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MICROWAVE SWITCH

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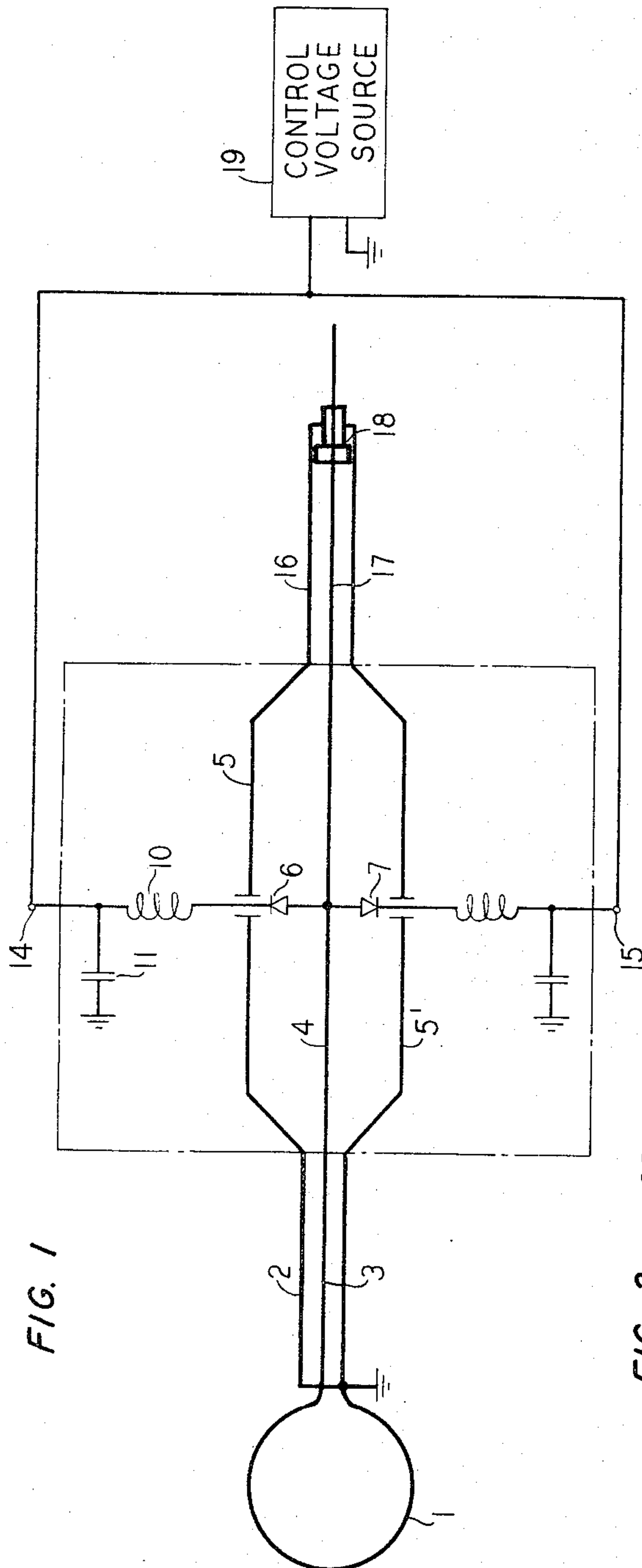


