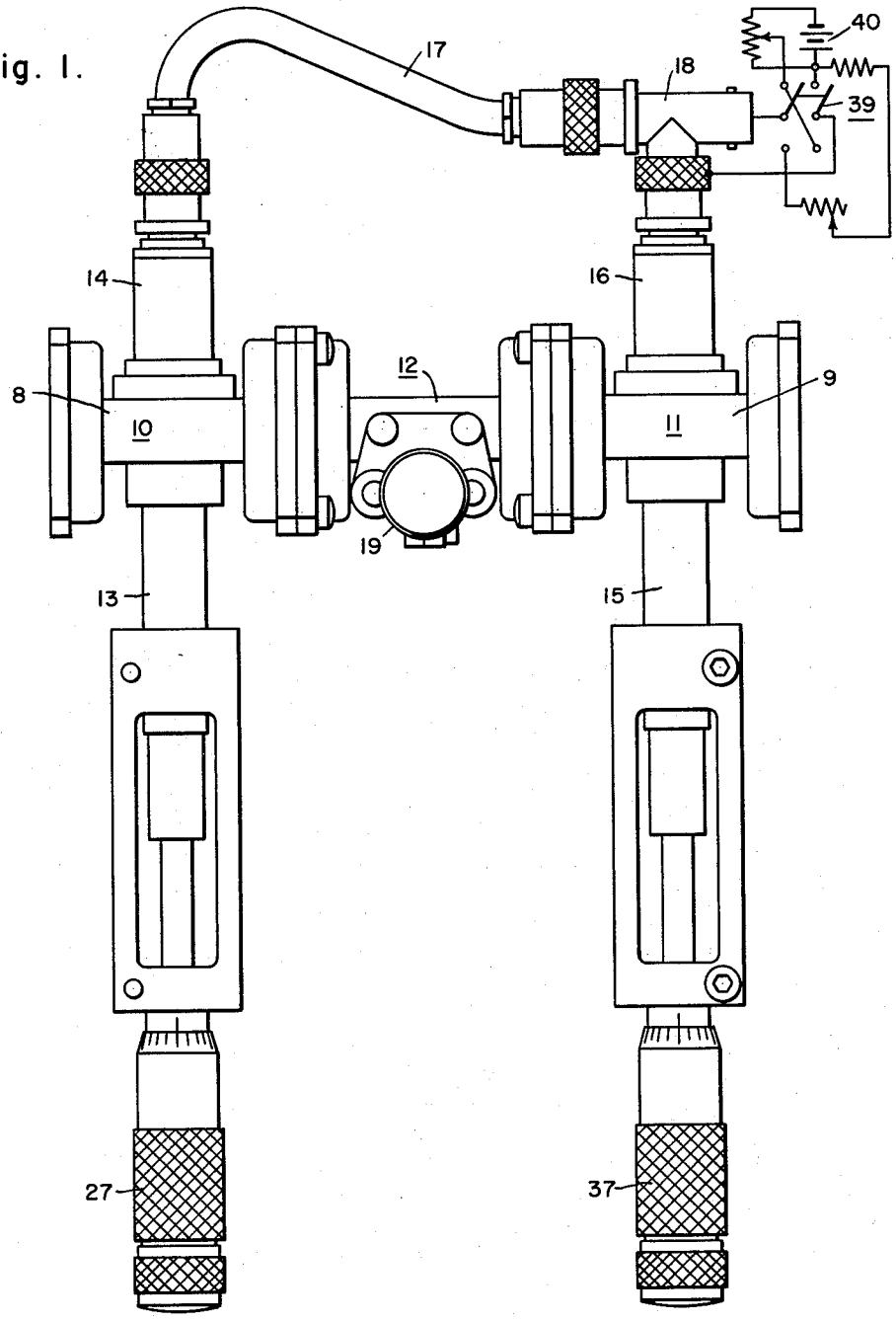
June 9, 1964 D. W. FELDMAN ETAL 3,136,963

HIGH SPEED MICROWAVE SWITCH HAVING BYPASS MEANS FOR CANCELLING SIGNAL LEAK DURING BLOCKED CONDITION

Filed July 6, 1960 4 Sheets-Sheet 1

Fig. 1.



WITNESSES

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Fig. 3A.

