

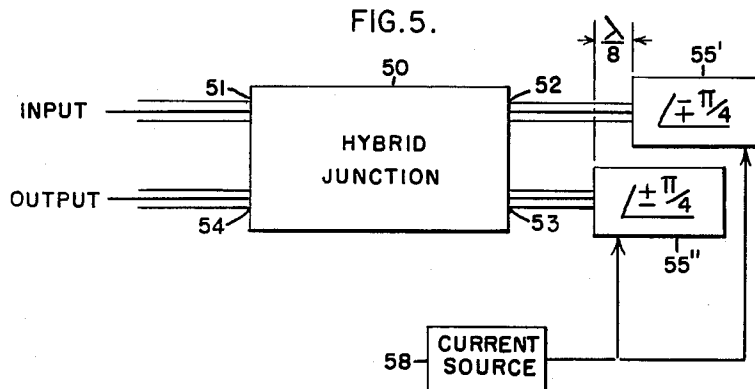
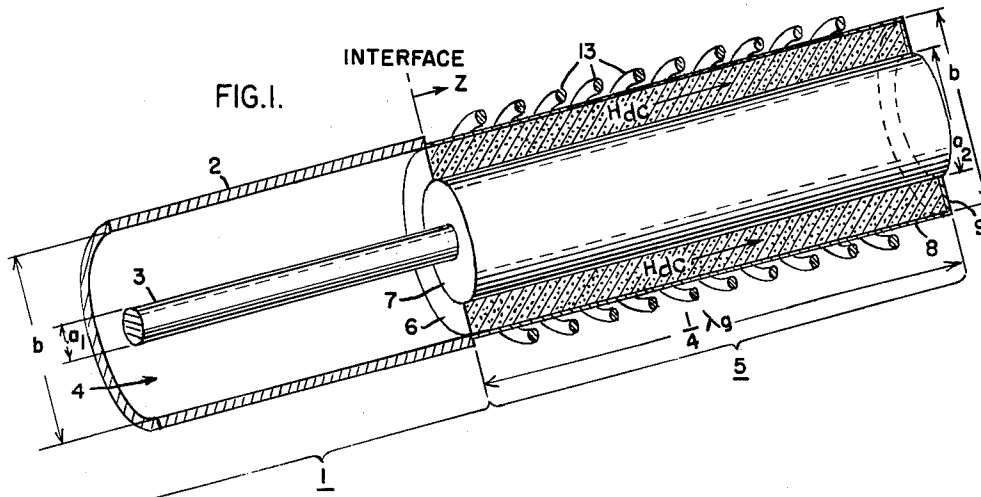
Nov. 30, 1965

E. STERN
MICROWAVE VARIABLE REACTANCE DEVICE OPERATING
ABOUT A RESONANT CONDITION

3,221,276

Filed April 27, 1961

3 Sheets-Sheet 1



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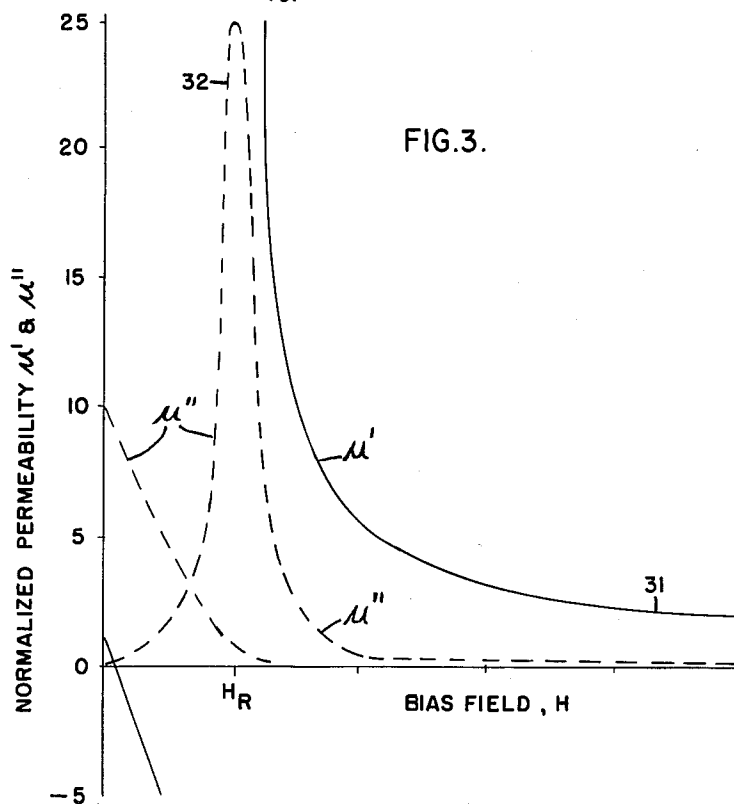
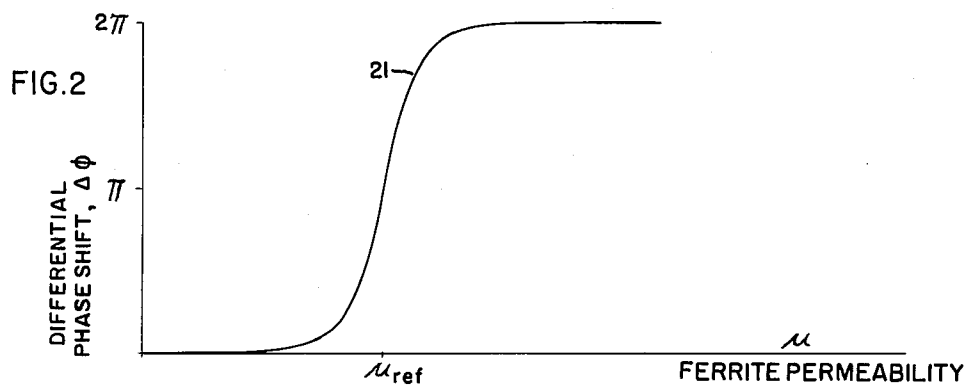
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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

