

Feb. 20, 1962

L. A. BLASBERG ET AL

3,022,475

MICROWAVE DEVICE

Filed Aug. 12, 1958

3 Sheets-Sheet 1

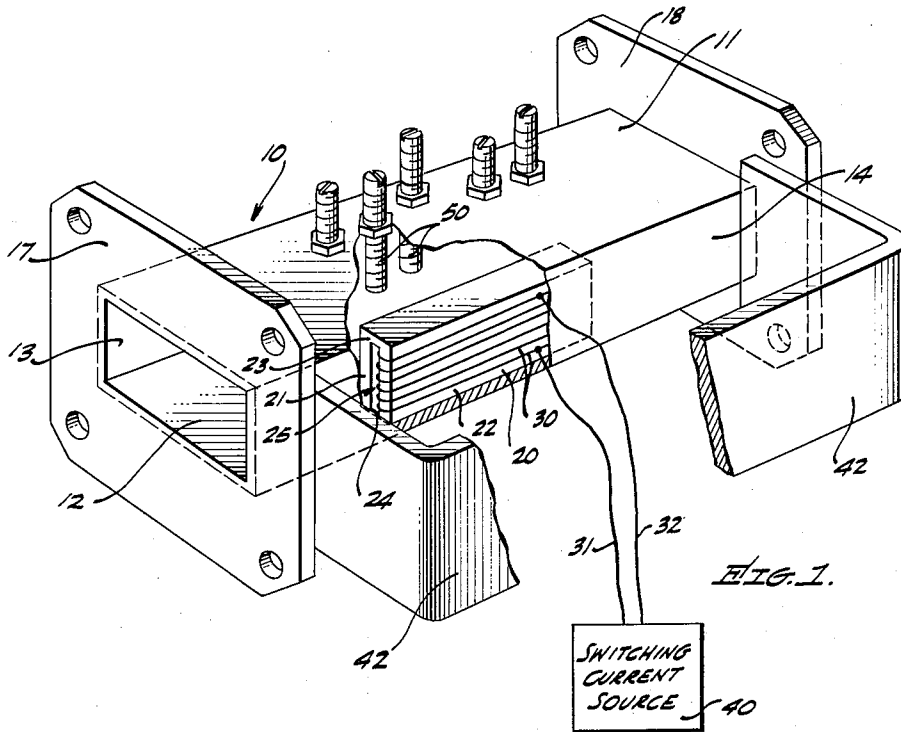


FIG. 1.

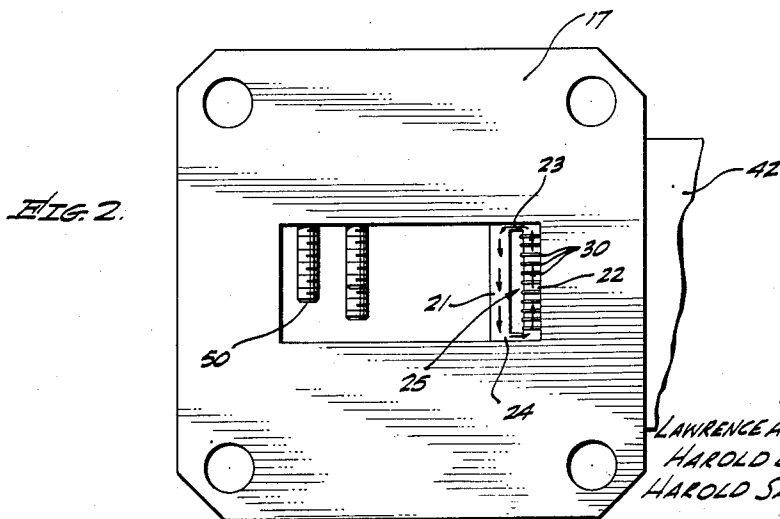


FIG. 2.

INVENTORS.
LAWRENCE A. BLASBERG,
HAROLD D. PERRY,
HAROLD SALTZMAN,

BY

R. A. Boguski

ATTORNEY

Feb. 20, 1962

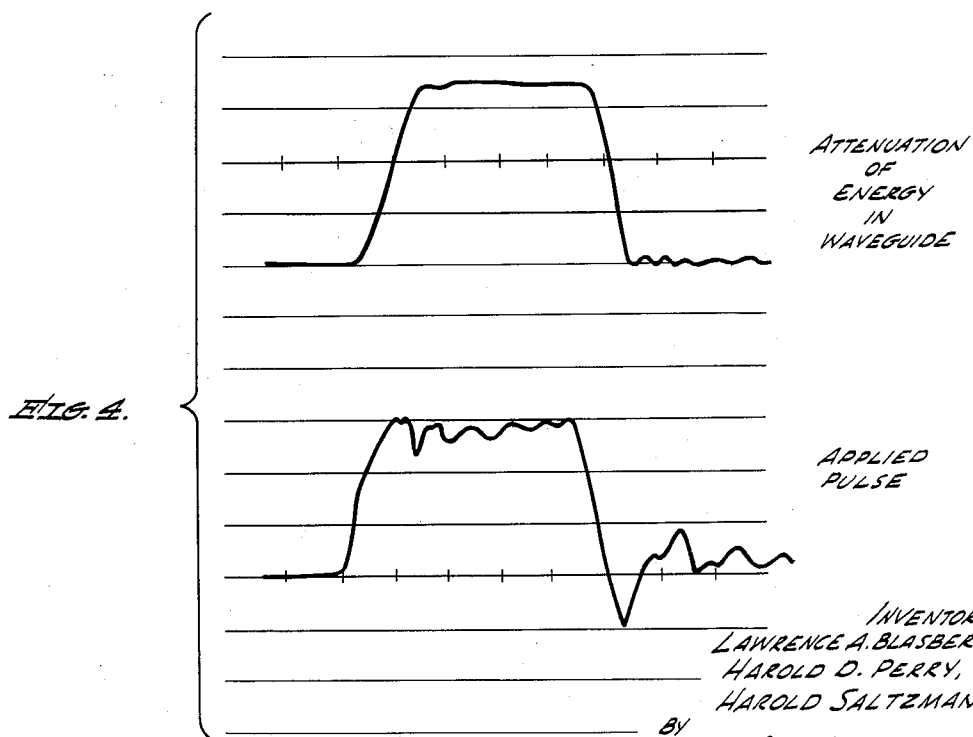
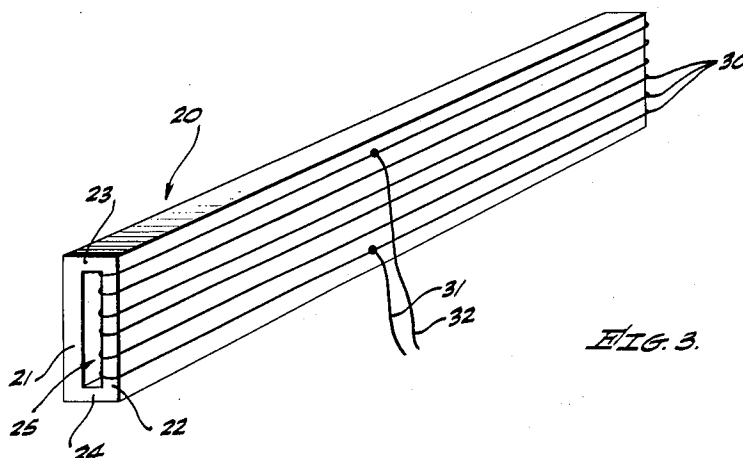
L. A. BLASBERG ETAL

3,022,475

MICROWAVE DEVICE

Filed Aug. 12, 1958

3 Sheets-Sheet 2



INVENTORS.
LAWRENCE A. BLASBERG,
HAROLD D. PERRY,
HAROLD SALTZMAN,

BY

R. A. Boyacki

ATTORNEY.