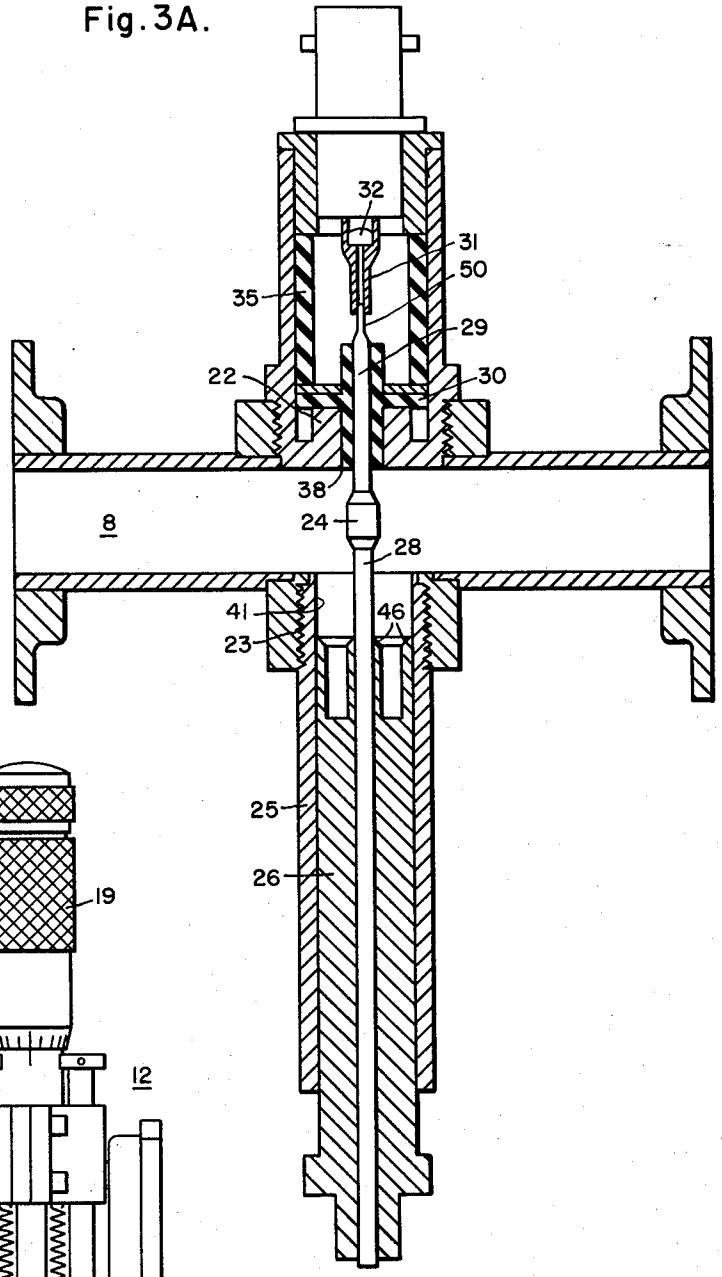


Fig. 2.

Fig. 3B.

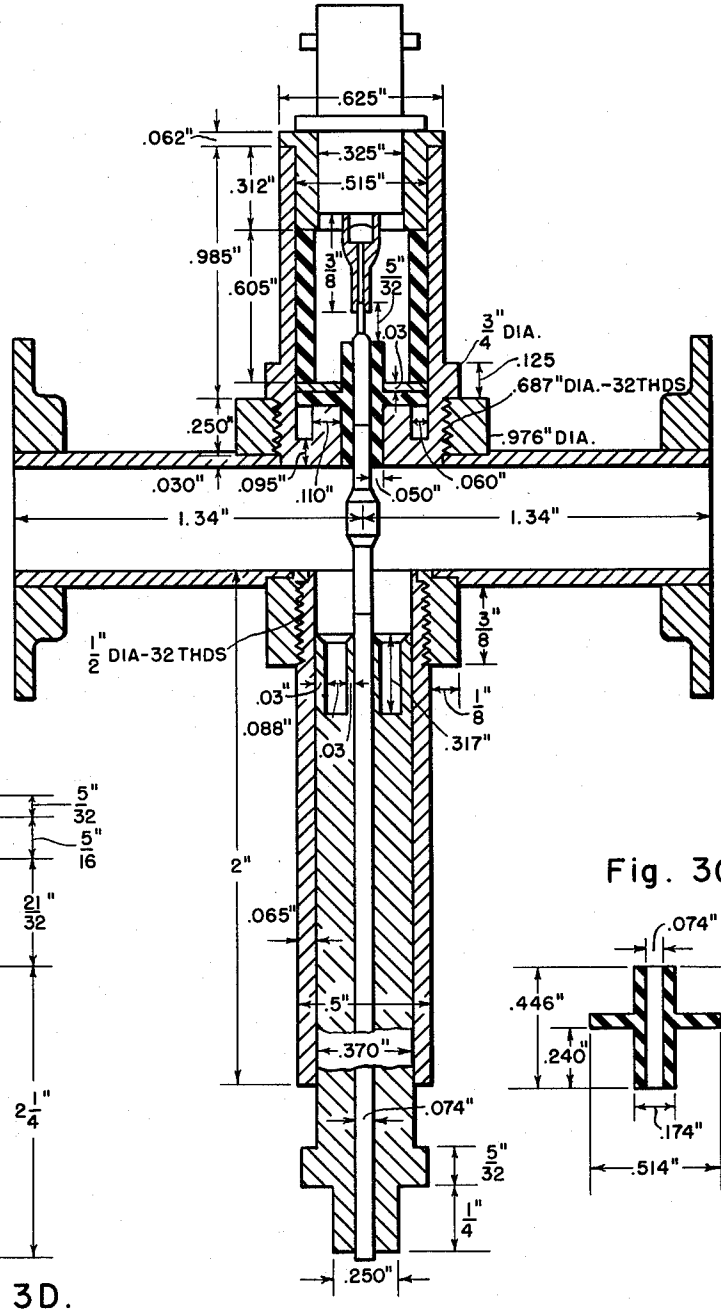


Fig. 3D.

Fig. 3C.

Fig. 4.

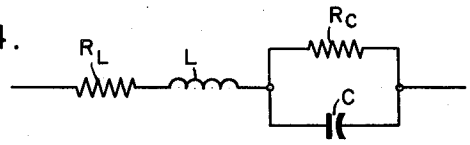


Fig. 5.

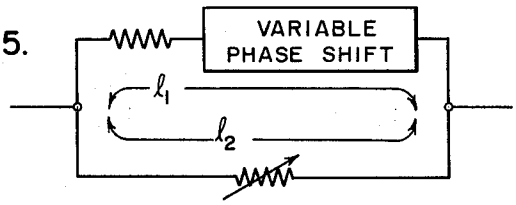


Fig. 6.

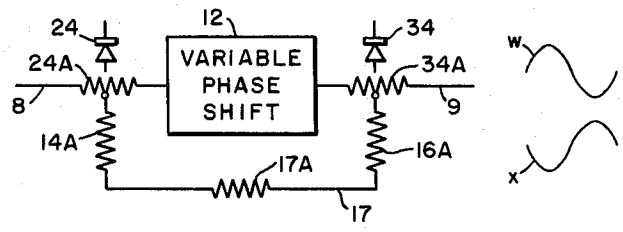
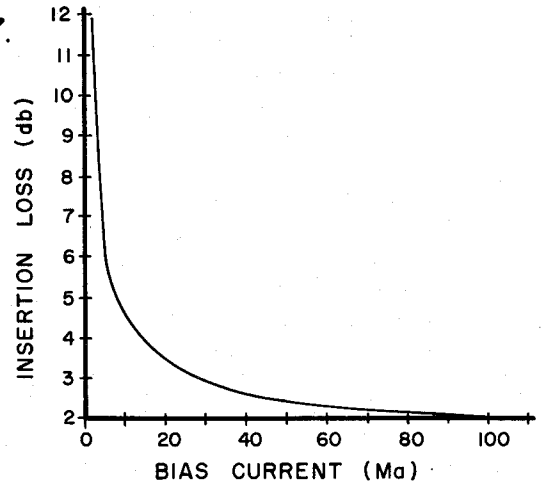


Fig. 7.



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3,136,963

HIGH SPEED MICROWAVE SWITCH HAVING BY-PASS MEANS FOR CANCELLING SIGNAL LEAK DURING BLOCKED CONDITION

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8 Claims. (Cl. 333—7)

This invention relates to improvements in microwave switches, and more particularly to an improved high speed microwave switch employing a plurality of semiconductor diodes mounted in a waveguide and having the biases on the diodes selectively varied between forward and reverse directions to control the transmission of wave energy through the waveguide and switch from an "on" condition in which energy is transmitted without substantial attenuation to an "off" condition in which great attenuation in excess of 100 decibels is obtained.

Many prior art microwave switches do not have the necessary requirements of both high speed and sufficient attenuation. A conventional TR switch is unsatisfactory in that it does not provide sufficient attenuation over a broad tunable band and does not completely recover within a specified time, for example, one microsecond. In our experience, two readily available commercial ferrite switches used in tandem do not provide sufficient attenuation even when used in conjunction with a TR switch, and further, have an insertion loss of —6 decibels; attainment of high speed was found to be very difficult.

The switching apparatus of the invention overcomes the disadvantages and limitations of TR and ferrite switches by employing a pair of semiconductor diodes in a waveguide microwave interference device having phase shifting means interposed between the diodes, and providing a shunt coaxial transmission line path for bringing an attenuated signal to be used for wave cancellation purposes at the second diode.

It has been known in the prior art that the energy transmission through a microwave waveguide may be controlled or varied by mounting a semiconductor diode within the waveguide and electrically connecting the diode so that the bias thereon may be varied between forward and reverse directions. The diode has a certain capacity between the elements thereof, and the resistance of the diode, which is effectively in shunt with the diode capacitance, varies markedly between forward bias and reverse bias conditions. The leads to the diode have a certain inductance and resistance, so that the diode and leads have a certain impedance while the diode is biased in a forward direction, and form a series resonant circuit while the diode is biased in a reverse direction, due to the fact that the shunt resistance across the diode capacitance becomes very high and the diode capacitance becomes effective to, in series with the lead inductance, form a series resonant circuit of low impedance. The impedance of the crystal and leads is effectively in shunt with the waveguide impedance. A certain impedance transformation can take place within the waveguide and switch; the diode can offer or be made to offer a very small impedance in one bias condition and in the other bias condition can be made to offer a large and considerable impedance at the frequency of the electromagnetic wave so that in effect the reverse-biased diode causes a large mismatch with accompanying reflection and attenuation of the energy in the waveguide, whereas the forward biased diode results in a small mismatch and small insertion loss.

