Nov. 12, 1968 F. REGGIA ET AL 3,411,115

RECIPROCAL FERRITE ATTENUATOR

Filed Nov. 16, 1966

FIG. 1.

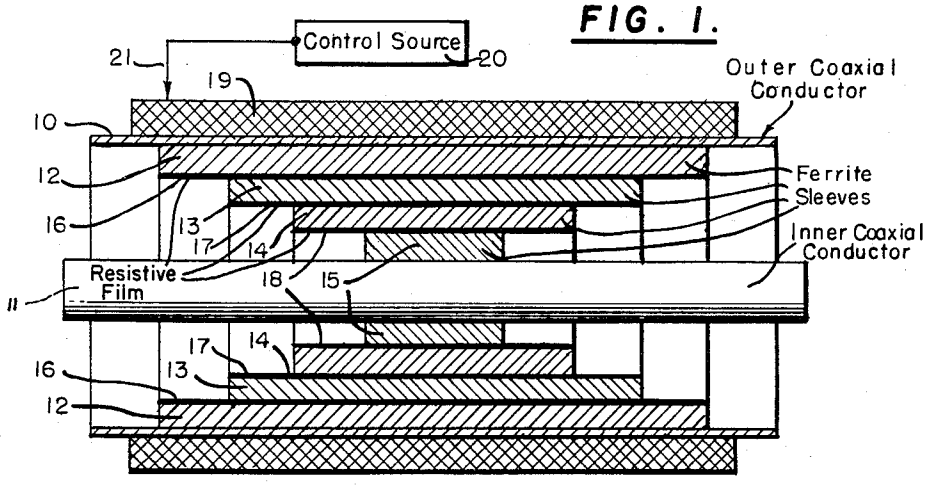


FIG. 1A.

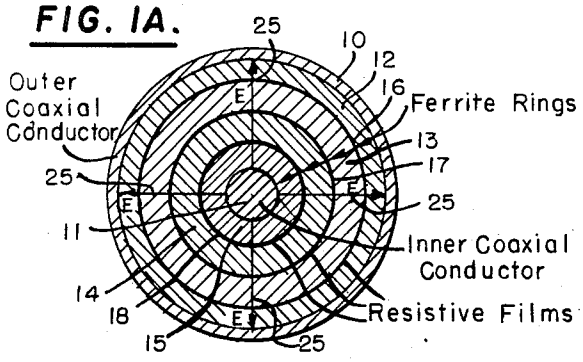


FIG. 1B.

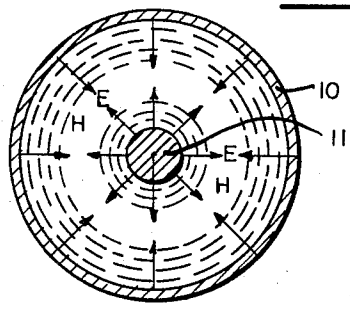


FIG. 1C.

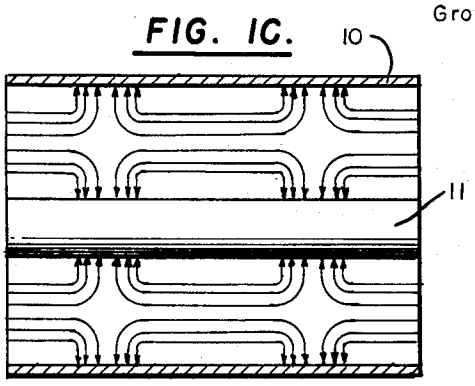


FIG. 2A.

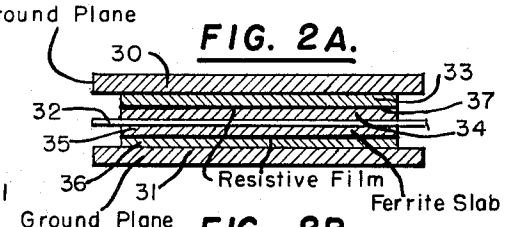
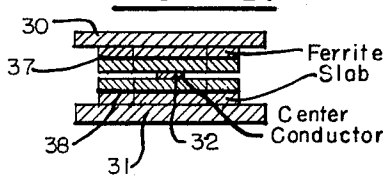


FIG. 2B.



INVENTORS

Frank Reggia

Ting Hei Mak

BY Harry M. Saragovitz, Edward J. Kelly, Herbert Berl & J. D. Edgerton

ATTORNEYS

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RECIPROCAL FERRITE ATTENUATOR

Frank Reggia, Bethesda, Md., and Ting Hei Mak, Washington, D.C., assignors to the United States of America as represented by the Secretary of the Army

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ABSTRACT OF THE DISCLOSURE

Coaxial or stripline structure having a propagating medium of a laminated configuration comprising plural layers of ferrite material separated from one another by layers of resistive material symmetrically placed within the conductor. When the ferrite layers are unmagnetized, the resistive material has no effect on wave propagation. When the ferrite is magnetized, a component of the RF field is generated in a direction parallel to the plane of the resistive layers resulting in reciprocal attenuation of the electromagnetic field.

The invention described herein may be manufactured 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.

The present invention relates to improved devices for modulating, switching, or attenuating microwave power, and is more particularly concerned with structures for the purposes described which employ an arrangement of ferrite and resistive materials as the propagating medium in a coaxial line or stripline waveguide.

Various structures have been suggested heretofore for modulating, attenuating, or switching microwave power. These structures have, in general, been relatively large in size, complex and costly in construction, have exhibited relatively poor efficiencies, and have responded relatively slowly during a desired control operation. The present invention, by utilizing a novel arrangement of ferrite and resistive materials, provides a structure which can achieve desired switching or modulation of microwave power in a device which is small in physical size, simple and inexpensive to fabricate, responds rapidly to a relatively small magnetic control field, and is capable of operating at relatively high temperatures.

More particularly, the present invention contemplates the provision of a novel coaxial or stripline structure arranged to transfer power, and having an internal structure of unique configuration acting as a propagating medium and adapted to respond to an applied magnetic field in a manner tending to vary the amount of power actually being transmitted. The internal structure is of laminated configuration consisting of plural layers of ferrite material separated from one another by layers of resistive material. The structure is so arranged with respect to the electric field of the power being transmitted that said resistive material has no appreciable effect on the transmission of power when the ferrite layers are unmagnetized, but said resistive layers effect attenuation of at least a portion of the power being transmitted when said ferrite layers are properly magnetized.

It is accordingly an object of the present invention to provide an improved coaxial or stripline amplitude modulator adapted for use in power modulating, switching, and attenuating operations.

Another object of the present invention resides in the provisions of an improved absorption structure for use in microwave environments, adapted to respond to an applied magnetic control field in a manner varying the power absorption characteristics of the structure with variations in said field.

Still another object of the present invention resides in the provision of an improved coaxial amplitude modulator having an internal structure consisting of a number of concentric ferrite sleeves separated respectively by a thin resistive film.

Still another object of the present invention resides in the provision of an improved stripline amplitude modulator which employs a novel propagating medium consisting of a laminated ferrite structure the laminations of which are separated by resistive films.

Another object of the present invention resides in the provision of a microwave power modulator, switch, or attenuator structure which can be made in small sizes, and which is arranged to respond in a novel manner to an applied magnetic control field.

A further object of the present invention resides in the provision of an improved microwave power modulator, switch, or attenuator which exhibits an extremely rapid response to control, which has low insertion loss when in its "on" state, and which has high isolation in its "off" state.

The foregoing objects and advantages will become more readily apparent from the following description and accompanying drawings wherein:

FIGURE 1 is a side view of a coaxial amplitude modulator constructed in accordance with the present invention;

FIGURE 1A is an end view of a portion of the structure shown in FIGURE 1, illustrating the operation of the structure in the absence of an applied control field;

FIGURES 1B and 1C are diagrammatic end and side views respectively of a portion of the structure shown in FIGURE 1, illustrating the effect of an applied control field;

FIGURE 2A is a side view of a stripline amplitude modulator constructed in accordance with the principles of the present invention; and

FIGURE 2B is an end view of the structure shown in FIGURE 2A.