Feb. 20, 1962

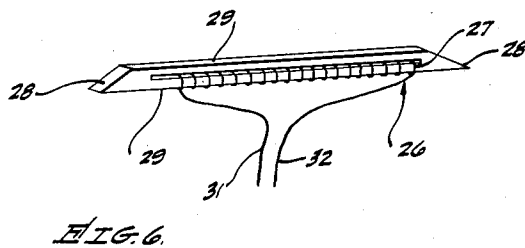
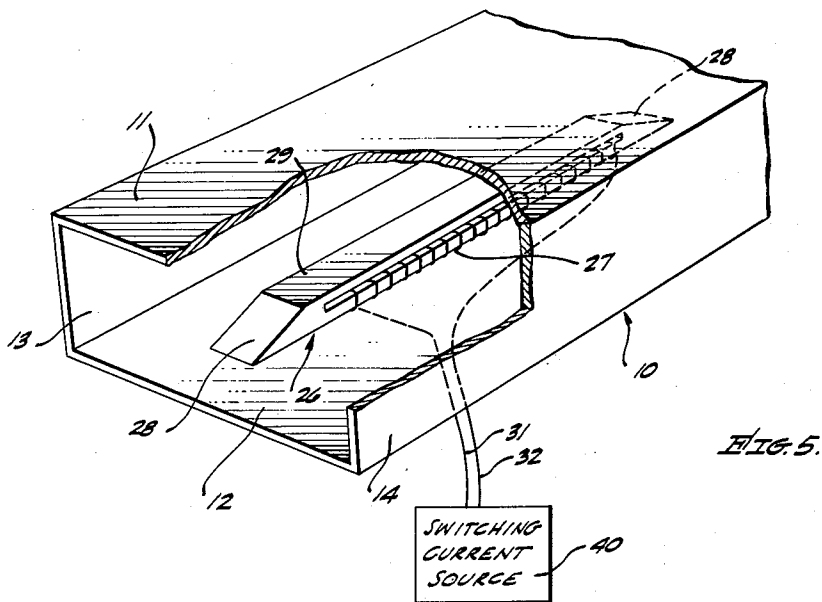
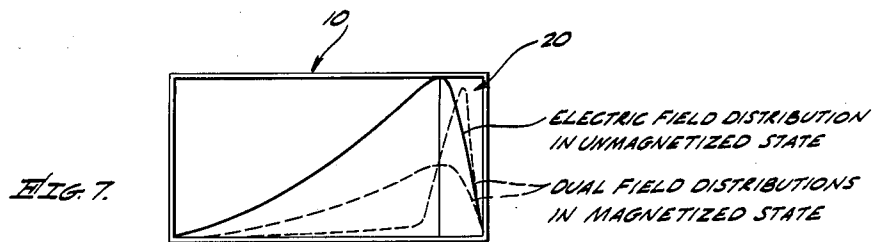
L. A. BLASBERG ETAL

3,022,475

MICROWAVE DEVICE

Filed Aug. 12, 1958

3 Sheets-Sheet 3



INVENTORS.
LAWRENCE A. BLASBERG,
HAROLD D. PERRY,
HAROLD SALTZMAN,
BY
R. A. Boquechi
ATTORNEY

1

3,022,475

MICROWAVE DEVICE

Lawrence A. Blasberg, Delaware Township, Camden County, N.J., and Harold D. Perry, Manhattan Beach, and Harold Saltzman, Los Angeles, Calif., assignors to Hughes Aircraft Company, Culver City, Calif., a corporation of Delaware

Filed Aug. 12, 1958, Ser. No. 754,664

2 Claims. (Cl. 333-97)

This invention relates to devices for the control of microwave energy, and particularly to those microwave devices which use magnetized ferromagnetic materials.

Devices which utilize the gyromagnetic nature of magnetized ferromagnetic materials at microwave frequencies are finding increasing use. Such devices are described generally in an article entitled "Behavior and Applications of Ferrites in the Microwave Region" by Fox, Miller and Weiss at pp. 5-103 of the January 1955 issue of the Bell System Technical Journal. As therein described, such devices may have various characteristics, dependent upon the relationship between the energy being transmitted, the ferromagnetic material and the sense and magnitude of the magnetization. The devices are divided generally into Faraday rotation types and transverse field types. Either of these types may be operated in a resonance region to effect the absorption of energy under certain circumstances. A further form of the transverse field effect is a field displacement effect.

The microwave devices using these various effects comprise isolators, circulators and phase shifters. The devices are principally nonreciprocal, although reciprocal effects may also be achieved. The isolating and circulating actions may be considered to be forms of switching, as may the phase shifting in certain configurations. Further, the devices may be used for modulation, filtering and amplification. It will be seen, therefore, that ferromagnetic loaded microwave devices can be used for most every purpose for which there may be a need in microwave systems.

A number of devices have been constructed in accordance with current knowledge to provide selective control of energy within microwave waveguides. These devices have, however, usually been static devices operating with permanent magnets. A number have been electrically or electromagnetically controlled. Devices using electromagnetics and associated circuitry have usually been restricted to certain maximum speeds of operation due to the difficulties involved in obtaining high speed magnetization of ferromagnetic elements. For example, previous devices have employed an external electromagnet pulsing the ferromagnetic element through the waveguide wall. The eddy currents which are set up in the waveguide wall usually interfere with the rate of increase of the flux through the waveguide walls. Such eddy current effects remain even when the waveguide wall is reduced in thickness at the ferromagnetic element to the minimum permissible reduction in size of the air gap across the ferromagnetic element. Furthermore, it has been found that in some of the prior art devices a time limit is imposed by the interval needed for the gyromagnetic effects to occur.

Size considerations and driving power requirements are other limitations which it is desirable to overcome in any microwave transmission device. The higher the driving requirements and the larger the size the less satisfactory these devices are for general use. Heretofore, ferromagnetic devices have not satisfactorily combined high speed operation with low driving power and compactness. Furthermore, the devices have been essentially narrow band and when operated over a broader

2

band have been restricted, at least in particular regions, to low power operation.

Accordingly it is an object of this invention to provide an improved high speed device for controlling the transmission of energy in a microwave conductor.

Another object of this invention is to provide an improved ferromagnetic loaded microwave device, which device is simpler to construct and operate than the devices of the prior art.

Still another object of this invention is to provide a novel ferromagnetic microwave device operable with lower driving powers than comparable devices previously available.

A further object of this invention is to provide a novel microwave device utilizing ferromagnetic elements to effect extremely high speed control of microwave energy.

Another object of this invention is to provide an improved switching device for microwave transmission elements, which device operates at higher speeds and with lower driving powers than has heretofore been practicable.

Yet another object of this invention is to provide an extremely compact high speed switching device using ferromagnetic elements for microwave systems, which device operates with lower driving current and over a wider range of frequencies than the devices of the prior art.

A further object of this invention is to provide a pulsed energy transmission control device for microwave systems having extremely rapid rise and fall times.

Still a further object of this invention is to provide a selectively operable pulsed phase shifter device which can be operated at high speeds with extremely low driving currents.

A ferromagnetic loaded microwave device in accordance with this invention may employ a relatively thick ferromagnetic slab inside a rectangular waveguide. It is known that the length and thickness of such a slab can be arranged for a given frequency region so that, with relatively low magnetic fields, there can be effective control of energy propagated in the waveguide. A feature of this invention is that the relatively thick ferromagnetic slab may have a central aperture, so that the slab has a cross section which defines a rectangular loop. With this construction, a coil may be wound about one of the legs of the rectangular loop completely internal to the rectangular waveguide. Thus the entire magnetic structure is internal to the waveguide so that flux leakages, eddy current losses, and driving requirements are at a minimum. A switching arrangement in accordance with this invention may further be provided by utilizing the ferromagnetic slab so that its height is normal to the broad walls of the rectangular waveguide, and so that the slab is adjacent one of the narrow walls of the waveguide. An arrangement thus constructed provides low attenuation of energy in the waveguide in the absence of the application of a driving current. When the ferromagnetic slab is magnetized by the application of a signal pulse to the winding about the closed loop, however, effects occur within the ferromagnetic slab which attenuate substantially all microwave energy, thus controlling transmission through the waveguide.

In accordance with a further feature of this invention the broad bandedness of the arrangement just described may be augmented by the use of a moding arrangement, such as a number of tuning screws or a dielectric member placed within the rectangular waveguide on the opposite side from the ferromagnetic slab. This combination does not disturb transmission of energy at zero magnetic field but increases the effectiveness of the switching function over a range of frequencies.

In accordance with still another feature of this inven-

3

tion, a ferromagnetic slab of the above or a different configuration may be employed within a waveguide for phase shift purposes. The magnetization may be in the direction of elongation of the ferromagnetic slab, which in turn is parallel to the waveguide. The phase shift is achieved by effectively changing the propagation constant of the waveguide upon application of the driving current to the coil winding.

The novel features of this invention, as well as the invention itself both as to its organization and method of operation, may best be understood when considered in the light of the following description, when taken in connection with the accompanying drawing, in which like reference numerals refer to like parts, and in which:

FIG. 1 is a perspective view, partly broken away, of a microwave energy switching arrangement using a ferromagnetic slab having a central aperture and with an internal winding in accordance with the invention;

FIG. 2 is an end view of the arrangement of FIG. 1;

FIG. 3 is a fragmentary view, showing the closed loop ferromagnetic slab and the winding thereon of FIG. 1;

FIG. 4 is a wave diagram which shows a pair of waveforms illustrating the operation of a switching device in accordance with the invention;

FIG. 5 is a perspective view, partly broken away, of a phase shifter device in accordance with the invention;

FIG. 6 is a fragmentary view showing further details of the arrangement of FIG. 5, and

FIG. 7 is a diagram of electric field distributions believed to exist within a device in accordance with the invention.

A switching arrangement in accordance with the invention, referring now to FIGURES 1-3, employs ferromagnetic materials within a rectangular waveguide. The term "ferromagnetic materials" generally includes the specific classes of materials known as ferrites, and also the garnet types of material. The term "ferrite" alone may be used but where used is intended to be in conformity with the general current practice which employs this term synonymously with "ferromagnetic."