For a discussion of the use of semiconductor diodes in waveguide switches, reference may be had to an

article by M. Bloom, entitled "Microwave Switching With Computer Diodes," appearing in "Electronics," January 15, 1960, pp. 85–87.

It is also old in the art to utilize two diodes in one waveguide structure, the diodes being spaced apart from each other by a predetermined wavelength or portion of a wavelength. Such a device is shown in an article by Garver, Spencer, and Harper, entitled "Microwave Semiconductor Switching Techniques," appearing in the IRE Transactions on Microwave Theory and Techniques, October 1958, pages 378 to 383. The last mentioned article appears to represent the present state of advance in the art, and it does not provide for attenuation in an amount appreciably greater than the sum of the attenuations obtained by the two diodes considered separately, that is, the total attenuation is equal to the sum of the individual attenuations plus a very small and insignificant amount, as shown by the curves of FIG. 4 of the article, where a maximum attenuation of 55 decibels is indicated.

As previously stated, the apparatus of the instant invention employs two diodes disposed in a waveguide and separated by a phase shifter, the waveguide and phase shifter providing a first path for wave energy between the two diodes. Coupled into the waveguide at substantially the diode points is a second wave energy transmission path, so that in effect a bridge circuit is formed, in which the effective length through one path between diodes may be varied by varying the adjustable phase shift, thereby providing for interference at the second diode and providing a microwave semiconductor switch characterized by an attenuation many times that obtainable in prior art waveguide switches, for example four orders of magnitude greater attenuation. The waveguide switch of the instant invention exhibits very small insertion loss; it may be tuned easily over a large microwave frequency band; and it has very fast switching characteristics.

Accordingly, a primary object of the instant invention is to provide a new and improved high speed microwave switch.

Another object is to provide a new and improved microwave switch employing semiconductor diodes.

Still another object is to provide a new and improved microwave switch utilizing semiconductor diodes and providing increased attenuation while the device is switched to an "off" condition.

A further object is to provide a new and improved tunable microwave semiconductor diode switch which may be tuned over a broad wave band.

A still further object is to provide new and improved microwave semiconductor diode switching apparatus in which the apparatus while switched to a circuit "on" condition provides only a very small insertion loss.

These and other objects will become more clearly apparent after a study of the following specification, when read in connection with the accompanying drawings, in which:

FIGURE 1 is a front elevation of apparatus embodying the invention;

FIG. 2 is a bottom view of the phase shifter of FIG. 1;

FIGS. 3A and 3B are a cross section through one of the diode switch portions of the waveguide structure;

FIGS. 3C and 3D are detail views;

FIG. 4 is the equivalent electrical circuit of a diode;

FIG. 5 is a diagram illustrating the operation of the apparatus of FIG. 1;

FIG. 6 is a simplified diagram helpful in describing the operation of the apparatus of FIG. 1; and

FIG. 7 is a graph illustrating the operation of the apparatus of FIG. 1.

Referring now to the drawings for a more detailed understanding of the invention, in which like reference

numerals are used throughout to designate like parts, and in particular to FIG. 1, there are shown at **10** and **11** two microwave waveguide semiconductor switches separated by a variable phase shifter generally designated **12**. The waveguide structure has input portion **8** and output portion **9**. The microwave semiconductor switch **10** includes, as will become more clearly apparent from the view of FIG. 3A, a variable impedance in the form of a shorted co-axial line, the length of which may be adjusted by the micrometer control **27**, this portion of the semiconductor switch being designated **13**. A diode, not shown in FIG. 1, and hereinafter to be described more fully, is mounted in the waveguide switch **10**, and the waveguide switch **10** also includes coaxial line coupling means generally designated **14**, this portion **14** including a radio frequency choke and lead means for applying direct current biasing potentials of selected polarity and predetermined amplitudes to the aforementioned diode, not shown in FIG. 1. The other semiconductor switch **11** has a shorted coaxial line portion **15**, the length of which is controlled by the micrometer device **37** shown, and a coaxial line coupling portion **16** including a radio frequency choke portion and conductor means for applying a biasing potential to a diode, not shown in FIG. 1, disposed in the switch **11**. The portions **14** and **16** are interconnected by a coaxial cable **17**, the coaxial cable **17** having a suitable characteristic impedance and preferably being of a low loss variety, the coaxial cable **17** having a connector **18** thereto which is adapted to be connected by way of suitable switching means symbolized by **39** to a source or sources of direct-current potential **40** for selectively applying reverse biases and forward biases simultaneously to the two aforementioned semiconductor diodes in switches **10** and **11**.

Particular reference is made now to FIG. 2 in which a bottom view of the aforementioned phase shifter is shown. The variable phase shifter **12** is seen to have means **19** for adjusting the phase shift and suitable means **20** for calibrating or indicating the adjustment of the device. The phase shifter may be of conventional design and may comprise a dielectric slab within the waveguide, extending along the Z axis and being perpendicular to one inner surface and parallel to the other, the slab being movable across the waveguide, the position of the slab being carefully controlled by knob **19** and the position indicated with precision by the indicator device **20**.

Particular reference is made now to FIG. 3A which shows a cross section through the waveguide switch **10** and the waveguide switch **11**, which may be substantially identical to each other. A diode **24** is shown mounted in the semiconductor switch **10**. The shorted coaxial line portion is seen to include a sleeve member **25** firmly attached to the remainder of the waveguide structure as at **23** and having slidable or movable therein the member **26** under the control of the micrometer head **27**, FIG. 1. It will be seen that member **26** has contact spring portions **46** so that movement of member **26** within the sleeve **25** changes the effective length of the connector portion **28** forming one conductor to the aforementioned diode **24** and the effective length of inner wall **41** thereby providing a shorted coaxial line of adjustable length; the impedance may be varied by adjusting the micrometer setting. This variable impedance which is in series with the diode in the form of the aforementioned shorted coaxial line enables the user of the apparatus to obtain optimum switching loss over substantially the entire waveguide band. The insertion loss, as will be seen more clearly hereinafter, is not appreciably affected by the tuning technique of the shorted coaxial line of adjustable length.

Members **30** and **35** may be composed of an insulating material known in the trade as electrical grade Teflon having a dielectric constant of the order of 2. All metallic parts may be brass or copper or silver.

The portion **22** forms a radio frequency choke, and it is seen that the upper contact rod member **29** for diode **24** is slidable within the fitting or member **30** and has a portion of reduced diameter **50** slidable in a conducting member **31** attached to the center conductor **32** of a coaxial line connector which, as previously explained, is coupled by a coaxial line **17**, shown in FIG. 1, to the other microwave switch **11**, and which is also connected to a suitable source of direct-current biasing potential for the diode **24** and a second diode **34** which it is understood is mounted in the other semiconductor switch **11**. The diode **34** is shown in FIG. 6 which will be presently considered. Whereas the direction of transmission through the apparatus of FIG. 1 is immaterial, for the purposes of the following description of the invention, wave energy will be presumed to be flowing from left to right in FIG. 1.

It will be seen that the structure shown in FIG. 3A and described in connection therewith serves the dual function of connecting the diode effectively in shunt with the waveguide by way of the variable impedance of the adjustable shorted coaxial stub, and also functions as a coupler for coupling the coaxial transmission line to the waveguide. In addition, attenuation in the coaxial connection is provided. For a fuller discussion of coupling between waveguides and coaxial lines, reference may be had to "Microwave Transmission" by Slater, McGraw-Hill Book Co., 1942, pp. 280–304; for a fuller treatment of shorted coaxial lines for impedance transformation, reference may be had to any standard text and to "Reference Data for Radio Engineers," 3rd Ed., Federal Telephone and Radio Corp., 1946. It will be seen also that in the semiconductor switch **10** an aperture **38** is formed in the wall of the waveguide, this aperture playing an important role in the operation of the radio frequency choke of the device.

The dimensions of the switch structure shown in FIG. 3B are suitable for a 9.3 kmc. design point center frequency.

Particular reference is made now to FIG. 4 in which the equivalent circuit of the diode **24** is shown. The diode **24** may be a point contact diode in which the diode has a diode capacitance C in accordance with the materials and dimensions thereof, as will be understood by those skilled in the art. The diode while biased in a forward direction also has a very low resistance R_C, as will be understood by those skilled in the art, whereas the connections to the diode provide a lead inductance L and the leads and other connections to the diode also have some resistance, the value of which is indicated by the resistor R_L in FIG. 4. It will be readily seen that while the diode is biased in a forward direction, the value of R_C is very low, which effectively shunts the diode capacitance C so that this portion of the circuit of FIG. 4 looks in effect like a very low impedance with substantially no capacitative reactive component. The lead inductance L of the diode with its equivalent resistance R_L results in an impedance which can be transformed easily to the impedance of the waveguide. This impedance transformation it is understood is accomplished by the dimensions and configuration of the switch itself and also the shorted coaxial line of adjustable length may provide for adjustable impedance transformation. The result is that the impedance of the diode while the forward bias is supplied thereto is transformed substantially to that of the waveguide, resulting in a very small radio frequency loss due to mismatch nad resulting reflection.

Assume now by way of description that a reverse bias is applied to the diode **24** by way of the connections **28** and **29** member **31** and coaxial cable center conductor **32**. It will be understood that the direct-current potential on connector **32** is applied with reference to the metallic portion of the waveguide completing an electrical circuit at diode **24**. While a reverse potential is supplied to the diode, the resistor R_C is made very large and

as a result the capacity C of the diode becomes effective. L and C then comprise a series resonant circuit of an impedance substantially less than that of the waveguide, and since the impedance transformation ratio is unchanged during the switching operation, this series resonant circuit with its low impedance results in a large reflective loss.