FIG. 1

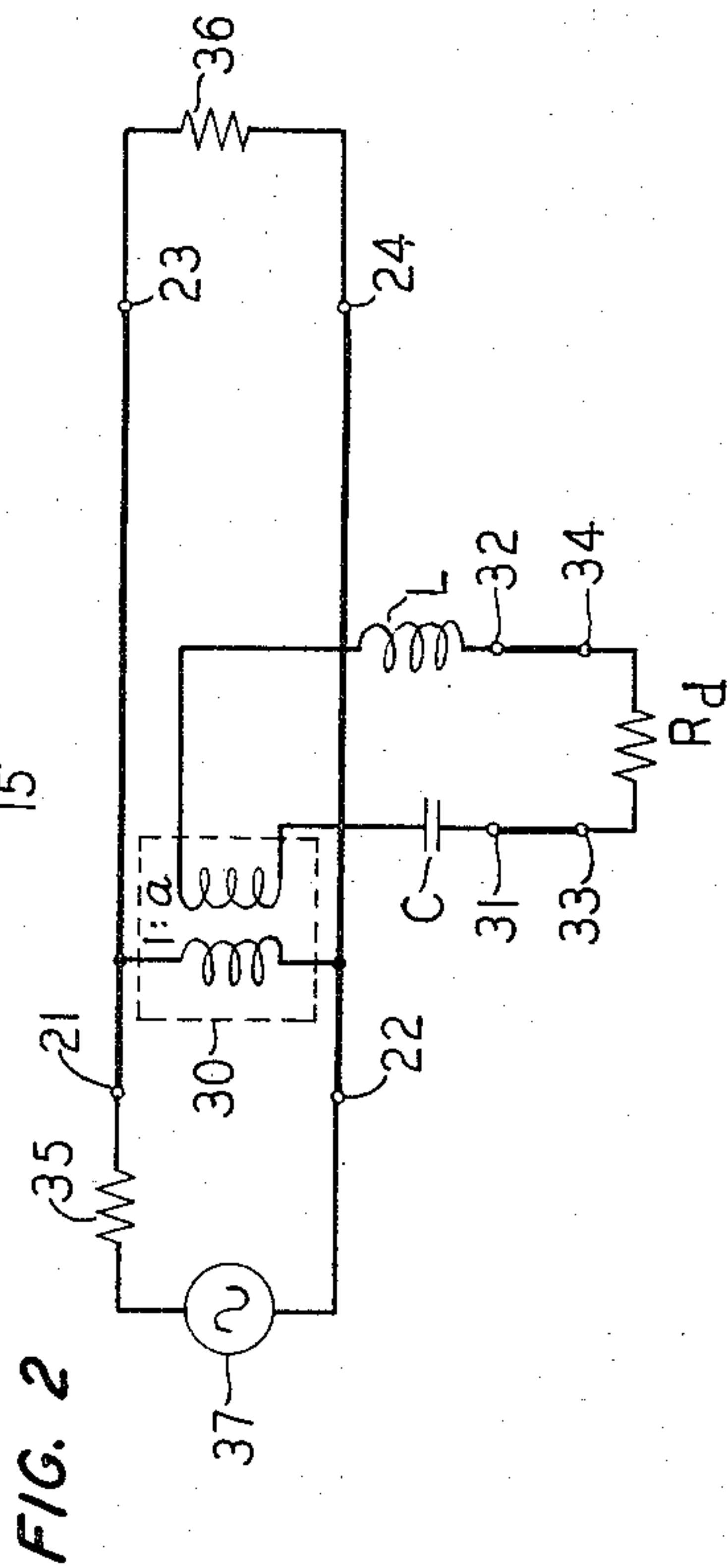


FIG. 2

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MICROWAVE SWITCH

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ABSTRACT OF THE DISCLOSURE

A high power microwave switch is disclosed having external ON-OFF control. The switch consists of a plurality of sections of diode switching elements coupled to a waveguide through a resonant loop. The diode elements are fixed an odd number of $\frac{1}{4}$ wavelengths from the loop in a transmission line having a short circuited stub which antiresonates with the diode impedance.

This invention relates to microwave frequency switching devices and more particularly to externally controlled high power microwave switches having an adjustable attenuation.

Frequently, as in duplexing systems, there is a requirement for a switching element to decouple one portion of the circuit from another during a specified interval. For example, in radar systems with pulse transmission and echo reception, it is the practice to couple both the receiver and the transmitter via a single transmission line to a single antenna. In such systems, to prevent damage to the receiver from high power transmitter signals, a transmit-receive or so-called TR switch is inserted in the receiver channel near the point of juncture of the common transmit and receive paths. To prevent loss of the received signal in the transmitter, it is decoupled by means of an antitransmit-receive or ATR device inserted in the transmitter path near the junction point.

Various types of microwave switches including those functioning as TR and ATR switches exist in the art. Some such switches commonly found in the art operate through the use of some breakdown means such as a gaseous atmosphere which ionizes a resonant cavity during the transmission of a high power pulse. Others have various other breakdown means included within a cavity or have a specially structured cavity which breaks down upon receipt of a high energy pulse to cause a reflection of transmitted energy and thus an attenuation of power in the direction of transmission.

A common problem occurring in prior art switches lies in the difficulty of constructing a device which has both the capability of passing high power with a minimum of switching loss and the ability to introduce a high attenuation in the transmission path when the switch is OFF. While some switches provide a high attenuation they do not efficiently pass high power energy when in the OFF condition. In addition, many of the prior art switches are constructed in a manner that would require for installation special and extensive modification of existing waveguide structures. Furthermore, many of the existing switches have no provision for externally controlling the switching action and no ability to vary the attenuation introduced.

Accordingly, it is a principal object of this invention to provide a microwave switching device with a high attenuation characteristic in the OFF condition along with the ability to pass high power with low loss in the ON condition.

It is another object of this invention to provide an externally controlled microwave switch having an attenuation which may be varied.

In accordance with the principal features of this inven-

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tion, these and other objects are achieved by providing a switch consisting of a diode switching element externally coupled to a waveguide transmission path through a resonant loop. The coupling between the diode switch and the terminals of the loop is external to the waveguide and consists of a transmission line having a length sufficient to present the diode impedance maximum and minimum at the loop terminals. Also connected to the diode switching element is an adjustable tuning stub providing an impedance which antiresonates with the back-biased diode impedance. The bias on the diode switching element is controlled by a bipolar control voltage which acts to either back-bias or forward-bias the diode switch to obtain, respectively, a very high impedance or a very low impedance. The diode impedance appears transformed at the loop terminals either as an approximate short or as an approximate open circuit by virtue of the transmission line interconnecting the loop with the diode switching elements. A very high impedance loop termination, or open circuit, permits the transmission of energy within the waveguide (defined as the ON condition for the switch), while a very low impedance, or short, at the loop terminals causes a reflection of transmitted energy and consequently an attenuation (defined as the switch OFF condition). The magnitude of attenuation can be controlled by adjusting the angle the loop plane makes with a reference plane in the waveguide.

A plurality of such switches can be arranged consecutively along the length of the waveguide transmission line so that mutual coupling exists between adjacent resonant loops. If the loops are separated by an ascertainable optimum distance, the total attenuation introduced by the composite group switches will exceed the attenuation introduced by summing the contribution of each switch. Furthermore, the power capabilities of the composite switch can be increased by increasing the number of individual switch sections.

The invention can be better understood if reference is had to the drawings in which:

FIG. 1 is a schematic representation of a single switch section;

FIG. 2 is an equivalent circuit of one switch section coupled to a waveguide;

FIGS. 3 and 3A are cross sectional views of a complete switch showing a number of such switch sections; and

FIG. 4 is an equivalent circuit of a composite switch having a number of switch sections coupled to the waveguide.

The schematic diagram of a single switch section shown in FIG. 1 includes a planar loop conductor 1 having a circumferential length of one wavelength measured in free space at the transmission frequency connected by means of a coaxial line having outer conductor 2 and inner conductor 3 to a strip line of matching impedance having ground planes 5 and 5' and center conductor 4. The ground planes 5 and 5' are both connected to the outer grounded conductor 2 of the coaxial line and the inner strip line conductor 4 is connected to the center conductor 3 of the coaxial line. Located within the strip line is a diode switch consisting of a pair of diodes 6 and 7 brought out from the center strip line conductor 4 through opposite ground planes 5 and 5' to voltage control terminals 14 and 15 decoupled from the transmission line. Each decoupling network consists of a low pass LC filter (such as choke coil 10 and capacitor 11) connected between a terminal and its respective diode. A D.C. control voltage source 19 is connected to terminals 14 and 15 to either forward-bias or back-bias diodes 6 and 7. Illustratively, a D.C. control voltage is applied to bias diode 6 over a circuit path which includes source 19, terminal 14, choke coil 10, diode 6, conductors 4 and 3,