Referring initially to FIGURE 1, the coaxial amplitude modulator of the present invention consists of a coaxial transmission structure comprising an outer conductor **10** and an inner conductor **11**. The coaxial conductors **10** and **11** are separated from one another by a plurality of concentric ferrite sleeves **12–15** inclusive, with said sleeves being of successively shorter length proceeding inwardly from the outer conductor as illustrated in FIGURE 1. The ends of the successively shorter ferrite sleeves form a taper which will match the impedance of the coaxial modulator to that of the device to which it is connected. The sleeves are symmetrically placed within the conductor to provide for reciprocal operation. The several sleeves **12–15** are, moreover, further separated from one another by thin resistive films **16**, **17**, and **18**. The resistive films **16–18** are preferably less than 0.0001 inch in thickness, and preferably comprise a material having a resistivity of about 50 ohm-cm. The resistive films may, if desired, be deposited on the exterior surfaces of one or

more of the ferrite sleeves prior to assembly of the overall laminated structure.

The overall modulator structure includes a solenoid **19** surrounding conductor **10** and adapted to selectively generate a controlling magnetic field. The presence or absence of said field, and its magnitude, is under the control of an appropriate signal or potential source **20**, coupled to solenoid **19** via appropriate means diagrammatically illustrated at **21**; and said field in turn varies the state of magnetization of ferrite sleeves **12–15**.

When the ferrite sleeves **12–15** are not magnetized, and the coaxial line **10–11** is transmitting the fundamental TEM mode, the RF electric field present in the coaxial line is perpendicular to the several resistive films **16–18**. This is diagrammatically illustrated in FIGURE 1A, with the direction of the RF electric field under these circumstances being designated by the arrows **25**. Due to the fact that the electric field is perpendicular to the resistive films when the ferrite sleeves are not magnetized, the electromagnetic wave will be transmitted through the coaxial lines **10–11** without any significant attenuation.

When the control source **20** applies current to solenoid **19** to produce a magnetic field in the several ferrite sleeves **12–15**, to properly magnetize said sleeves longitudinally, a component of the electric field is generated parallel to the resistive films **16–18**. A transverse magnetic field may be utilized to obtain the results described hereinbelow, as well. As a result, the dominant mode propagating through the coaxial conductor will be changed from TEM to TM_{01}. The resulting TM_{01} mode is illustrated in FIGURES 1B and 1C. FIGURE 1B shows an end view of the electric and magnetic fields under these circumstances, and FIGURE 1C shows a side view through the central conductor when the structure is operating in said TM_{01} coaxial mode. The component of the RF field thus generated in a direction parallel to the resistive films **16–18** will be dissipated in said films and, as a result, at least a portion of the electromagnetic wave will be attenuated. The attenuation can be varied under the control of source **20** by appropriately varying the strength of the magnetic control field produced by solenoid **19**.

When the device is operated in the foregoing manner, it acts as a broad band absorption modulator adapted for high speed switching or amplitude modulation of microwave power. The modulator has electrical characteristics particularly desirable, in a microwave switch, including very low insertion loss in the "on" state, a high isolation in the "off" state which is nearly independent of the magnetic control field in this state, and a nearly matched input impedance for all values of applied field. These electrical characteristics remain substantially constant over a relatively wide frequency range.

Other characteristics of the modulator shown in FIGURE 1 include its small physical size, the small magnetic control fields which need be employed, and an operating temperature which can be well above 100° C. Because of the small electrical inertia associated with the low-field solenoid **19**, the ferrite modulator shown in FIGURE 1 (as well as that to be described in reference to FIGURE 2) can be designed to switch microwave energy in less than 1 microsecond with non-critical magnetic control fields.

The structure shown in FIGURE 1 (and to be described hereinafter in reference to FIGURE 2), may also be employed as an electrically-controlled variable attenuator for automatically stabilizing the amplitude of FM oscillators; can be employed to effect pulse-shaping of microwave energy; and can be utilized as a high speed TR switch in microwave radar systems.