A rectangular waveguide 10 for use with the present invention may include broad walls 11 and 12 and narrow walls 13 and 14. The rectangular waveguide 10 has a central longitudinal axis and for purposes of convenience may be spoken of as having a height dimension and a width dimension, these dimensions being related to the narrow and broad walls, respectively, of the waveguide 10 and with respect to the illustration of FIGS. 1 and 2.

The rectangular waveguide 10 also may have an input terminal 17 and an output terminal 18, these portions again being given specific designations for convenience. In the normal direction of energy transmission, energy will be assumed to be propagated between the input terminal 17 and the output terminal 18. The input and output terminals 17 and 18 may have flanged portions, as shown in FIGS. 1 and 2, for coupling to other microwave waveguides (not shown).

A substantially rectangular ferromagnetic slab 20 (best seen in FIG. 3) may be positioned within the rectangular waveguide 10. The direction of elongation of the ferromagnetic slab 20 may be substantially parallel to the longitudinal axis of the rectangular waveguide 10, and the slab 20 may be positioned adjacent one of the narrow walls 14 of the rectangular waveguide 10. The ferromagnetic slab 20 may have a height dimension substantially like that of the interior dimension of the adjacent narrow wall 14. Thus the ferromagnetic slab 20 may be said to have a pair of broad walls or legs 21, 22 and a pair of narrow walls or legs 23, 24 defining a central aperture 25. Therefore, in cross section, the legs 21 to 24 of the ferromagnetic slab 20 define a closed rectangular loop, taking the cross section in a plane normal to the longitudinal axis of the rectangular waveguide 10.

Internal to the waveguide 10 and encompassing one of

4

the broad legs 22 of the ferromagnetic slab 20 may be a plurality of turns of a conductor forming a winding 30 about the portion of the ferromagnetic slab 20. As shown, the winding 30 encompasses the leg 22 of the ferromagnetic slab 20 in such manner that the application of a driving current through the winding 30 creates a magnetic field in the ferromagnetic slab extending about the closed loop defined by the slab 20. In the broad walls or legs 21 and 22 the direction of this magnetic field is transverse to the planes of the broad walls 11 and 12 of the rectangular waveguide 10, as illustrated by the arrows in FIG. 2. The direction of magnetization is, of course, dependent upon the direction of the current flowing in the winding 30. Leads 31 and 32 may extend from winding 30 to an associated switching current source 40. Brackets 42 may be coupled to the waveguide 10 to provide a means for supporting a detachable coupling (not shown) between the leads 31, 32 and the winding 30. The external leads 31, 32 may be coupled to the winding 30 through apertures (not illustrated) in the associated narrow wall 14 of the rectangular waveguide 10. The size and position of these apertures may be selected with known techniques so as not to present any reactive element to microwave energy within the rectangular waveguide 10.

The body of the ferromagnetic slab 20 may be made in a unitary piece, as shown in FIG. 3 particularly. The slab 20 may also be comprised of separate pieces fixed together, if this is easier for construction purposes, although such an arrangement might increase the amount of driving power needed as the path or the reluctance is increased. The ferromagnetic slab 20 may be fixed by cementing or other means (not shown) in the desired position close to or in contact with the adjacent narrow wall 14. A foam plastic or other member (not shown) having a dielectric constant of substantially unity may be employed to hold the slab 20 in the desired longitudinal and transverse position within the rectangular waveguide 10.

Thus it may be seen that there is a ferromagnetic core structure within the waveguide 10 driven by the switching current source 40. If desired, suitable insulating and potting material may be employed around the windings 30. The switching current source 40 may be any system source operating in timed relation with other system elements to actuate the device of the present invention at desired intervals. With a radar system, for example, the switch may be closed to permit the passage of echo pulses but opened at other times. Or the switch arrangement of FIGS. 1, 2 and 3 may be actuated by the switching current source 40 only at particular intervals.

A coupling mechanism which may consist of a plurality of tuning mode screws 50 may be positioned within the waveguide 10 along the length thereof and on the opposite side of the centerline of the waveguide 10 from the ferromagnetic slab 20. The tuning mode screws 50 may be positioned at different transverse and longitudinal positions with respect to the associated broad waveguide wall 11. These tuning mode screws 50 may be fixed or, as shown, they may be provided with threaded exterior portions operatively associated with internal threads in the associated waveguide wall 11. Thus the tuning mode screws 50 may be moved relative to the broad wall 11 in a direction normal to that wall 11.

In operation, the arrangement shown in FIGS. 1-3 may be employed as a switch for selectively controlling the transmission of microwave energy between the input terminal 17 and the output terminal 18 of the rectangular waveguide 10. When the switching current source 40 provides a pulse, it is desired that energy transmitted along the rectangular waveguide 10 be highly attenuated in the direction toward the output terminal 18, thus effectively opening the switch. The arrangement shown is such that an extremely low insertion loss exists when there is zero magnetic field in the ferromagnetic slab

20. This may be explained by considering that although the ferromagnetic slab 20 introduces a protuberance into the waveguide, and although the geometry of the ferromagnetic element 20 is relatively thick in the direction transverse to the broad waveguide walls 11 and 12, a geometry for the ferromagnetic slab 20 exists which does not set up disturbing reflections. In what may be called the ferrite mode the energy concentration in the ferromagnetic element 20 is such that the energy is principally displaced to the side of the waveguide 10 containing the ferromagnetic slab 20. This may be seen particularly in FIG. 7, in which the electric field distribution is shown in the magnetized and unmagnetized states. Accordingly, the tuning mode screws 50 do not extend into a region which materially affects the insertion or reflection losses. For this reason, the energy transmission in the unmagnetized state is accompanied by little attenuation.

When the winding 30 is actuated by a signal from the switching current source 40, however, a magnetic field is set up within the closed loop in the ferrite slab 20 such that the modes of energy within the waveguide 10 are materially affected. Only a relatively small number of ampere turns are needed to provide the desired attenuation. An arrangement in accordance with this invention has been constructed in a waveguide of 0.4" by 0.9", for operation in the frequency region between 9,000 mc. and 9,500 mc. The ferromagnetic slab was 2" long and 0.4" high, with a thickness of 0.130". With this arrangement, ten turns of wire in the winding 30 were employed. This number of turns in this arrangement resulted in an inductance of approximately 15 microhenries. The arrangement was placed against the adjacent narrow wall 14.

While the phenomenon under which such an arrangement operates to switch microwave energy is not completely understood certain explanations may be given. Thus, the behavior of the phenomena involved is strongly suggestive of reflective type losses within the ferromagnetic slab 20. These losses are achieved despite the fact that the ferromagnetic material is magnetized at a level below gyromagnetic resonance. It is assumed, therefore, that the losses which are encountered are due either to multiple reflections within the waveguide or internal reflections within the ferromagnetic slab 20.

Explanations may be offered in terms of bridge circuit and coupled mode theory, which indicates a similar behavior. In the bridge circuit description, at least two propagating modes with phase constants are considered to exist in the ferrite loaded waveguide. The presence of tuning mode screws 50 in the waveguide 10 enables these modes to couple to each other. For certain lengths and thicknesses of ferromagnetic slab 20, these modes are equal and out of phase at the end of the ferrite loaded section. Such modes are illustrated by the pair of modes shown for the magnetized condition in FIG. 7. As a result, there is complete cancellation of energy in this situation and total reflection of energy from this point back toward the input terminal.

In the coupled mode description, the results of tight-coupling theory apply when the coupling is uniform along the direction of wave propagation. Again it is considered that the field distributions of FIG. 7 are present. This theory shows that a periodic exchange of energy takes place provided that the attenuation and phase constants are both equal or provided that the phase constants are equal and the difference between the attenuation constants is small compared to the coefficient of coupling. The length and thickness of the ferromagnetic slab 20 are so chosen that complete transfer of energy from a fundamental ferrite waveguide mode to one of the many higher order ferrite modes takes place. The presence of tuning mode screws 50 in the waveguide 10 affects the coupling by modifying the phase constants of the higher order ferrite modes with respect to the fundamental waveguide modes. At the

end of the section containing the ferromagnetic slab 20, the higher order ferrite modes are reflected because of the different impedance characteristics of the rectangular waveguide TE₁₀ mode. In the reverse direction, complete transfer of energy to another ferrite mode is possible because the phase constants of the two modes which exchanged energy in the forward direction can be entirely different in the reverse direction. Multiple reflections within the ferromagnetic slab 20 are, consequently, possible due to continuous changes of energy between the high order ferrite modes.

The coupling mechanism between the modes may also be achieved by the use of dielectric loading. A dielectric loading member (not shown) may be positioned within the waveguide adjacent the ferromagnetic slab 20. The shape and size of the member would be dependent, as is the use of the tuning mode screws, on the frequency and operating requirements involved.