loop 1 and ground. A similar circuit can be traced for the bias voltage applied to diode 7. A coaxial line having outer conductor 16 and inner conductor 17 and an adjustable shorted tuning stub is connected to the strip line with conductors 5 and 5' connected to outer conductor 16 and conductor 4 connected to conductor 17. The position of the adjustable short 18 is adjusted so that the reactive impedance presented by the line on the stub side of the diodes antiresonates with the back-biased reactive impedance of each diode to provide a very high resistive impedance for this condition. Coupling of the switch to a waveguide transmission line is accomplished by inserting only the loop 1 into the interior of the waveguide. All other portions of the switch section including the control source may be located outside of the waveguide.

In the embodiment disclosed in FIG. 1, the strip line section of the switch is shown for convenience only and may be replaced by a coaxial line having similar electrical properties. Furthermore, instead of an adjustable shorting stub to antiresonate with the diode back impedance, an adjustable open stub may be employed with identical results. Because of considerations to be discussed below, the total length of transmission line between the diode switching elements 6 and 7 and the loop 1 is selected to be three quarters of a wavelength of the transmission signal measured in the coaxial line. For this configuration, the inverse of the diode impedance is presented at the loop terminals so that when the diodes are forward-biased, a very high impedance appears at the loop terminals and when the diodes are back-biased a very low impedance or a short appears at the loop terminals. Since the planar loop is inserted in the waveguide transmission line the impedance existing at its terminals affects the transmission of energy. The high impedance appearing at its terminals causes the loop to appear as an open circuit to produce virtually no effect on energy transmitted within the guide. On the other hand, a back-biased diode switch produces a short circuit at the loop terminals which in turn produces a reflection of transmitted energy within the waveguide to effectively attenuate the transmitted signal. An odd number of quarter wavelengths is generally desired for the length of transmission line between the loop terminals and diode switch elements so that the diodes will be forward-biased when the switch is in the condition permitting transmission. An even number of quarter wavelengths could theoretically be used instead, but this would curtail the power handling capabilities of the switch since the diodes would have to be back-biased during the time the switch permitted unattenuated transmission and would, therefore, have to withstand high voltages without breaking down. A three-quarter wavelength line was selected rather than a quarter wavelength line in order to provide a line having a dimension at the frequency of operation which permitted easy construction and assembly.

An equivalent circuit for the switch section shown in FIG. 1 is disclosed in FIG. 2 wherein the line between terminals 21-22 and 23-24 represents the waveguide section in which the switch is inserted. The energy to be transmitted is represented as coming from source 37 having an output impedance 35 equal to the characteristic impedance Z_0 of the line. The line is terminated in its characteristic impedance Z_0 as represented by resistor 36. The switch may be represented as being coupled to the waveguide dominant mode by an ideal transformer 30 having a primary to secondary turns ratio of 1: a . The inductive element L and capacitive element C connected to the secondary of the transformer represent an equivalent impedance of the resonant loop 1 and have values which are defined by the relationship

$$LC = \frac{1}{\omega_0^2} \quad (1)$$

Resistor R_d represents the effective diode back resistance including circuit losses and is shown connected to the ele-

ments representing the equivalent of the resonant loop by means of a transmission line having terminals 31-32 and 33-34. This transmission line has a length equal to an odd number of quarter wavelengths and more particularly three quarters of a wavelength.

If reference is had to FIGS. 3 and 3A wherein a length of waveguide transmission line is shown in cross-sectional front and side views, it may be seen that the resonant loop is planar, and in the embodiment shown, makes an angle θ with a plane parallel to a broad wall of the waveguide (which broad wall plane is also parallel to the plane of the magnetic field propagating within the waveguide). An expression for the turns ratio a of the ideal transformer 30 shown in FIG. 2 may be obtained as a function of this angle θ . This expression is as follows:

$$a(\theta) = \frac{r_0}{\sqrt{a_0 b_0}} \sqrt{\frac{8k_0 \eta_0}{k Z_0}} \sin \theta F(\theta) \quad (2)$$

where

r_0 is the radius of the loop 1,
 a_0 is the width of the rectangular waveguide 38,
 b_0 is the height of waveguide 38,
 k_0 is the free space propagation constant equal to $2/\lambda_0$,
 η_0 is the free space wave impedance,
 k is the propagation constant of the dominant mode in the waveguide, and

$$F(\theta) = 2 \sin \mu \int_0^{\pi/2} \cos(\mu \cos \Phi) \cos(\rho \sin \Phi) \cos^2 \Phi d\Phi \quad (3)$$

with

$$\mu = \frac{\pi r_0}{a_0} \text{ and } \rho = k r_0 \cos \theta \quad (4)$$

The attenuation or loss attributable to one switch is found to be a function of the angle θ and is expressed as follows:

$$L_1 = 1 + \frac{a^2 R_d}{2 Z_0} \quad (5)$$

When Equations 5 and 2 are plotted, it is found that both the loss L_1 and the turns ratio a are monotonically increasing functions of θ .

A number of switches identical with that shown in FIG. 1 may, in accordance with a feature of the invention, be inserted in a waveguide to provide a composite switch having enhanced attenuation capabilities and a greater power handling capacity. In the illustrative embodiment shown in FIGS. 3 and 3A, four switches are arranged consecutively along the length of a waveguide 38 so that the planar loop of each switch section is inserted through a narrow wall of the waveguide at an angle θ with the broad wall. The spacing between each switch is made to be an odd number of quarter wavelengths so that the impedance presented to a given switch by those adjacent is transformed to a high value, thereby increasing the effectiveness of the switching action in a fashion obvious to those versed in the art. For reasons to be indicated below, the uniform displacement between adjacent switches is made equal to three-quarters of the wavelength measured within the waveguide and the planar loops make alternately positive and negative angles θ with a plane parallel to the broad wall. An equivalent circuit representation of the composite switch is shown in FIG. 4 wherein the waveguide transmission line is represented by its lumped parameter equivalent of series inductors and shunt capacitors between terminals 60-61 and 62-63. The line is terminated at both the source and load ends by the characteristic impedance Z_0 of the transmission line. Coupled to the waveguide line at regular intervals is the switch as represented by the equivalent circuit of FIG. 2 as an ideal transformer having turns ratio 1: a feeding the effective diode back resistance R_d in series with the lumped capacitive and inductive elements representing the resonant loop. A mutual inductance between adjacent loops is represented by the quantity M . Using conven-

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tional network theory and the equivalent circuit shown in FIG. 4, the loss of a composite switch having a multiplicity of sections may be calculated. Illustratively, if three sections are coupled to the waveguide transmission line, the loss relationship is as follows:

$$L_3 = \frac{D + 2b(b-1)x^2(1+x)}{1 + 2b(b-1)x^2} \quad (6)$$

where

$$D = 1 + \frac{3}{2}x + x^2 + \frac{1}{2}x^3 \quad (7)$$

$$x = \omega M = \frac{Z_0}{R_d} a^2(\theta) \quad (8)$$

and

$$b(\theta) = \frac{E_2}{I_0} \frac{1}{a^2 Z_0} \quad (9)$$

the normalized mutual reactance.

The normalized mutual reactance is defined as the voltage E_2 induced in one switch section loop by a current I_0 flowing in an adjacent switch section loop and normalized as shown. The mutual inductance may be further defined qualitatively as resulting from the coupling of evanescent or higher order nontransmitted modes existing beyond cut-off.

The properties of a multisection switch may be examined through an analysis of a three-section switch described by Equation 6 and other supporting equations. If it is assumed all loops are at the same angle θ and that the loops are spaced far enough apart so that the mutual reactance is negligible, $b(\theta)$ as defined by Equation 9 is set to zero in Equation 6 and a monotonically increasing loss function results. If the loops are all maintained at the same angle θ and the spacing between loops is made three-quarters of a wavelength so that mutual reactance between adjacent loops exists, a similar monotonically increasing loss function results. If now, however, the spacing of three-quarters of a wavelength is maintained it will be seen that it is theoretically possible to obtain an infinite attenuation for a particular magnitude of the angle θ if the loops are alternately situated at angles of $+\theta$ and $-\theta$ as shown in FIGS. 3 and 3A. For this configuration the mutual coupling between adjacent loops will be out of phase with the dominant mode coupling and therefore $b(\theta)$ in Equation 6 must be replaced by $-b(\theta)$. This introduces the possibility of a zero in the denominator of the loss expression of Equation 6 and consequently a pole in the loss function. A plot of loss versus θ indicates that a pole does indeed exist for this configuration, if the spacing between loops is such that the mutual coupling or coupling to evanescent modes is approximately equal to the dominant mode coupling. This only occurs for spacings near three-quarters of a wavelength. It is therefore obvious that mutual coupling amongst loops having the spacing as indicated above serves to greatly improve the loss characteristics.

In an arrangement using four coaxial switch sections having a characteristic impedance of 50 ohms and having a forward-biased diode resistance of a tenth of an ohm, a back-biased diode effective resistance (including losses in the external circuit) of 630 ohms, a value of $a(\theta)$ equal to .6 and a spacing between loops of three-quarters of a wavelength for a 960-megacycle signal, the insertion loss (when the diodes were forward-biased) was found to be less than .2 of a db and the attenuation exceeded 40 db (when the diodes were back-biased). With 10 kilowatts of power flowing through the waveguide, the switch elements operated satisfactorily and variations in diode parameters were permissibly wide. It is to be noted that the power capability of the switch may be increased by adding additional switch sections. Furthermore, an increase in the number of switch sections permits a lighter coupling of each switch to the waveguide (decreasing the value of $a(\theta)$) while simultaneously maintaining a large

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attenuation by virtue of the mutual coupling effect. Because a lighter coupling is possible, burn-out of the forward-biased diodes may be prevented. While the switch sections are shown coupled through a narrow wall to the electric field in the waveguide, alternative coupling arrangements may of course be employed.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of this invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A switch for insertion in a waveguide comprising a plurality of sections each having an open-circuited resonant loop conductor mutually coupled within said waveguide to loops from adjacent sections and means for shorting the ends of said loop to effect an attenuation of energy transmitted through said waveguide including a diode element, a control voltage source connected to said diode element for selectively biasing said diode and a transmission line interconnecting said diode element with said loop ends having sufficient length to transform the impedance of said diode for a selected bias to a short at said loop ends.
2. A microwave frequency switch for insertion in a waveguide comprising a first section having a resonant planar loop with open-circuited ends disposed within said waveguide, control means for actuating said switch to attenuate energy propagated through said waveguide including a diode switch having a forward and a reverse bias impedance, a line adjusted to transform said diode impedance to its inverse interconnecting said loop ends with said diode and a source for selectively biasing said diode, and a plurality of similar sections each having its resonant loop mutually coupled within said waveguide to adjacent loops.
3. A microwave frequency switch in accordance with claim 2 wherein said planar loops make alternately positive and negative identical angles with a plane of magnetic field lines of a dominant mode wave propagating in said waveguide.
4. A microwave frequency switch in accordance with claim 3 further including means for varying the magnitude of said angle to provide a continuously adjustable quantum of attenuation.
5. In a waveguide, a microwave frequency switch comprising a plurality of switch sections each having a resonant planar loop with open-circuited ends disposed within said waveguide, means for controlling the attenuation of energy transmitted through said waveguide including a diode switching element having a forward and a reverse bias impedance, tunable means connected to said diode element for antiresonating with said reverse diode impedance, a line of sufficient length to transform said diode impedance to its inverse interconnecting said loop ends with said diode element and means for varying the angle said planar loop makes with a wall of said waveguide to adjust the attenuation introduced, said sections disposed with a distance between loops fixed so that the coupling between adjacent loops by means of the dominant field mode within the waveguide is equal and opposite to coupling between adjacent loops due to evanescent modes in said waveguide.
6. A microwave frequency switch in accordance with claim 5 wherein said tunable means includes a transmission line having a characteristic impedance matched to said impedance transforming line and having an adjustable shorting stub and wherein said loop planes make alternately positive and negative equal magnitude angles with a broad wall of said waveguide.
7. A microwave frequency switch for insertion in a waveguide comprising a first switch section having a resonant planar loop with open-circuited ends disposed within said waveguide, means external to said waveguide for controlling the attenuation of energy transmitted through said waveguide including a diode switching ele-

ment having a forward and a reverse bias impedance, a first transmission line having an adjustable shorting stub connected to said diode to antiresonate with the reactive component of said reverse diode impedance, a second transmission line having a length equal to an odd number of quarter wavelengths measured within said line interconnecting said loop ends with said diode element, means for selectively biasing said diode element to said forward impedance to permit passage of energy propagating in said waveguide and to said reverse impedance to attenuate said energy and means for varying the angle said planar loop makes with a plane of magnetic field lines of a wave propagating in said waveguide to adjust the quantum of attenuation introduced, and a plurality of other substantially identical switch sections disposed longitudinally along said waveguide so that the spacing between adjacent loops is three quarters of a wavelength measured in said waveguide and so that said loop angle is alternately positive and negative for adjustment loop sections.

8. A microwave frequency switch in accordance with claim 7 wherein said first and second transmission lines are a composite of a coaxial line and a strip line having identical characteristic impedances, said second transmission line has a length of three quarters of a wavelength and wherein said diode switch element is included in said strip line portion of said composite lines.

9. A microwave frequency switch in accordance with claim 8 wherein said strip line contains provision for permitting external connection to said diode switching element, said diode switching element comprises a pair of diodes connected from the strip conductor of said strip line to said biasing means and wherein decoupling filter means are connected between said biasing means and said diode element.

10. A microwave frequency switch in accordance with claim 9 wherein said resonant loop has a perimetric length equal to one wavelength measured in air.

11. In a waveguide, a switch comprising a resonant conductive loop with open ends disposed within said waveguide, means for sharply decreasing the impedance existing at said loop ends to attenuate energy transmitted through said waveguide including a diode switching element having a forward and a reverse bias impedance, a control voltage connected to said diode to selectively bias said diode and a transmission line interconnecting said diode switch with said loop ends having a sufficient length to transform the impedance of said diode for a selected bias to a short at said loop ends.

12. A switch in accordance with claim 11 wherein said transmission line length is sufficient to transform said diode impedance to its inverse.

13. A switch in accordance with claim 11 wherein said loop defines a plane and wherein there is included means for varying the angle said loop plane makes with a magnetic field plane of propagating waves existing in said waveguide to adjust the quantum of attenuation introduced.

14. A switch for insertion within a waveguide comprising a resonant planar loop with open-circuited ends disposed within said waveguide, means for controlling the attenuation of energy propagated through said waveguide including a diode switching element having a forward and a reverse bias impedance, a first transmission line having an adjustable shorting stub connected to said diode to antiresonate with said diode reverse impedance, a second transmission line having a length equal to an odd number of quarter wavelengths measured within said line interconnecting said loop ends with said diode element, means for selectively biasing said diode to said forward impedance to permit the passage of energy in said waveguide and to said reverse impedance to attenuate said energy and means for varying the angle said planar loop makes with a plane of magnetic field lines of a wave propagating in said waveguide to adjust the quantum of attenuation introduced.

15. A switch in accordance with claim 14 wherein said first and second transmission lines are a composite of a coaxial line and a strip line having identical characteristic impedance, said second transmission line is three quarters of a wavelength long, said diode switch element is included in said strip line portion of said composite lines and said resonant loop has a perimetric length equal to one wavelength measured in air.

16. A switch in accordance with claim 15 wherein said strip line contains provision for permitting external connection to said diode switching element, said diode switching element further comprises a pair of diodes connected in a balanced configuration from the strip conductor of said strip line to said biasing means and wherein a low-pass filter is connected to decouple said biasing means from said switch.

No references cited.

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