With respect to the switching operations mentioned above, it will be appreciated that solenoid **19** and control source **20**, rather than providing a variable field adapted to effect modulation of the transmitted power, can have an "on-off" characteristic arranged to produce substantially no magnetization of the ferrite layers **12–15**, in which event power is transferred substantially unattenuated, or alternatively providing such significant magnetization of ferrite layers **12–15** as to effect substantially complete absorption of the electromagnetic wave.

The general principles of the present invention can also be utilized in the fabrication of stripline amplitude modulators such as are shown in FIGURES 2A and 2B. In this form of the structure, the power transmission device comprises a pair of spaced, substantially parallel ground planes **30** and **31** having a central conductor **32** positioned therebetween. A laminated ferrite structure consisting of ferrite slabs **33–36** is disposed, as illustrated, between and parallel to planes **30** and **31**, there being at least two such slabs between each ground plane and central conductor **32**. Slabs **33** and **34** are separated by a resistive film **37**, while slabs **35** and **36** are separated from one another by a further resistive film **38**. The resistive films **37** and **38** extend parallel to ground planes **30** and **31**, and may have the dimensions and resistivity already discussed in reference to the embodiment of FIGURE 1. The overall structure of FIGURES 2A and 2B is, moreover, associated with appropriate means adapted to produce a control magnetic field; but these control means have not been shown in FIGURES 2A and 2B.

When the ferrite slabs **33–36** are not magnetized, the electric field in the structure is again perpendicular to the resistive films **37** and **38**, and the transmitted wave propagates substantially unattenuated. When the ferrite is longitudinally magnetized, however, a component of the electric field is generated parallel to the resistive films. This component of the electric field will therefore be dissipated and, as a result, amplitude modulation, switching, absorption, etc. of the transmitted wave is obtained.

While we have thus described preferred embodiments of the present invention, many variations will be suggested to those skilled in the art; and the foregoing description is therefore intended to be illustrative only and not limitative of the present invention. All such variations and modifications as are in accordance with the principles described are meant to fall within the scope of the appended claims.

Having thus described our invention, we claim:

1. A reciprocal microwave absorption device comprising a two conductor RF conducting means, a propagating medium disposed symmetrically within said conducting means comprising a plurality of ferrite elements positioned in spaced relation to one another, adjacent ones of said ferrite elements being separated from one another by a layer of resistive material, said layer of resitive material extending in a direction substantially at right angles to the normal direction of the electric field generated as power is transmitted through said device, and magnetic control means disposed adjacent to said medium for selectively magnetizing said ferrite elements so as to generate a component of said electric field in a direction generally parallel to the direction of said layer of resistive material for either direction of propagation through said conducting means, whereby at least a portion of the power being transmitted through said device is absorbed in said resistive layer.

2. The device of claim **1** wherein said conducting means comprises a coaxial structure having a central conductor and an outer cylindrical conductor, said ferrite elements comprising a plurality of concentric ferrite sleeves separated from one another by a film of resistive material and positioned in surrounding relation to said central conductor between said central conductor and said outer cylindrical conductor.

3. The device of claim **2** wherein said concentric ferrite sleeves are of different lengths in the direction of extension of said coaxial structure.

4. The device of claim **1** wherein said conducting means comprises a pair of ground planes disposed in spaced parallel relation to one another, a central conductor positioned between said ground planes, said ferrite ele-

ments comprising a plurality of ferrite slabs positioned between each of said ground planes and said central conductor, and said resistive layer comprising a film of resistive material located in a plane parallel to each of said ground planes and spaced from both said ground planes and said central conductor.

5. The device of claim 1 wherein said magnetic control means includes means for varying the degree of magnetization of said ferrite elements.

6. The device of claim 1 wherein said layer of resistive material comprises a thin resistive film deposited on at least one of said ferrite elements.

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HERMAN KARL SAALBACH, *Primary Examiner.*

P. L. GENSLER, *Assistant Examiner.*