The reverse biasing potential applied to the diode **24** may be 30 volts; the forward bias may be one volt or less to provide a forward bias current of approximately 50 milliamperes per diode. Switch **39** and battery **40** in FIG. 1 are merely symbolical; in practice, the diodes may be pulsed at any repetition rate from a cathode follower pulse source, the circuit providing for a bias of the other polarity between pulses.

In the apparatus of the instant invention, the coaxial tuning feature of each semiconductor switch is provided to compensate for differences in the diode characteristics at a chosen operating frequency, so that equal attenuation is obtainable in the two paths, and also so that the relative phase shift of the two paths is such as to cause destructive cancellation at the second diode. It will be readily understood that the phase shifter **12** allows a continuous change in the effective separation of the diodes **24** and **34**.

For a more detailed understanding of interference at the output of a device having multiple transmission paths, reference may be had to a work by Montgomery, Dicke and Purcell, entitled "Principles of Microwave Circuits," being volume 8 of the Radiation Laboratory Series, McGraw-Hill Book Co., Inc., New York, 1948, chapter 6.

Particular reference is made now to FIG. 5 which generally illustrates the manner in which large attenuations can be obtained in the manner described. In FIG. 5, the following formulas for interference condition apply:

$$\frac{2\pi l_1}{\lambda_1}=\frac{2\pi}{\lambda_1}(n_1\lambda_1+\Delta_1)$$

$$\frac{2\pi l_2}{\lambda_2}=\frac{2\pi}{\lambda_2}(n_2\lambda_2+\Delta_2)$$

$$\lambda_1=K\lambda_2$$

$$\phi=2\pi\left[\left(n_2+\frac{\Delta_2}{\lambda_2}\right)-\left(n_1+\frac{\Delta_1}{K\lambda_2}\right)\right]=\pi$$

where

λ_1=wavelength in path 1, FIG. 5.
λ_2=wavelength in path 2, FIG. 5.
n_1=number of wavelengths (λ_1) in path 1
n_2=number of wavelengths (λ_2) in path 2
Δ_1=fractional wavelength in path 1 in addition to integral wavelengths.
Δ_2=fractional wavelength in path 2 in addition to integral wavelengths.
K=constant relating transmission line wavelengths in path 1 and path 2.
ϕ=phase angle

FIG. 7 to which particular attention is directed is a graph showing insertion loss as a function of bias current while the diodes are biased in forward directions. Where the diodes are of a type known in the trade as IN419, the insertion loss (for both diodes) reaches a minimum of approximately 2 decibels for a bias current of 100 milliamperes. A further increase in bias current results in substantially no change in insertion loss. Operating in this region where a change in bias current does not change the attenuation eliminates noise and instability.

Particular reference is made now to FIG. 6, which shows a simplified equivalent circuit of the apparatus of FIG. 1. Resistors **24A** and **34A** represent the attenuations at the diodes **24** and **34** respectively of switches **10** and **11** respectively. Resistors **14A** and **16A** represent attenuations in couplers **14** and **16** respectively, and **17A** represents the small loss in the coaxial cable **17**. Because of phase shifter **12**, and the phase shift in the path of cable **17**, the energy represented by signal W reaching **9** by the path through the waveguide is 180 degrees out of phase with the signal X reaching **9** by the path through the coaxial cable **17**.

In the operation of the device, while diodes **24** and **34** are forward biased, the attenuation or insertion loss of 2 db results in no substantial reduction in signal amplitude through the waveguide path. However, attenuations at **14A** and **16A**, are at least 20 db each, or a total of 40 decibels; the signal arriving at **34** by coaxial cable path **17** has less than $\frac{1}{10,000}$ of the original signal amplitude, and although the signals arriving by the two paths are 180 degrees out of phase, no appreciable or noticeable cancellation takes place.

Assume now by way of description that diodes **24** and **34** are reverse biased, each then providing some 20 db attenuation; the signals arriving at **9** by the two paths (through the waveguide and coaxial cable) may closely approach each other in amplitude. Cancellation takes place because of the 180 degree phase difference, the cancellation being substantially complete, so that a total attenuation of over 100 decibels is obtained at output **9**.

In adjusting the device, with the diodes reverse biased a user of the apparatus adjusts the lengths of the shorted coaxial lines and the phase shifter for maximum attenuation.

The wave energy at input **8** may be in the waveguide principle mode, for example TE_{10}.

The apparatus of the instant invention has many possible fields of application:

(1) It may be used as a high-speed, high attenuation waveguide switch in radar applications and in microwave spectroscopy;

(2) It is especially applicable to the protection of easily saturable amplifiers such as a maser;

(3) It may be used as a type of band stop or band pass filter;

(4) It may be used as a continuously variable attenuator or modulator;

(5) In the region of low forward bias current, very low input power results in large attenuation changes which may extend the usefulness of the device to low power amplitude control or modulation circuits; and

(6) The use of more than two diodes would enable broad banding the attenuation or enable preselection of bands to be attenuated, by having the diodes tuned to individual frequencies with means for selecting pairs of diodes.

Whereas the device has been shown and described with respect to point contact diodes, it will be understood that other diodes including junction diodes may be employed if desired. As will be readily understood by those skilled in the art, when a junction diode has a reverse bias applied thereto, a depletion region is set up in the diode adjacent the junction, the depletion region providing capacitance which varies with the width of the depletion layer, and it will be readily understood that in a junction diode the value of capacity C in FIG. 4 may change as the bias is changed from a forward bias to a reverse bias condition. However, the transformed impedances in shunt with the transmission line under forward bias and reverse bias conditions may still have relative amplitudes similar to those previously described in connection with a point contact diode, so that under one bias condition the device transmits energy with very small attenuation or insertion losses, and under the other bias condition the device effectively switches the energy completely off. The junction diode has the advantage that it may be electrically tuned by varying the amplitude of a reverse bias potential.

Whereas the second path is shown as joining the first path at the diodes, the second path junctions could be before the first diode and after the second diode.

The term "microwave" as employed herein includes radio frequencies from 0.8 kmc. to 300 kmc.

Whereas a manually operated phase shifter is shown, an electrically operated phase shifter, such for example as a ferrite phase shifter, could be employed.

The first and second wave transmission paths may be provided by any type transmission line including waveguides of other shapes than the one shown.

The phase shift may be provided by means in the second path instead of the first, or the total desired phase shift provided as the sum of shifts in both paths.

Whereas the invention has been shown and described with respect to an embodiment thereof which gives satisfactory results, it will be understood that changes may be made and equivalents substituted without departing from the spirit and scope of the invention.

We claim as our invention:

1. A microwave switch comprising, in combination, waveguide means, a first semiconductor diode mounted in the waveguide means, a second semiconductor diode mounted in the waveguide means, variable phase shift means interposed in the waveguide means between the first and second semiconductor diodes, means forming an additional path for wave energy coupled between the first semiconductor diode and the second semiconductor diode, and first means and second means at the first and second semiconductor diodes respectively for varying the effective shunt impedances introduced into the waveguide means by the diodes to thereby provide substantially total destructive interference of wave energy at the output of the waveguide means and effectively cut off the flow of wave energy through the waveguide means.

2. Apparatus according to claim 1 additionally characterized as having means for selectively biasing both the first and second semiconductor diodes in forward and reverse directions, the change in the bias between the two directions effectively changing the equivalent impedances of the diodes, and additionally characterized as including impedance transforming means coupling the diode impedances in shunt with the impedance of the waveguide means, said first and second semiconductor diodes providing substantially lossless impedance matches and minimum attenuation while biases of one polarity are applied to the first and second diodes, said semiconductor diodes providing impedance mismatches with large reflection losses and maximum attenuation while biases of the other polarity are applied to the first and second diodes, said maximum attenuation resulting in substantially complete cancellation of wave energy at the output of the waveguide means thereby effectively switching the wave energy off.

3. Microwave switching apparatus comprising, in combination, a first semiconductor switch, a variable phase shifter, a second semiconductor switch, waveguide means connecting said first semiconductor switch, variable phase shifter, and second semiconductor switch in series in the order named to form a wave energy transmission path, said first semiconductor switch and second semiconductor switch including first and second semiconductor diodes respectively, means operatively connected to the first and second semiconductor diodes for selectively applying forward and reverse biases to the first and second diodes simultaneously, said first and second semiconductor switches being additionally characterized as including impedance transforming means operatively connected to the first and second diodes respectively and to the waveguide means for transforming the impedances of the diodes into impedances in shunt with that of the waveguide means, variations in the polarity of the bias between forward and reverse directions causing large variations in the impedances at the diodes thereby resulting in large variations in the shunt impedances at the waveguide means, the shunt impedances while the diodes are biased in one direction being substantially equal to the waveguide means impedance with no substantial resulting reflection loss, the shunt impedances while the diodes are biased in the other direction being substantially less than the waveguide means impedance and resulting in substantial reflection loss in the waveguide means and resulting in attenuation of the wave energy therein, and a coaxial transmission line including attenuating means interconnecting the first and second switches and providing a second path for the transmission of wave energy substantially 180° out of phase at the second semiconductor switch with the energy transmitted through the first-named path and phase shifting means thereby providing substantially complete cancellation of the wave energy at the second semiconductor switch.

4. A microwave switch comprising, in combination, waveguide means, a first semiconductor diode positioned within the waveguide means, a second semiconductor diode positioned within the waveguide means, variable phase shift means interposed in the waveguide means between the first semiconductor diode and the second semiconductor diode, means including a source of direct-current potential operatively connected to the first and second diodes for selectively biasing the first and second diodes simultaneously in forward directions and reverse directions, changes in the direction of bias changing the resistance in the diode and thereby changing the equivalent impedance of the diode, first and second impedance transforming means in the waveguide means operatively connecting the equivalent impedances of the diodes in shunt with the impedance of the waveguide means, said first and second impedance transforming means being variable, said impedance transforming means being adjusted whereby while the first and second diodes are biased in forward directions their equivalent impedances are transformed into impedances substantially equal to the impedance of the waveguide means whereby no substantial reflection losses are introduced into the waveguide means, said first and second diodes while biased in reverse directions having impedances which when transformed result in impedances in shunt with the waveguide means impedance which provide substantial mismatches and reflection losses thereby resulting in attenuation of a microwave signal in the waveguide means, first and second signal coupling means in the waveguide means at the first and second semiconductor diodes, and coaxial cable means interconnecting the first and second coupling means and providing a second path for the microwave signal between the first diode and the second diode, the signal arriving at the second diode by way of the second path being substantially 180° out of phase with the signal arriving by the first path thereby providing substantially complete cancellation of signal wave energy in the waveguide means and effectively switching the waveguide means off.

5. In microwave switching apparatus, in combination, waveguide means for the microwave energy, a first semiconductor diode mounted in a first predetermined position in the waveguide means, a second semiconductor diode mounted in a second predetermined position in the waveguide means, variable phase shift means in said waveguide means intermediate the first semiconductor diode and the second semiconductor diode, first variable impedance means in the waveguide means at the location of the first semiconductor diode for variably transforming the effective impedance of the first semiconductor diode to an effective first equivalent impedance in shunt with the waveguide means impedance at the location of the first semiconductor diode, second variable impedance means in the waveguide means at the location of the second semiconductor diode for variably transforming the effective impedance of the second semiconductor diode to an effective second equivalent impedance in shunt with the waveguide means impedance at the second semiconductor diode, first and second wave energy coupling means in the waveguide means at the first and second semiconductor diodes, wave energy conducting means interconnecting the first and second coupling means, and

means operatively connected to the first and second semiconductor diodes for selectively biasing the first and second diodes simultaneously in forward and reverse directions, the equivalent impedances of the first and second diodes varying as the biases thereacross vary from forward and reverse directions, said equivalent impedances being transformed into impedances in shunt with the impedance of the waveguide means, said shunt impedances varying from a first value substantially equal to the waveguide means impedance while a bias in one direction is supplied to said two semiconductor diodes to a second shunt impedance value small relative to the first value while a bias in the other direction is applied to the semiconductor diodes, said small impedance value resulting in a large mismatch and a large attenuation of energy in the waveguide means.

6. Microwave switching apparatus comprising wave guide means, first semiconductor switch means in said wave guide, second semiconductor switch means in said wave guide and electrically spaced from said first switch means by substantially an odd multiple of one-quarter wavelength corresponding to the operating frequency of said wave guide means, means forming an additional path for microwave energy coupled between said first and second switch means for the transmission of wave energy substantially in anti-phase relation at the second switch means with the wave energy in said first wave guide means; means, including variable impedance means, for simultaneously changing the attenuation in said wave guide means and the coupling of the wave energy from said wave guide means into said second path; and means for varying the effective shunt impedances introduced into the wave guide means by said switch means for selectively permitting substantially unattenuated flow of wave energy through said wave guide means and for reducing the flow of wave energy through said wave guide means for providing substantially total cancellation and effective cutoff of wave energy at the output of said wave guide means.

7. Microwave switching apparatus comprising wave guide means, first semiconductor switch means in said wave guide, second semiconductor switch means in said wave guide means forming an additional path for microwave energy coupled between said first and second switch means, the electrical length of the wave guide means between said switches and the electrical length of said second path being such that the wave energy at said second switch means is substantially in antiphase relation; means, including variable impedance means, for simultaneously changing the attenuation in said wave guide means and the coupling of the wave energy from said wave guide means into said second path; and means for varying the effective shunt impedances introduced into the wave guide means by said switch means for selectively permitting substantially unattenuated flow of wave energy through said wave guide means and for reducing the flow of wave energy through said wave guide means for providing substantially total cancellation and effective cutoff of wave energy at the output of said wave guide means.

8. Microwave switching apparatus comprising wave guide means, first semiconductor switch means in said wave guide means, second semiconductor switch means in said wave guide means, variable phase shifting means in said wave guide means interposed between said first and said second switch means to vary the electrical length of the wave guide between said switch means, means coupled to said wave guide means forming an additional path for transmitting microwave energy between said first and second switch means, the electrical length of said additional path being such that wave energy transmitted through said additional path will be substantially 180° out of phase at said second switch means with the wave energy transmitted through said wave guide means; means, including variable impedance means, for simultaneously changing the attenuation in said wave guide means and the coupling of the wave energy from said wave guide means into said second path; and means for varying the effective shunt impedances introduced into the wave guide means by said switch means for selectively permitting substantially unattenuated flow of wave energy through said wave guide means and for reducing the flow of wave energy through said wave guide means for providing substantially total cancellation and effective cutoff of wave energy at the output of said wave guide means.

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