With the arrangement constructed as shown in FIG. 1, it had been found that pulse attenuation of more than 25 db may be obtained for a specific frequency. Attenuation of at least 18 db may be obtained over a 30 megacycle bandwidth without modification of the tuning mode screws 50 or the driving current conditions. If it is possible to vary the current pulse with the operating frequency (a condition which can often readily be obtained) similar attenuations can be provided for more than a 100 megacycle bandwidth. The rapid attenuation which results is limited principally by the effectiveness of characteristics of the applied driving pulse. This is illustrated graphically in FIG. 4, in which the applied pulse may be compared in time to the attenuation afforded by the device. It will be noted that the rise and fall of the attenuation is very similar in form to the applied pulse, and that the delay between the attenuation and applied pulse is virtually imperceptible. A switching speed of less than 0.1 microsecond has been achieved. Accordingly, this arrangement may be employed for a great variety of switching purposes in which the speed of operation has heretofore been critical.

Optimum tuning of the arrangement of FIG. 1 may be achieved by controlling the extent of insertion and use of the tuning mode screws 50. If only specific frequencies are to be involved, the tuning mode screws 50 need not be used or may be reduced in number. With the arrangement of FIG. 1, a driving current was employed of about 30 ampere turns. The ferromagnetic slab 20 was positioned against the adjacent narrow waveguide wall 14. It is also possible, however, to move the ferromagnetic slab 20 toward the center of the waveguide 10 to some extent. Generally speaking, the inward movement of the ferromagnetic slab 20 in the waveguide 10 lowers the frequency at which maximum attenuation will occur. A slight displacement of the ferromagnetic slab may effect substantially the same operation with less driving current. When the ferromagnetic slab 20 was placed 0.003 inch from the closed narrow wall 14, for example, approximately the same attenuation and bandwidth characteristics were provided with only 20 ampere turns of driving current.

The thickness of the ferromagnetic slab 20 is a material departure from the arrangements of the prior art. In prior practice, it was considered that a vanishingly thin ferromagnetic element positioned at a point of particular microwave polarization would best operate to provide attenuation. In the present arrangement, however, the thickness of the slab which is employed is appreciably greater. The insertion and reflection loss is minimized and the attenuation is achieved, apparently through the concentration of the electric fields and the establishment of coupling modes in the magnetized state, in the manner discussed above. Another critical departure from the prior art is in the use of the closed loop internal to the waveguide and defined by the thick ferromagnetic slab 20. This arrangement not only sets up the effects which

enable the high speed operation with low power, but also makes possible the use of very low driving currents. A further departure is in the employment of magnetic fields through the ferromagnetic slab 20 which are considerably below the gyromagnetic resonance level. The reflective type losses which are considered to be present are a different phenomenon than is encountered with other forms of ferromagnetic devices. An additional significant departure is the employment of a coupling mechanism, such as the tuning mode screws in the arrangement of FIG. 1 or dielectric loading. This coupling mechanism introduces no perturbation of wave energy at zero magnetic field, but in combination with the magnetized ferromagnetic slab 20 results in the energy coupling effects which provide improved attenuation over a broader band of frequencies.

A further advantage lies in the use of the thick ferromagnetic slab 20. The greater surface and contact areas of the slab 20 provide greater heat dissipation and conduction, with consequent greater stability and reliability. Arrangements in accordance with the invention may also be employed as far as shifters. Such an arrangement may be achieved, for example, by using the arrangement of FIG. 1 without the tuning mode screws 50 when operated in the phase shift mode of operation, the device would operate as does the transverse field phase shifters of the prior art, including the devices described in the above referenced article. Briefly, a change in the permeability of the ferromagnetic element due to a change in the magnetic field therethrough results in a change of the speed of propagation of the energy along the waveguide 10. The change in speed of propagation, of course, results in a phase shift of energy transmitted along the waveguide. In this device, using the coupling analogy given above both of the modes are propagated together and the overall result is the change of propagation constant of the device because of the change in the real part of the permeability, which is a function of the applied magnetic field. The coupling effect between the regular and higher order modes is not involved, so that no coupling mechanism need be employed.

A different type of phase shifter may be employed in accordance with the invention, as shown in FIG. 5, to which reference may now be made. As shown in FIG. 5, a ferromagnetic slab 26 may be positioned along the longitudinal axis of a rectangular waveguide 10 adjacent a broad wall 12 thereof. While phase shift effects can be provided with a ferromagnetic slab positioned asymmetrically with respect to the broad wall, in the present instance a preferable arrangement is to employ the ferromagnetic slab 26 in a position symmetric with the broad walls 11, 12 of the waveguide 10. The central aperture 27 of the phase shifter slab 26 is in this instance along the length and the direction of elongation of the slab 26. The leading and trailing edges of the slab 26, from the standpoint of the edges presented to energy transmitted along the waveguide 10, are tapered to thin edges 28 to the slab 26 has a closed rectangular loop about the central aperture 27, but in this instance the loop extends around the length dimensions of the slab 26. To provide magnetic fields around this rectangular loop which extend principally along the length of the ferromagnetic slab, a winding 30 may be placed around one of the longer legs 29 of the slab 26. This may be the longer leg 29 which, as shown, is adjacent the associated broad waveguide wall 12. A driving current may be provided, as with FIG. 1, from a current switching source 40, through coupled leads 31, 32.

In operation, the arrangement of FIG. 5 effects a phase shift in the manner described above, by changing the propagation constant of the waveguide 10 upon the application of a driving pulse from the source 40. As with other devices of this nature, the magnetic field extending longitudinally through the centrally positioned ferromagnetic slab 26 determines the extent of the phase shift

within the slab. Again, the modes are propagated together and no coupling mechanism is needed. Apart from the geometrical differences in the ferromagnetic slab 20 used in FIG. 1, the phase shifter arrangement of FIGS. 5 and 6 is a considerably longer length along the waveguide 10. It has been found that with a four inch ferromagnetic slab 26 phase shifts of up to 600° could be attained. The presence of a closed rectangular loop within the waveguide 10 again makes possible rapid pulsed phase shift operation and the use of lower driving currents.

It may be seen that the term switching is employed herein to designate operations in which energy transmitted within a waveguide is either permitted to pass through the waveguide virtually unaffected or is blocked from passage. With phase shifter arrangements, this same switching result is achieved through the use of accompany devices, such as hybrid T junctions. A wide variety of microwave devices, such as to position mechanically operated switches, waveguide shutters, TR tubes and other devices perform these general functions.

Thus there has been described an improved device for controlling the transmission of microwave energy. The device is extremely compact but is simple to construct and may be operated with low driving currents. By permitting minimization of driving current and by using a structure which has superior heat conductivity, the arrangement provides advantages for attenuation, switching and phase shifting arrangements.

We claim:

1. A high speed switch for microwave energy comprising a section of rectangular waveguide having broad and narrow walls for propagating microwave energy in a fundamental mode, a substantially thick ferrite slab mounted in said waveguide transversely between said broad walls and extending parallel and substantially adjacent to one of said narrow walls, means for selectively magnetizing said slab, and conductive tuning means extending into said waveguide through one of said broad walls and disposed between the centerline of said waveguide and the other one of said narrow walls.

2. A high speed switch for microwave energy comprising a section of rectangular waveguide having broad and narrow walls for propagating microwave energy in a fundamental mode, a substantially thick ferrite cylinder having broad and narrow walls, the broad walls thereof being disposed transverse to the broad walls of said waveguide and one of the broad walls thereof being positioned substantially adjacent to one of the narrow walls of said waveguide, a conductive winding encompassing a broad wall of said cylinder and being wound thereabout in a direction to provide a magnetic field transverse to the broad walls of said waveguide, means coupled to said winding for selectively applying a current thereto to provide a magnetic field, and a plurality of conductive screws positioned on the opposite side of the centerline of said waveguide from said cylinder.

References Cited in the file of this patent

UNITED STATES PATENTS

2,197,122	Bowen	Apr. 16, 1940
2,629,774	Longacre	Feb. 24, 1953
2,760,166	Fox	Aug. 21, 1956
2,811,697	Hogan	Oct. 29, 1957
2,848,688	Fraser	Aug. 19, 1958
2,849,683	Miller	Aug. 26, 1958
2,849,684	Miller	Aug. 26, 1958
2,849,685	Weiss	Aug. 26, 1958
2,853,687	Weber	Sept. 23, 1958
2,908,878	Sullivan et al.	Oct. 13, 1959
2,948,864	Miller	Aug. 9, 1960
2,956,245	Duncan	Oct. 11, 1960

(Other references on following page)

FOREIGN PATENTS

165,097 Australia ----- June 17, 1954

OTHER REFERENCES

Ragan: Microwave Transmission Circuits, McGraw-Hill, 1948, pp. 485-489.

Weiss: IRE Transactions on Microwave Theory and Techniques, October 1956, pp. 240-243.

Terman: Electronic and Radio Engineering, 4th ed., copyright 1955, pp. 148-150.

Blasberg et al.: Microsecond Ferrite Microwave Switch, presented at Wescon August 20-23, 1957, abstract in the IRE Wescon Convention Record, part I Microwaves, Antennas and Propagation, on p. 70.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,022,475

February 20, 1962

Lawrence A. Blasberg et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 7, line 57, after "edges 28 to" insert -- provide smooth microwave energy transitions. Thus --.

Signed and sealed this 23rd day of October 1962.

(SEAL)

Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents