flow out of output aperture **32** can be accomplished.

Leads **41** and **42** may tend to produce certain somewhat undesirable effects. It is possible to dispense with coil **14** and with leads **41** and **42**, and to apply the necessary magnetic field to rod **12** by placing the entire cavity structure **26** in an external axial magnetic field. If this external field is time-varying, the wall of structure **26** must be slotted so as not to act as a shorted turn. However, we do not consider this method desirable for use with a

cavity where rotation of the plane of polarization of the TE_{11} mode occurs, because radiation from the slot and phase shift due to radiation will vary as the plane of polarization changes.

To keep eddy current losses down, coil **14** should not be too close to the inner wall of cavity structure **26**. This is one of several considerations that determine the optimum diameters of rod **12** and tube **13** in relation to the inner diameter of structure **26**.

Dielectric tube **13** may be omitted if desired; coil **14** may be wound directly on ferrite rod **12**. However, we prefer to include dielectric tube **13** because we have found that we are thus able to obtain higher attenuations. We believe that the poorer performance when tube **13** is omitted is due to mode ellipticity, and that tube **13** improves the performance by reducing the energy density in the vicinity of the coil, thus reducing mode ellipticity.

It will be apparent that in certain embodiments of our invention it may be advantageous to provide tunability for the cavity **27**, and that tunability can readily be provided with known capacitative tuning screws, for example. Furthermore, it will be understood that the detuning effect of residual magnetism of the ferrite can be counteracted by a steady-state magnetic field obtained from a coil carrying a low current or from a magnet.

We prefer to provide an improved tuning arrangement comprising stubs **63***a* and **63***b* of adjustable length. These stubs are in the same plane and at right angles to each other, projecting radially inward into cavity **27** from the walls of structure **26**. Let stub **63***a* be parallel to the E vector with no current applied to coil **14**. Suppose for the moment that stub **63***b* is omitted. With a particular adjustment of stub **63***a*, cavity **27** is resonant at a certain frequency f_0 when no current is applied to coil **14**. Application of current to coil **14** will now cause rotation of the plane of polarization. Because the E vector is no longer parallel to stub **63***a*, stub **63***a* produces ellipticity of the rotated wave. This ellipticity is undesirable, tending to reduce attenuation. However, by adding stub **63***b* and adjusting its length we are able to minimize the ellipticity due to stub **63***a* and to maximize the attenuation.

Although we have described particular forms of our invention in which a ferrite body is located axially in a cylindrical cavity, it will be understood that other forms of the invention may be constructed. It is possible to provide other cavity structures capable of propagating each of the two circular polarized components of a wave consisting of two such components. Also, materials other than ferrites may be found to have the property of experiencing the necessary change of effective permeability and causing the necessary rotation when subjected to an appropirate magnetic field.

It will be understood that the amount of attenuation provided by the device in the figure will be a function of the magnetic field applied to ferrite rod **12** and thus of the current applied to coil **14**, and that this current and this field may be readily varied to provide various desired amounts of attenuation.

A particularly valuable application of the invention is as a high-speed on-off switch, and this application entails rapidly switching on and off the current applied to coil **14** and the resulting field applied to rod **12**. Particularly for high-speed switch applications we prefer to keep the inductance of coil **14** low.

In one satisfactory switch model constructed in accordance with the invention we used a cavity structure **26** having an inner diameter of 7/8 inch and a length of 3⅜ inches. Apertures **31** and **32** were circular irises of 0.453 inch diameter. Ferrite rod **12** was a rod of a magnesium-manganese ferrite (Ferramic R–1) having a diameter of 0.23 inch and a length of 1 3/16 inches. Tube **13** was a Teflon tube of 0.625 inch outer diameter. Supports **21** were of a foamed polystyrene material having a dielectric constant closely approximating that of air. Coil **14** consisted of 20 turns of No. 30 wire, single spaced. This model was found to have a coil inductance of 5 microhenries, an insertion loss of 0.8 db at the resonant frequency (approximately 9160 megacycles), a loaded Q of 200 (no current applied to coil), and a voltage standing wave ratio of 1.2. When coil **14** of this model was fed with 0.2 microsecond unidirectional pulses from a thyratron pulser the observed switching time (switching time of the microwave energy from "on" to "off" or from "off" to "on") was only 0.025 microsecond. Attenuation was 45 decibels above the insertion loss when the current was of optimum amplitude and was better than 31 decibels over a 2-to-1 current range.

Advantages of switches in accordance with our invention over known rotation-type ferrite switches include the following: (1) Our switches provide high attenuation that is not critically dependent upon the amplitude of the magnetic field applied to the ferrite; known rotation-type ferrite switches are capable of providing isolation of the order of 30 db or more only when the magnetic field is held to within a few percent of the optimum value. (2) Our switches are less temperature sensitive; rotation by a ferrite is dependent on the state of magnetization of the ferrite, which is temperature-dependent; the isolation provided by our switches is much less dependent on magnetic field, on state of magnetization, and hence on temperature. (3) Our switches can be used at higher average power levels, partly because the detuning of the cavity in our switches in the "off" condition means that less power is dissipated in the ferrite, which is somewhat lossy at microwave frequencies.

Among the useful applications that we contemplate for microwave switches in accordance with our invention are the following:

(1) In two-antenna transmitting-receiving systems, as a switch to isolate the receiver from the receiving antenna during period of transmission.

(2) In one-antenna transmitting-receiving systems, as a replacement for the usual TR tube; one or more of our switches can be placed in the line in series between the receiver and the antenna, and the switches can readily be switched "off" simultaneously with the application of transmitter power. Such an arrangement would have distinct advantages over the usual TR tube arrangement. For one thing, our switches recover—i.e., switch from the "off" to the "on" condition—much faster than the usual TR tube, and the relatively slow recovery time of TR tubes is a serious limitation in some applications. Furthermore, the usual TR tube—unlike our switches—has an uncertain shelf life because of susceptibility to envelope leaks and to envelope outgassing, so that TR tubes in systems not used continuously must be checked periodically.

(3) In one-antenna systems using ferrite circulators, as a switch between the circulator and the receiver, to provide more isolation of the receiver from the transmitter than is provided by the circulator alone.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of the invention as defined in the appended claim.

We claim:

A microwave switching device operating at a predetermined frequency and comprising in combination: a structure defining a cylindrical microwave cavity, said structure having an axial input aperture at one end and an axial output aperture at the other end, said input aperture being adapted to receive microwave energy having said predetermined frequency and a predetermined plane of polarization, a microwave section coupled to said output aperture and adapted to accept microwave energy of said predetermined frequency having said predetermined plane of polarization while discriminating against waves having other planes of polarization, a ferrite rod coaxially mounted within said cavity, and electrical means for applying an axial magnetic field to said rod,

said electrical means comprising a coil within said cavity surrounding said rod, means for applying a current to said coil, and a tubular layer of solid low-loss material having a dielectric constant greater than that of air interposed between said ferrite rod and said coil, said cavity being adapted to resonate in the TE_{11} mode at said predetermined frequency in the absence of said magnetic field, and means for adjusting the resonant frequency of said cavity comprising first and second adjustable tuning stubs projecting radially inward from the periphery of said structure, said stubs being coplanar and having their axes at right angles to each other, said ferrite rod being so constructed and arranged in cooperation with said cavity that a large part of the energy that reaches said output aperture from said input aperture passes through said ferrite rod, said microwave energy applied to said input aperture thereby propagating into said microwave section at a relatively high rate in the absence of said magnetic field, the application of said magnetic field to said rod acting to simultaneously detune said microwave cavity and rotate the plane of polarization of said microwave energy passing through said rod so as to then cause relatively little energy to be propagated to said microwave section.

References Cited in the file of this patent

UNITED STATES PATENTS

2,568,881	Schoenberg	Sept. 25, 1951
2,606,248	Dicke	Apr. 5, 1952
2,645,758	Van De Lindt	July 14, 1953
2,671,884	Zaleski	Mar. 9, 1954
2,719,274	Luhrs	Sept. 27, 1955
2,742,612	Cohn	Apr. 17, 1956
2,752,495	Kroger	June 26, 1956
2,784,378	Yager	Mar. 5, 1957
2,825,765	Marie	Mar. 4, 1958
2,877,144	Iversen	Mar. 10, 1959

FOREIGN PATENTS

674,874	Great Britain	July 2, 1952

OTHER REFERENCES

Van Trier: "Experiments on Faraday Rotation of Guided Waves," Applied Scientific Research, vol. 3, No. 2, July 27, 1953, pages 142–144.

Fox et al.: Bell System Technical Journal, vol. 34, No. 1, January 1955, pages 31–32.