FIG. 4.

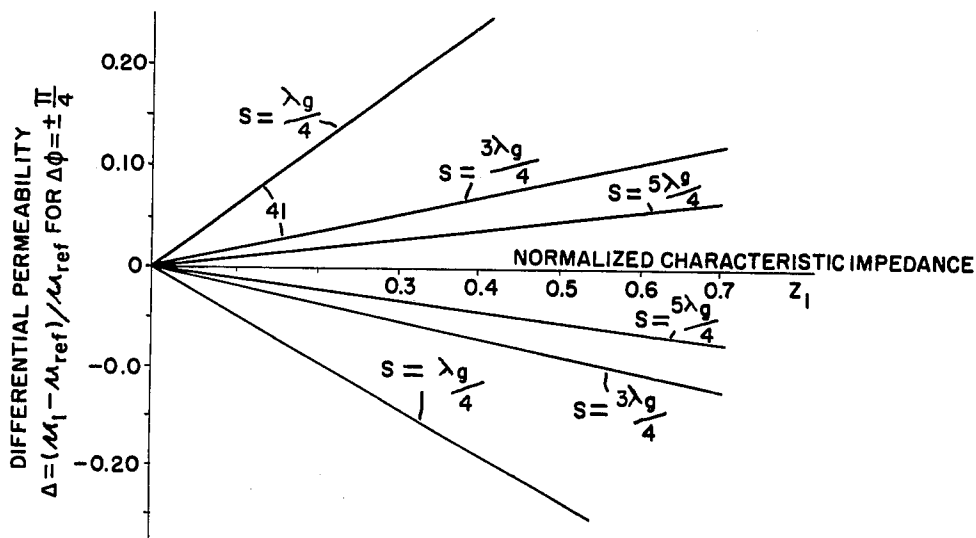
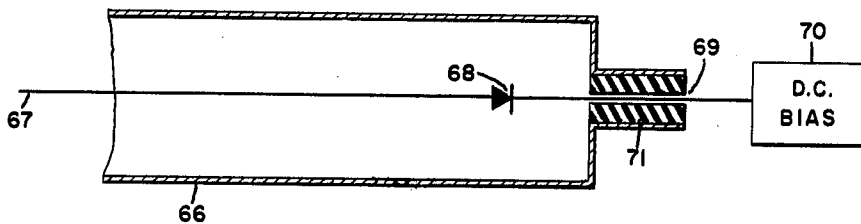


FIG. 6.



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3,221,276

MICROWAVE VARIABLE REACTANCE DEVICE OPERATING ABOUT A RESONANT CONDITION

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8 Claims. (Cl. 333-11)

The invention relates to a novel electrically variable reactive transmission line termination device and to transmission line systems incorporating this variable device.

The invention is particularly adapted for use at microwave frequencies, wherein the transmission elements may take the form of waveguides, coaxial lines, strip lines, and the like; and wherein the wavelengths of the propagated waves in such transmission elements are conveniently small permitting switching functions to be performed by hybrids, circulators and directional couplers fabricated of like transmission elements. In the following passages, all of these transmission elements will be referred to as "waveguides."

In its system aspects, the invention has application to the electric control and fast switching of microwave energy. In such systems, the effect of adjusting these electrically variable reactive terminations is to vary the phase of the energy reflected from these terminations, and thus the distribution of traveling wave cancels and adds at the ports of the system.

A phase shift in a microwave system is an introduction of a time advance or delay in a wave as it appears at some point in the system. Phase shifting in waveguides has often been obtained by introducing a body into the waveguide having a permittivity or permeability which differs substantially from that of free space. In this body, the velocity of wave propagation is substantially changed in accordance with the variation in the electromagnetic permeability and a phase shift is produced in accordance with the difference in the velocity of wave propagation and the length of the body. Accordingly, if either the electromagnetic constant or the length of the body is varied, the phase shift will be correspondingly varied. For example, in a ferrite body, the permeability is a function of the applied magnetic field, H . Accordingly, a variable phase shift can be obtained by applying a variable magnetic field bias to vary the permeability and thereby control the phase shift. However, prior arrangements have required large bodies of ferrites on the order of a free space wavelength long and large switching energies to provide adequate differential magnetic field bias. For example, conventional L-band devices have been limited to switching speeds on the order of one thousandth of a second with reasonable drive power.

This has been a rather general problem in electrically variable reactance devices at microwave frequencies. The devices have required large switching energy and have been bulky. To reduce the size and energy requirements it is necessary to either discover a new effect which produces larger variable reactances from known devices or to provide a novel device which produces larger variations in the reactance from known effects.

It is therefore an object of the invention to provide a microwave device which is controlled with reasonable switching powers that produces rapid and large variations of reactance.

Another object of the invention is to provide a phase shifter which is compact and controlled by small switching energies with very short transient response times.

A further object of the invention is to provide a switching system which is compact, requires small switching energies for very short transient response times and at an output port provides excellent isolation in an "off" condition and small loss in an "on" condition.

Briefly stated, in accordance with one aspect of the invention, a novel microwave device is obtained which produces a large variable reactance effect with small variations in the permeability of a ferrite loaded waveguide section. The waveguide section is adapted to be connected at one end to a waveguide line and the other end is shorted. In one embodiment, the waveguide section is ferrite filled, having a mean electrical length of $\pi/2$ radians, and a variable current bias coil is provided to vary the permeability of the ferrite. Relatively small variations in permeability vary the electrical length of the waveguide section whereby the reactance of the section varies about the large reactance values presented near resonance. Resonance is that condition of an electrical impedance device or network having inductive and capacitive reactances wherein an applied alternating signal voltage generates maximum currents. It occurs when the period of the applied signal corresponds to the natural period of the element or network. The characteristic impedance of the termination is selected to be small with respect to the characteristic impedance of the waveguide. Accordingly, a wave is reflected by the device with large variations in the phase shifts. When the termination is tuned through resonance as by small changes in permeability, marked changes are caused in the phase of the energy reflected by the termination as the termination appears to go from a high capacitive reactance to near zero reactance and then to a high inductive reactance. This rate of change is heightened by the indicated characteristic impedance ratio.

The features of the invention which are believed to be novel are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description when taken in connection with the drawings wherein:

FIGURE 1 is an enlarged perspective view partially in cross section of an embodiment of a microwave variable reactance device constructed in accordance with the invention.

FIGURE 2 is a graph of the relation between the phase of a wave reflected by the FIGURE 1 device as a function of the permeability of the ferrite filled waveguide section.

FIGURE 3 is a conventional graph of ferrite permeability components as a function of magnetic bias field.

FIGURE 4 is a graph of the required change in permeability $\Delta\mu$ for a given phase shift $\pm\pi/4$ as a function of the ratio of normalized impedance and of the variable reactance device of FIGURE 1 for three lengths of the phase shifter.

FIGURE 5 is a block diagram of an electrically controlled, microwave switch utilizing a pair of variable reactance devices constructed in accordance with the invention.

FIGURE 6 is an illustration of a novel reactance device utilizing a variable capacitance diode.

FIGURE 1 is a perspective view in cross section of an embodiment of a variable reactance device suitable for L-band application which is constructed in accordance with the invention. The reactance device is connected to a conventional coaxial line 1 which is comprised of an outer shield conductor 2, an inner conductor 3 and an intermediate air space 4 which serves as the dielectric. The variable reactance device proper, designated generally as 5, is comprised of a ferrite cylinder 6 formed about a coaxial inner conductor 7. An outer coaxial conductor is provided by a thin conductive coating 8. The reactance device is shorted by a conductive coating 9 between the inner conductor 7 and the outer conductive coating 8. A variable axial magnetic bias field is provided by a coil 13 and it is preferable to provide a constant magnetic

bias field with a conventional permanent magnet producing a field having a direction indicated by H_{dc} .

The FIGURE 1 embodiment of the invention illustrates several features which when combined together produce a variable reactance in a novel manner. These features include: a reactive reflecting waveguide termination; a near resonant waveguide section; a large differential in the impedance of the waveguide section was compared with the characteristic impedance of the waveguide; and a waveguide material filling the waveguide section in said termination which provides a substantially variable impedance and velocity of wave propagation. Since the variable reactance device 5 is a coaxial section having outer and inner conductors 7 and 8, the reflection is conveniently provided by the shorting conductor 9. The waveguide section resonance is provided by the selection of the longitudinal dimension to be approximately an odd quarter wavelength long, in FIGURES 1, a quarter wavelength is indicated. The ratio of the section impedance to the characteristic impedance of the waveguide is determined by the selection of the ratio of radial dimensions of the reactance element. The variation in the velocity of wave propagation is obtained by the use of a suitable ferrite that is controlled by a variable magnetic field which changes the permeability of the dielectric.

The phase of a wave reflected by the reactance device 5 is a tangent function determined by the normalized impedance Z_1 of the waveguide section presented to the interface with the coaxial line. For transmission lines in general, the phase of a phase shifted wave, relative to a wave reflected by a pure resistive termination is determined by the relation,

$$\tan\left(\frac{1}{2}\phi\right) = \frac{-X}{Z_0}$$

where Z_0 is the characteristic impedance of the coaxial waveguide line and X is the reactance of the termination.

The reactance at the interface of the ferrite filled shorted section of waveguide is determined by the length and the velocity of wave propagation for a given frequency. To produce resonance, it is sufficient that the section have a mean electrical length equal to an odd quarter wavelength (or a multiple of a half wavelength for an open line termination). That is, the length divided by the velocity must be an odd quarter wavelength,

$$\begin{aligned} \text{Electrical length} &= \frac{2\pi s}{\lambda_g} \sqrt{\mu\epsilon} = \left(\frac{n}{2} + \frac{1}{4}\right) 2\pi \\ &= \frac{\pi}{2}, \text{ for } n=0 \end{aligned}$$

where s is the section length, λ_g is the wavelength, μ_{res} is the relative permeability in the unenergized state, ϵ is the relative permittivity and n is an integral number. The reactance of the section, as the relation of length to velocity of wave propagation varies, is the tangent function, $Z = jZ_0 \tan \beta s$, where Z_0 is the characteristic impedance of the section, β is the phase velocity term and s is the length. When the βs factor is near an odd quarter wavelength resonance, as in the FIGURE 1 embodiment, the reactance seen at the interface of the coaxial line is large and has large variations for small changes in the βs factor. This factor is varied by a change in the permeability of the wave propagating medium. The introduction of the tangent function to the controllable variation in permeability is essential to the invention.

The reactance seen by a wave is also a function of the normalized characteristic impedance, that is, the ratio of characteristic impedance of the coaxial line to the characteristic impedance of the variable reactance device. The variables which can be adjusted are the relative dimensions of the waveguide line and the variable reactance device. In the embodiment of FIGURE 1, the normalized characteristic impedance for an unenergized waveguide section, assuming negligible losses, is determined as follows:

$$Z_1 = \frac{Z_{line}}{Z_{section}} \sqrt{\frac{\mu_r}{\epsilon_r}} \frac{\log_e \frac{b}{a_2}}{\log_e \frac{b}{a_1}}$$

wherein μ_r is the relative permeability, ϵ_r is the relative dielectric constant, b is the inside diameter of the coaxial waveguide and the diameter of the phase shifter section, a_1 is the center conductor diameter of the coaxial waveguide, a_2 is the inner conductor diameter of the variable reactance device 5, λ_g is the wavelength in the variable reactance device and s is the length of the section. Accordingly, a large value of a_2 relative to a_1 produces a relatively small normalized characteristic impedance and a corresponding desired increase in phase shift.

However, the determining dimensional factor is the overall relative dimensions so that any one or more dimensions may be varied. For example, the illustrated embodiment has the same outer conductor diameters for both the transmission line and the waveguide section for convenience, but this is optional and the outer conductor diameters may be varied as described. The above equation holds for coaxial elements and different types of microwave transmission lines produce corresponding characteristic impedance effects.

For the illustrated embodiment, which has a mean electrical length of an odd quarter wavelength and is therefore essentially parallel resonant, it is desired to have a normalized characteristic impedance substantially less than one. This will be evident from the overall relation expressed below. However, for waveguide sections having a mean electrical length of an integral multiple of a half wavelength, the reverse is true, and relatively large normalized characteristic impedances increase the variable reactance effect.

The normalized characteristic impedance is also a function of the relative permeability and permittivity of the waveguide section and line. It is for this reason that the waveguide section is ferrite filled. Where the section is only partially filled, the electrical length and overall reactance effect remains variable, but the effect is relatively reduced by the decreased normalized characteristic impedance effect.

FIGURE 2 illustrates the relation between the phase shift, $\Delta\phi$ (21), of the reflected wave and the permeability of the ferrite. For small changes in permeability such that

$$\sqrt{1 + \frac{\Delta\mu}{\mu_{ref}}} \approx 1 + \frac{\Delta\mu}{2\mu_{ref}}$$

and a mean electrical length of $\pi/4$, the relation may be expressed as follows from the above equations:

$$\tan\left(\frac{\Delta\phi}{2}\right) \approx \frac{\tan \frac{\pi\Delta\mu}{4\mu_{ref}}}{Z_1\left(1 \pm \frac{\Delta\mu}{2\mu_{ref}}\right)}$$

where $\Delta\phi$ is the differential phase shift, $\Delta\mu$ is the differential permeability, μ_{ref} is the ferrite permeability at H_{dc} and Z_1 is the normalized characteristic impedance of the phase shifter section. This relation is nonlinear and is approximately of odd ordered symmetry about the phase shift, produced at the reference permeability, μ_{ref} , with zero switching current in the coil and only the constant magnetic field bias present in the ferrite. For small changes in permeability near the reference permeability, there are relatively large changes in the phase of the reflected wave.

Considering the operation of the device qualitatively, it may be said that a selection of a resonant terminating element provides a highly efficient and highly sensitive phase control. When steady state oscillation has been established, minor amounts of energy are absorbed in the termination but none is lost in radiation along another path and the energy reflected from the termination is thus

substantially equal to that applied. Accordingly it may be seen that as in any coupled resonant system, that the energy reflection will rapidly vary through a large leading to a large lagging phase angle as the system is tuned through resonance to the applied waves. The adjustment of the permeability of the ferrite thus has the effect of tuning the termination through resonance, and as explained mathematically before, the selection of a substantially lower characteristic termination impedance than the characteristic waveguide impedance tends to heighten the tuning rate near the resonance frequency. The heightened tuning rate referred to is the ability to effect large phase changes with minimal changes in ferrite permeability.

FIGURE 3 is a conventional graph of the ferrite permeability components as a function of the magnetic bias field H . For a wave of a given frequency, the real component of permeability μ' (31) exhibits a nonlinear relation with large variations from that of free space. The most prominent feature is a gyromagnetic resonance absorption response for a particular magnetic bias field. The imaginary component of the permeability μ'' (32) represents lossy interactions which are particularly prominent in the region of gyromagnetic resonance about H_R . In addition to this loss, there is also a "zero field" loss at lower magnetic bias field strengths separately shown. The latter loss is due to such factors as domain wall motion.

The graph of FIGURE 3 can also be considered as a graph of permeability versus frequency. This is because the gyromagnetic resonance frequency is a direct function of the magnitude of the applied magnetic bias field. Since it is necessary to minimize the loss of the device, a practical device must operate in a region where the imaginary permeability is negligible. For low frequency applications, this requires operation above the gyromagnetic resonance because the zero field loss characteristic tends to merge with gyromagnetic resonance losses. However, for high frequency applications such as X band the ferrite may be operated below the gyromagnetic resonance frequency.

FIGURE 4 is a graph of the required change in permeability, Δ (41), where $\mu = \mu_{ref} (1 \pm \Delta)$ for a given phase shift, $\pm \pi/4$, as a function of the normalized characteristic impedance of the FIGURE 1 variable reactance device for three lengths of the phase shifter.

The normalized impedance plotted in FIGURE 4 is the ratio of the terminating characteristic impedance to the characteristic impedance of the waveguide. The graph (based on each of its three lines providing a phase shift of $\pm \pi/4$) shows that relatively low differential permeabilities and relatively low normalized characteristic impedance ratios go hand in hand. Thus by reducing the normalized impedance ratio, one requires a smaller change in permeability to effect the same phase shift. If one selects a larger normalized characteristic impedance ratio, one requires a larger change in permeability. The graph also illustrates that with long lines, the differential permeability need not be so great.

A minor constraint on the reduction of normalized characteristic impedance is that a shunting capacitance effect becomes significant at an impedance ratio on the order of 0.1. This effect can be considered to arise from close proximity of the outer conductor of the coaxial line and the inner conductor of the phase shifter line and can be neglected except for extreme impedance ratios. A comparison of the relations for different lengths of phase shifters illustrates the substantial reduction in the required change in permeability for longer phase shifter sections. However, this advantage is usually offset by the increased sensitivity to different wave frequencies and broadband operation generally is simplified for a quarter wavelength axial dimension.

A further consideration is the permissible loss of the device. In general, it is necessary to maintain loss at less than one decibel and this factor imposes requirements

and limitations on the ferrite material composition and configuration. One consideration is that the wave loss is inherently proportional to the distance through which the wave propagates. Accordingly, minimum loss from the inherent properties of the material is obtained in a quarter wavelength configuration. The permissible loss factor of the ferrite is conveniently considered in terms of the known loss $\tan \delta$ of the material which is the relation between the real and imaginary components of the material permeability and permittivity. A typical requirement is $\tan \delta = 0.01$ and can be met by commercially available ferrites such as garnet (YIG) and MgMnAl ferrites.

For operation at L-band frequencies, the coaxial line configuration of FIGURE 1 is suitable. However, the invention is applicable to all types of waveguide configurations. The essential effect, a reactance variation from a variation in the electrical length of a reflectively terminated distributed impedance, is obtainable in any transmission line. Also, in addition to the shunted, odd quarter wavelength configuration of the FIGURE 1 embodiment, it is possible to utilize half wavelength sections with open circuit terminations.

A typical example of a phase shifter of the FIGURE 1 type provides a $\pi/4$ phase shift with a change in permeability of the ferrite of ± 0.01 . This is obtainable with a coil of less than 1.0 microhenry and a current of ± 10 amperes. Accordingly, switching times on the order of 10^{-7} seconds are easily obtained at L-band. Because of their smaller size, devices for application at higher frequencies are correspondingly faster. The FIGURE 1 configuration provides satisfactory heat dissipation for medium power applications and the large exterior surface permits supplementary cooling procedures where necessary. The silver conductive coating 8 provides the outer conductive boundary for the waveguide. This coating is made of a thickness on the order of one micron to avoid the "shorted turn" effect on the bias coil.

FIGURE 5 is a block diagram of an on-off switch. The switch is comprised of a pair of phase shifters, variable reactance elements 55' and 55'', and a device for effecting switch action, which is conveniently a hybrid 50. The hybrid 50 illustrated is a four port, forward-coupling device which includes a first waveguide section between ports 51 and 52 and a second contiguous section between ports 54 and 53. The two sections are coupled along a substantial length so that a wave introduced at any port is divided in order that half of the power, with a $\pi/2$ phase lag, is delivered to the other waveguide section. For example, a wave introduced at port 51 is delivered half to port 52 and half to port 53, the latter with a $\pi/2$ phase shift. The phase shifters 55' and 55'' are connected to ports 52 and 53 and reflect waves appearing at these ports. These phase shifters are variable reactance devices such as shown in FIGURE 1 which produce a variable phase shift in the reflected waves. Accordingly, when an input wave propagates into port 51, it can appear at output port 54 or back at input port 51, as determined by the phase of the reflected waves which either cancel or reinforce at the input and output ports.

A wave, propagating into port 51 is coupled half to port 54 with a phase delay of $\pi/2$ and half to port 52. The variable reactance device 55' is set off an eighth of a wavelength relative to elements 55'' to provide a constant relative phase lag factor of $\pi/2$. Further constant factors are produced by the quarter wavelength lag in coupling from one section of waveguide to the other section. Variable factors are introduced by the variable reactance devices 55' and 55'' which introduce phase factors of opposite one-eighth quarter wavelength, $\pm \pi/4$. In FIGURE 5, reactance element 55' produces a relative phase lag, $-\pi/4$, and the accumulated phase factors produce a phase delay of $3\pi/4$. The wave reflected by reactance element 55'' is advanced in phase by $+\pi/4$ and the ac-

cumulated phase factors produce a delay of $-\pi/4$. Additional phase delays of $\pi/4$ are introduced in the reflected waves which are coupled from section to section. Accordingly, the wave reflected by reactance element 55' reaches port 51 in phase with the wave from reactance element 55'' and the waves combine additively. The waves propagating towards port 53 are a half wavelength out of phase and therefore cancel. The switch is "off" and no waves will appear at the output port 54.

If the phase shifts produced by variable reactance devices 55' and 55'' are reversed, the switch is in the "on" condition. The waves reflected back toward ports 52 and 53 have phase lags of $\pi/4$ and $3\pi/4$, respectively. This is a reversal of the phase factors of the reflected waves relative to each other. This results in a reversal of the interference relations and a switching of the wave from port 51 to port 54. The result is that hybrid 50 and variable reactance devices 55' and 55'' perform a single-pole-single-throw switching operation. Other switching functions and more complex coupling structures are possible. For example, a single-pole-double-throw switch can be provided with a six-port hybrid and variable reactance devices arranged in a manner analogous to FIGURE 5.

The control of variable reactance devices 55' and 55'' is by means of a current control source 58. The source 58 is conveniently connected to devices 55' and 55'' in series or in parallel and the connections are made with reverse polarity to produce opposite phase and reactance variations. The resulting combination is a highly efficient switching device because of the small losses produced in the completely reflecting terminations. The symmetrical nature of the paths in the hybrid, where waves are operated upon by identical devices, facilitates accurate superposition of the wave components. Those losses which do exist in the devices and any nonlinear effects produced are largely cancelled. Generally, switching between on-off conditions at the output ports is desired, but variable attenuation is obtainable at intermediate conditions of superposition. In providing on-off switching, the time required to reverse switch conditions is primarily determined by the transient response of current control circuit 58. Because of the relatively small device inductance, the transient response can be easily made less than a microsecond at L band frequencies, and less than one tenth of a microsecond at substantially higher frequencies.

FIGURE 6 illustrates a variable reactance device suitable for L-band applications, similar to the device of FIGURE 1, utilizing a variable capacitance diode to provide the variable effect required in the near resonant waveguide section. The device includes a coaxial waveguide section having an inner conductor 67 and an outer shield conductor 66 adapted to be connected to a coaxial transmission line. The other end of the waveguide section is provided with a portion of the outer shield conductor 66 having a reduced diameter 71 and a short is provided by a dielectric body 69, such as barium titanate, therebetween. The inner conductor 67 is connected in series with a variable capacitance diode 68 and the inner conductor extends through the dielectric 69 to a source of back D.C. bias 70.

The FIGURE 6 embodiment of a variable reactance device operates in a manner similar to the FIGURE 1 embodiment. The device provides a variable reactance about a mean series resonant condition of the device. The diode 68 is comprised of a substantial variable capacitance in series with the inductance of the diode. The length of the section of coaxial waveguide is selected to provide an additional series inductance so that for a median bias voltage on the diode 68 the variable reactance device presents a series resonant circuit to a center frequency wave propagating into the waveguide section. When the bias voltage is varied, a relatively large change in the reactance of the series circuit is produced. The main difference between the embodiments of FIGURES 1

and 6 is that the latter utilizes a variable lumped impedance element and the former utilizes a distributed impedance.

The diode 69 is of the type known as a "varactor" or "parametric" diode which is characterized by having a nonlinear relationship between the applied voltage and the junction capacitance. An example of this kind of diode is a type MA460D manufactured by Microwave Associates, Inc. The obtainable relative variation in capacitance is typically of the order of three. In a non-resonant termination, this limits the phase shift variation to 60° for maximum bias variation. However, in a series resonant termination, having a substantial Q and an overall loss of less than one decibel, the obtainable phase shift variation is greatly increased, depending upon the diode characteristics.

The nonlinear capacitance effect of the diode produces harmonics. However, with bias voltages substantially larger than the signal voltages appearing across the diode, the harmonic generation process is negligible. Present variable reactance diodes are suitable for applications up to a watt average power. However, improved diodes and other lumped variable reactance elements such as biased ferroelectric capacitors have application at higher powers. Further increases in phase shift can be obtained by combining a pair of different variable reactance devices in series. In such a combination, one device has the waveguide section reflectively shorted for a quarter wavelength resonance and the second device is interposed between the first device and the transmission line and provides a half wavelength resonance.

While the fundamental novel features of the invention have been shown and described as applied to illustrative embodiments, it is to be understood that the invention is not to be limited thereto. For example, the ferroelectric dual of the ferrite filled waveguide section will produce substantially the same kind of variable reactance effect. In a coaxial waveguide section embodiment a variable voltage applied between the inner conductor and the outer conductor with a ferroelectric body extending therebetween will vary the reactance of the waveguide section and a phase shift corresponding to the variation in the electrical length of the waveguide section will be produced. The true scope of the invention, including those variations apparent to one skilled in the art is defined in the following claims.

What is claimed is:

1. A microwave variable reactance device comprising: a waveguide section having a first end for connection to a waveguide line; means reflectively terminating the second end of said waveguide section; electrically controlled reactive means within said waveguide section; and control means associated with said electrically controlled reactive means to control this reactance, which control means when set to its median value establishes a mean electrical length for said waveguide section which is near an integral multiple of a quarter wavelength and thereby produce a large variation in the reactance presented by said waveguide section to said waves propagating from said waveguide line.

2. A microwave variable reactance device comprising: a waveguide section having a first end for connection to a waveguide; a body of material having a substantially electrically variable electromagnetic constant such as to provide a medium which propagates waves with a variable velocity and extending the length of said waveguide section; means reflectively terminating the second end of said waveguide section; and control means associated with said body of material to vary the wave propagation velocity thereof which control means, when set to its median value establishes a mean electrical length for said waveguide section which is near an integral multiple of a quarter waveguide whereby a variation in the reactance of the waveguide section is obtained in accordance with the variation in the electrical length of said waveguide section.

3. A microwave variable reactance device comprising: a waveguide section having a first end for connection to a waveguide; a body of ferrite material, having a permeability which varies substantially as a function of the magnetic field strength in the material, extending the length of said waveguide section to provide a medium which propagates waves with a variable velocity; means reflectively terminating the second end of said waveguide section; and variable bias means producing a magnetic field in said body of ferrite to vary the wave propagation velocity of said ferrite which variable bias means when set to its median value establishes a mean electrical length for said waveguide section which is near an integral multiple of a quarter wavelength whereby a variation in the reactance of the waveguide section is obtained in accordance with the variation in the electrical length of said waveguide section.

4. A microwave variable reactance device comprising: a waveguide section having a first end for connection to a waveguide; a body of ferrite material, having a permeability which varies substantially as a function of the magnetic field strength in the material, filling said waveguide section to provide a medium which propagates waves with a variable velocity; means reflectively shorting the second end of said waveguide section; and variable bias means producing a magnetic field in said body ferrite to vary the velocity of wave propagation in said ferrite which variable bias means when set to its median value establishes a mean electrical length for said waveguide section which is near an integral multiple of a quarter wavelength whereby a variation in the reactance of the waveguide section and a corresponding phase shift are obtained in accordance with the variation in the electrical length of said waveguide section.

5. A microwave variable reactance device comprising: a waveguide section having a first end adapted for connection to a waveguide line and having a characteristic impedance which is small relative to said waveguide line; a body of ferrite material, having a permeability which varies substantially as a function of the magnetic field strength in the material, filling said waveguide section to provide a medium which propagates waves with a variable velocity; means reflectively shorting the second end of said waveguide section; and variable bias means producing a magnetic field in said body of ferrite to vary the wave propagation velocity in said ferrite which variable bias means, when set to its median value establishes a mean electrical length near an odd quarter wavelength whereby a variation in the reactance of the waveguide section is obtained in accordance with the variation in the electrical length of said waveguide section.

6. A microwave switching system comprising: a multi-port coupling device adapted to receive an input wave at at least one port and deliver said wave at a second port when a portion of said wave is delivered and reflected at a third port with a given phase shift; a waveguide section having a first end connected to the third port of said coupling device; means reflectively terminating the second end of said waveguide section; electrically controlled reactive means within said waveguide section; and control means associated with said electrically controllable reactive means to control this reactance which control means when set to its median value establishes a mean electrical length for said waveguide section which is near an integral multiple of a quarter wavelength whereby a large variation in the reactance of said waveguide section and a phase shift corresponding to said given phase shift in the reflected wave are obtained.

7. A microwave switching system comprising: a multi-port coupling device adapted to receive an input wave at at least one input port and propagate said wave through an output port when a portion of said wave is propagated

through a third port and reflected back through said third port with a first given phase shift, said input wave being isolated from said output port when said portion of the input wave is reflected back through said third port with a second given phase shift; a waveguide section having a first end connected to the third port of said coupling device; a body of ferrite material, having a permeability which varies substantially as a function of the magnetic field strength in the material, filling said waveguide section to provide a medium which propagates waves with a variable velocity; means reflectively terminating the second end of said waveguide section; and switching means adapted to produce two conditions of magnetic field strength in said ferrite to vary the ferrite permeability and thereby change the velocity of wave propagation in said ferrite which switching means when set to a median value between said two conditions establishes a mean electrical length for said waveguide section which is near an integral multiple of a quarter wavelength whereby a variation in the reactance of said waveguide section and a selection of one of two phase shifts corresponding to said first and second given phase shifts in the reflected wave are obtained in accordance with the variation in the electrical length of said waveguide section.

8. A microwave switching system comprising: a multi-port coupling device adapted to receive an input wave at at least one input port and propagate said wave through an output port when portions of said wave are propagated through third and fourth ports and reflected back through said third and fourth ports with a first pair of respective given phase shifts having equal magnitude and opposite sign, said input wave being isolated from said output port when said portion of the input wave is reflected back through said third and fourth ports with a second pair of respective given phase shifts having equal magnitude and opposite sign; a pair of waveguide sections connected at a first end to the third and fourth ports of said coupling device; bodies of ferrite material, having a permeability which varies substantially as a function of the magnetic field strength in the material, filling said waveguide sections to provide mediums which propagate waves with a variable velocity; means reflectively terminating each of said waveguide sections at a second end; and a pair of switching means adapted to produce two conditions of magnetic field strength in each of said bodies of ferrite to vary the ferrite permeability and thereby change the velocity of wave propagation in said ferrite which pair of switching means when set respectively to median values between said two conditions, establish a mean electrical length for said respective waveguide sections which are near an integral multiple of a quarter wavelength whereby a variation in the reactance of said waveguide section and a selection of one of two phase shifts corresponding to said first and second pairs of given phase shifts in the reflected wave are obtained in accordance with the variation in the electrical length of said waveguide section.

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