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MICROWAVE MODE CONVERTER

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18 Claims. (Cl. 333—13)

This invention relates generally to the transmission and reception of ultra-high frequency electromagnetic energy, and more particularly to a method and apparatus for controlling the mode of propagation of said energy.

In effecting the propagation of electromagnetic energy along wave guides, it is often desirable to effect a change in the mode of propagation of the waves. For purposes of this discussion, the term "Mode" is defined as a form of propagation of guided waves that is characterized by a particular field pattern configuration, without regard to the polarization direction of the pattern, in a plane transverse to the direction of propagation, which field pattern configuration is independent of position along the axis of the waveguide. A controllable mode switching apparatus finds particular usefulness for selectively guiding energy into desired channels. For example, in the case of radar obstacle detection devices it is common practice to operate the pulse transmitter and the pulse echo receiver in conjunction with a common antenna. By providing a mode converter in a section of the wave guide feeding the antenna, which is common to both the transmitter and receiver, it is possible to limit substantially all the transmitted energy to the antenna and all the received energy to the receiver with a minimum of interchange of energy between the transmitter and receiver. If the mode switching apparatus were made non-linear, that is, dependent upon the amplitude of applied energy, then an automatic mode switching would result.

It is an object of my invention, therefore, to provide a novel method and means for changing the mode of propagation of electromagnetic waves along a wave guide.

It is another object of my invention to provide a method and means for automatically changing the mode of propagation of electromagnetic waves along a wave guide in accordance with the intensity level of said waves.

It is another object of my invention to provide a novel method and means for selectively routing electromagnetic waves of different energy intensity into separate channels.

It is another object of my invention to provide novel means for changing the mode of propagation of electromagnetic waves in a substantially symmetrical wave guide by introducing an asymmetry into the wave guide in response to electromagnetic waves above a given intensity.

It is another object of my invention to provide non-linear means in a symmetrical wave guide for introducing an asymmetry into the wave guide thereby changing the mode of propagation of electromagnetic waves traveling along the wave guide.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My 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 taken in connection with the accompanying drawing in which Fig. 1 is a simplified perspective view of a transmit-receive switch and wave guide assembly embodying the invention; Fig. 2 illustrates graphically the nature of the mode

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conversion effected by the circuit arrangement of Fig. 1; Fig. 3 is a vertical elevation view of a mode filter employed in the arrangement of Fig. 1; and Fig. 4 is a vertical elevation view of the non-linear mode transformation fin employed in Fig. 1.

Referring to Fig. 1, there is shown a micro-wave duplexing arrangement in accordance with the invention for transmitting high intensity radar pulses available at the lower end of the rectangular guide 1, over the circular wave guide 2, comprising wave guide portions 3 and 4, to the rectangular wave guide 5 for application to the radar antenna, not shown. The radar pulses received on the antenna are passed through the wave guide 5 and the circular wave guide portion 4 to the rectangular wave guide 6 feeding the radar receiver, not shown. Wave guide 6 is of a rectangular form so oriented as to be incapable of transmitting to the receiver waves of the mode supplied through guide 2 toward the antenna.

To insure that echoes of these waves supplied through channel 2 may be received in the rectangular guide 6, mode changing means 7 is employed in channel 2 at a point beyond channel 6. This mode changing means converts the waves propagated through channel 2 toward the antenna to waves the echoes of which, when supplied backward through the channel, are of a mode which is readily and efficiently propagated through guide 6 to the receiver.

To prevent these latter echo waves from being transmitted on to portion 3 of the channel, a filter 9 is provided in the wave guide of a character to prevent transmission of such waves on through the channel.

Mode changing means 7 may comprise a vessel, suitably of glass, or other dielectric material, having the general fin or wedge shape form illustrated by the dotted lines 7 in Fig. 1 and containing a suitable ionizable gas such as argon. The plane of this vessel may be arranged to lie on a diameter of the waveguide, and the form of the vessel is such that the ionizable gas forms a thin sheet, or slab, on the diameter. With the gas in the non-ionized state, it is ineffective to cause a change in the mode of propagation of waves along the circular wave guide section 4. However, the ionizable medium in the vessel becomes ionized in response to electromagnetic waves of a sufficiently high intensity level. When ionized the ionized gas introduces an asymmetry into the normally symmetrical wave guide portion 4 which causes a change in the mode of propagation of waves therethrough.

In operation the system is energized from an ultra-high frequency transmitter, not shown, which supplies plane polarized waves of the rectangular TE_{01} mode at the lower end of wave guide section 1. The energy is transformed from the TE_{01} mode in the rectangular wave guide 1 to the TM_{01} mode in the circular wave guide 3 by the simple junction 8. The energy in the TM_{01} mode continues down the circular wave guide 3, past filter 9 and the wave guide 6. Wave guide 6 is so oriented with respect to the wave guide 3 that it will not receive waves propagated in the circular TM_{01} mode. The high intensity of the transmitted TM_{01} waves passing fin 7 causes the ionizable medium to ionize, thereby placing an effective conducting element in the normally symmetrical wave guide 4. Insertion of this conducting element in wave guide 4 introduces an asymmetry which causes the mode of propagation of waves passing the fin 7 to be altered. The details of how this is accomplished will be explained later in connection with Fig. 2 of the drawings. Briefly, the action of the fin is to transform the transmitted energy in the circular TM_{01} mode approaching the fin to the circular TE_{11} mode leaving the fin.

Wave guide section 10 comprises a transformer for converting the energy in the circular TE_{11} mode leaving

the fin 7 to the TE_{01} mode in the rectangular wave guide 5. Energy in the TE_{01} mode in the rectangular wave guide 5 may then be applied to the radar antenna, not shown, for transmission to an obstacle located in the path of the transmitted energy.

The echo pulses reflected from the obstacle and received by an antenna are propagated in the TE_{01} mode along wave guide 5, transformed to the circular TE_{11} mode by transformer 10, and pass the fin 7 contained in the circular wave guide 4. The received energy is not of sufficient intensity to ionize the medium in the fin 7, and hence the fin is inoperative to effect a change in the mode of propagation the passing received waves. Consequently, the received waves in the circular TE_{11} mode approaching the fin from the right hand side leave the fin at the left hand side in the same mode. The wave guide section 6 is oriented for maximum excitation by waves of the circular TE_{11} mode whereas previously its orientation substantially prevented excitation by the transmitted waves of the circular TM_{01} mode. Thus, the received waves in the TE_{11} mode, propagated in the circular wave guide section 4, approach the junction with the rectangular wave guide section 6, and are propagated over wave guide 6 in the rectangular TE_{01} mode to the receiver, not shown.

To prevent the loss of any received energy to the transmitter, the circular TE_{11} mode filter 9 is mounted within the wave guide portion 3 substantially a quarter wave length distance at the operating frequency from the junction of the rectangular wave guide 6 with the circular wave guide portion 3. The mode filter 9 comprises conductive wires so oriented that they are substantially ineffective to passage therethrough of waves propagated in the circular TM_{01} mode while effectively providing a short circuit for the received waves propagated in the circular TE_{11} mode. The effective short circuit located a quarter wave from the junction of wave guides 6 and 3 introduces a high impedance at this junction to the circular TE_{11} received waves traveling in the direction of the transmitter. The net result of the arrangement shown in Fig. 1 is substantially to couple all of the transmitted power to the radar antenna and all of the received radar power to the receiver without providing any intercoupling between the transmitter and receiver sections.

Referring to Fig. 2, the nature of the mode transformation is clearly illustrated graphically. Graph *a* illustrates the rectangular TE_{01} mode of the transmitted energy passing through wave guide section 1, whereas graph *b* illustrates the circular TM_{01} mode of propagation of the transmitted energy in the circular wave guide section 3. Upon arrival at the right hand leading edge of the fin 7, which is rendered ionizable by the high intensity of the transmitted energy, there occurs a mode transition which progresses along the fin substantially as shown in graph *d* to yield the circular TE_{11} mode of propagation of the transmitted power leaving the trailing edge of the fin 7 as shown in graph *e*. The transmitted energy in the circular TE_{11} mode shown in graph *e* is then transformed into the rectangular TE_{01} mode shown in graph *f* by the transformer 10. The received energy in the rectangular TE_{01} mode shown in graph *f* is changed to the circular TE_{11} mode after passage through the transformer 10. The fin, 7, remains non-ionized due to the low intensity of the received energy, permitting passage of the received waves in the circular TE_{11} mode without any mode change. The rectangular wave guide portion 6, which is oriented for minimum excitation by waves transmitted in the circular TM_{01} mode but a maximum excitation by waves in the circular TE_{11} mode, finally receives the waves in the circular TE_{11} mode and applies them to the receiver, not shown, in the rectangular TE_{01} mode.

Referring to Fig. 3, a specific construction of the

mode filter 9 is disclosed in detail. The filter is of a well known type, the metallic comprising rings 9 mounted within the guide 2 and so oriented that they are substantially perpendicular to the electric vector of the transmitted waves of the circular TM_{01} mode, thus having little effect on these waves. However, the rings 9 act as a resonant circuit parallel to the waveguide for the circular TE_{11} mode, thereby providing a substantial short circuit to transmission of received waves in the circular TE_{11} mode past the filter.

Fig. 4 shows in greater detail the mode transformation fin 7. In a particular embodiment the fin comprises a dielectric container 7, such as glass, containing an ionizable gas which renders the fin non-linear, that is, ionizable in response to wave energy above a given intensity. Thus, energy of relatively high level, such as that of transmitted radar pulses causes the gas to ionize and effectively place a conductor across vertical diameter of the circular wave guide portion 4. This introduces an asymmetry into the normally symmetrical wave guide portion 4 which causes a change in the mode of propagation of the transmitted waves. By tapering the fin in the direction of propagation of the transmitted waves, a smooth transfer from the circular TM_{01} mode to the circular TE_{11} mode is achieved.

After the passage of the transmitted energy the gas becomes deionized. The received waves being of insufficient intensity to ionize the gas pass by the fin without any change in their mode of propagation.

The materials forming the fin are selected and the fin so dimensioned that a minimum of transmitted energy is lost in passing the fin. In a particular embodiment the fin is made in the form of a wedge of glass filled with divided quartz and an inert gas which permits a rapid ionization and deionization time for the gas during the transmit period and hence provides a fast acting mode switching action.

While a specific configuration for the mode converter has been described in connection with the embodiment of Fig. 1, other configurations may be resorted to. Furthermore, other materials may be resorted to for introducing an asymmetry into a wave guide in accordance with the intensity of the waves propagated therein for achieving mode transformations.

While I have shown only a certain preferred embodiment of my invention by way of illustration, many modifications will occur to those skilled in the art, and I therefore wish to have it understood that I intend in the appended claims to cover all such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. Apparatus for processing electromagnetic waves comprising a wave guide substantially symmetrical about the axis of propagation thereof, means for propagating said waves in one mode through said guide, means for rendering said guide asymmetrical in a manner varying along the axis of propagation of said guide in response to said propagated waves above a predetermined intensity, said asymmetry in said wave guide being proportioned to change the mode of propagation of said waves.

2. An arrangement for processing electromagnetic waves of different amplitudes comprising a wave guide, means for transmitting a first wave through said wave guide, an ionizable medium positioned within said wave guide, said ionizable medium having a form and orientation adapted to change the mode of propagation of waves passing therethrough only upon becoming ionized, said first wave being of sufficient amplitude to cause ionization of said medium, means for transmitting a second wave through said wave guide, said wave having insufficient amplitude to cause ionization of said medium, whereby the mode of propagation of said first wave is altered and the mode or propagation of said second wave

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is unaltered, thereby processing said waves of different amplitudes.

3. Apparatus for processing electromagnetic waves of different intensities comprising a wave guide, a discrete ionizable medium being located within said wave guide, the form and orientation in said wave guide of said medium with respect to waves propagated in one mode along said wave guide adapted to guide the lines of force associated with said last named waves to change the mode of propagation of said waves to another mode when said medium becomes ionized, means for causing said waves to be propagated in said one mode along said wave guide, said medium being further oriented so that said medium is ionized by waves of said one mode having an intensity above a predetermined intensity, whereby waves of said one mode having an intensity above said predetermined intensity are propagated in said other mode along said wave guide and the mode of propagation of waves having an intensity below said predetermined intensity are unaffected.

4. Apparatus for selectively propagating plane polarized electromagnetic waves of different amplitudes, comprising a first wave guide capable of sustaining the propagation of waves of first and second modes, a second wave guide coupled to said first wave guide at a point between the ends thereof and oriented with respect to said first wave guide in a manner to be unexcitable by waves of said first mode in said first wave guide while being excitable by waves of said second mode in said first wave guide to propagate waves of said second mode, means for applying waves of said first mode to one end of said first wave guide, means for changing the mode of propagation of said waves of said first mode to said second mode when said waves of said first mode are large in amplitude, said means including an element positioned within said first wave guide between the other end thereof and the junction of said wave guides, said element being ionizable by waves of large amplitude and being unionizable by waves of small amplitude, means for applying waves of small amplitude of said second mode to said other end of said first wave guide, whereby said waves of large amplitude of said first mode are not propagated by said second wave guide while said waves of small amplitude of said second mode are propagated by said second wave guide.

5. A converter of the mode of propagation of electromagnetic waves comprising a wave guide substantially symmetrical with respect to the axis of propagation thereof, a normally electrically nonconductive element mounted within said guide, said element having a predetermined configuration varying in the direction of propagation of waves along said guide, said element being arranged to become electrically conductive in response to waves propagated along said guide having an intensity greater than a predetermined magnitude to render said guide asymmetrical in a manner and a degree varying in the direction of propagation of said waves sufficient to cause the mode of propagation of said waves to be changed.

6. A converter of the mode of propagation of electromagnetic waves comprising a wave guide substantially symmetrical along the axis of wave propagation of said wave guide, an element mounted within said wave guide, said element having a characteristic responsive to waves above a predetermined intensity to render said wave guide asymmetrical in a manner and a degree varying in the direction of propagation of said waves sufficient to cause the mode of propagation of said waves to be changed.

7. Apparatus for selectively propagating electromagnetic waves of different amplitudes, comprising a first wave guide capable of sustaining propagation of waves of first and second modes, a second wave guide coupled to said first wave guide at a point between the ends thereof and oriented with respect to said first wave guide in a manner to be unexcitable by waves of said first mode

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in said first wave guide while being excitable by waves of said second mode in said first wave guide to propagate waves of said second mode, means for applying waves of said first mode to one end of said first wave guide, means for changing the mode of propagation of said waves of said first mode to said second mode when said waves of said first mode are large in amplitude, comprising means responsive to first waves above a predetermined intensity for introducing an asymmetry into said first wave guide sufficient to cause said last-named change of mode small in amplitude to the other end of said first wave guide, whereby waves of large amplitude of said first mode propagated from said one end of said wave guide are not propagated by said second wave guide while waves of small amplitude from said other end of said wave guide are propagated in said second wave guide.

8. Apparatus for selectively propagating electromagnetic waves of different amplitudes, comprising a first wave guide capable of sustaining propagation of waves of first and second modes, a second wave guide coupled to said first wave guide at a point between the ends thereof and oriented with respect to said first wave guide in a manner to be unexcitable by waves of said first mode in said first wave guide while being excitable by waves of said second mode in said first wave guide to propagate waves of said second mode, means for applying waves of said first mode to one end of said first wave guide, means for changing the mode of propagation of said waves of said first mode to said second mode when said waves of said first mode are large in amplitude, comprising means responsive to said waves of said first mode having an amplitude above a predetermined level for introducing an asymmetry in said guide sufficient to cause said last-named change of mode small in amplitude to the other end of said first wave guide, means positioned between the junction of said wave guides and said one end for passing waves of said first mode and rejecting waves of said second mode, whereby waves of large amplitude of said first mode propagated from said one end of said first wave guide are not propagated by said second wave guide while waves of small amplitude from said other end of said first wave guide are propagated in said second wave guide.

9. In combination, a first wave guide adapted to propagate electromagnetic waves in two different modes, normally inoperative means mounted within said first guide and responsive to waves of one of said modes above a given amplitude to become operative and introduce an asymmetry into said guide sufficient to convert said waves propagated within said first guide to the other of said modes, and a second wave guide coupled to said first wave guide and adapted to propagate waves in said other mode and not of said one mode.

10. The combination, in a system for propagating electromagnetic waves, of a waveguide, means to propagate waves of one intensity along said guide in one mode and waves of another intensity along said guide in another mode comprising means within said guide responsive solely to waves having said one intensity and not said another intensity to change the symmetry of said guide sufficient to change said one mode of propagation to said another mode.

11. An arrangement for processing electromagnetic waves within a waveguide comprising means for propagating polarized waves of a first mode within said guide, means responsive to said propagated waves having an intensity above a predetermined level for introducing a change of symmetry in said waveguide sufficient to change said wave abruptly into two separate waves of the same mode but different polarization, and means for progressively combining said two separate waves to common waves of a predetermined polarization and a predetermined mode which are different from said first mode.

12. An arrangement for processing electromagnetic waves within a waveguide comprising means for propa-

gating electromagnetic waves of one pattern of lines of force within said guide, an ionizable medium of a predetermined size and shape positioned within said guide responsive to said propagated waves having an intensity above a predetermined level to become conductive and change, abruptly, the pattern of the lines of force of said waves received on said conductive medium and then to progressively guide said lines of force sufficiently to cause a change in the mode of propagation of said propagated waves.

13. In combination, a waveguide, means for propagating electromagnetic waves in a given mode through said waveguide, an element positioned within said waveguide, said element having a characteristic responsive to waves having an intensity above a predetermined level for rendering said waveguide asymmetrical in a manner and to a degree varying in the direction of propagation of said waves sufficient to change the mode of propagation of said waves.

14. An arrangement for processing electromagnetic waves within a waveguide which comprises means for propagating waves of a first mode within said guide, and means responsive only to propagated waves having an intensity above a predetermined level for introducing a change in the symmetry of said guide sufficient to change said last-named waves of said first mode into a plurality of separate waves of a common mode different from said first mode.

15. An arrangement for processing electromagnetic waves comprising a waveguide, means for propagating waves of a first mode within said waveguide, means responsive to said propagated waves having an intensity above a predetermined level for introducing an asymmetry into said guide sufficient to change said waves into two separate waves of the same mode but of different polarization, said same mode being different from said first mode.

16. In combination, a source of waves, a waveguide, means for propagating said waves within said guide in a first mode, means positioned within said guide and responsive to said propagated waves impinging thereon hav-

ing an intensity above a predetermined level for changing the waveguide symmetry to convert the mode of propagation of said waves from said one mode to a different mode.

17. An arrangement for processing electromagnetic waves of relatively high and low intensity comprising a substantially symmetrical waveguide, means for propagating said waves one at a time along said waveguide, means responsive to waves of said high intensity for introducing a changing degree of asymmetry in said waveguide along a predetermined portion of its length sufficient to change the mode of propagation of said waves, said means being non-responsive to waves of said low intensity for maintaining symmetry in said guide.

18. In combination a source of waves, a waveguide, means for propagating said waves within said waveguide a nonconductive means of predetermined dimensions positioned within said waveguide and rendered conductive in response to waves of one intensity and nonresponsive to waves of another intensity to change the mode of propagation of waves from one mode to another.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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December 10, 1957

Jabus Barker

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

Column 6, line 59, for "solely to waves" read -- solely to said waves of said one mode --.

Signed and sealed this 28th day of October 1958.

(SEAL)
Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents