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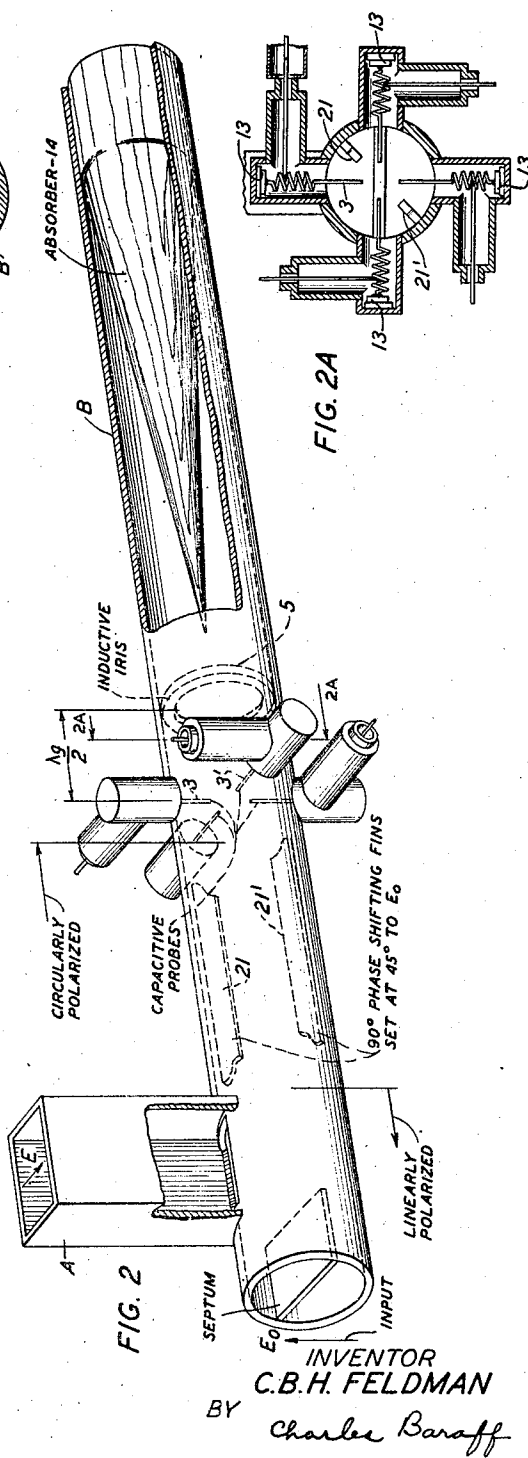
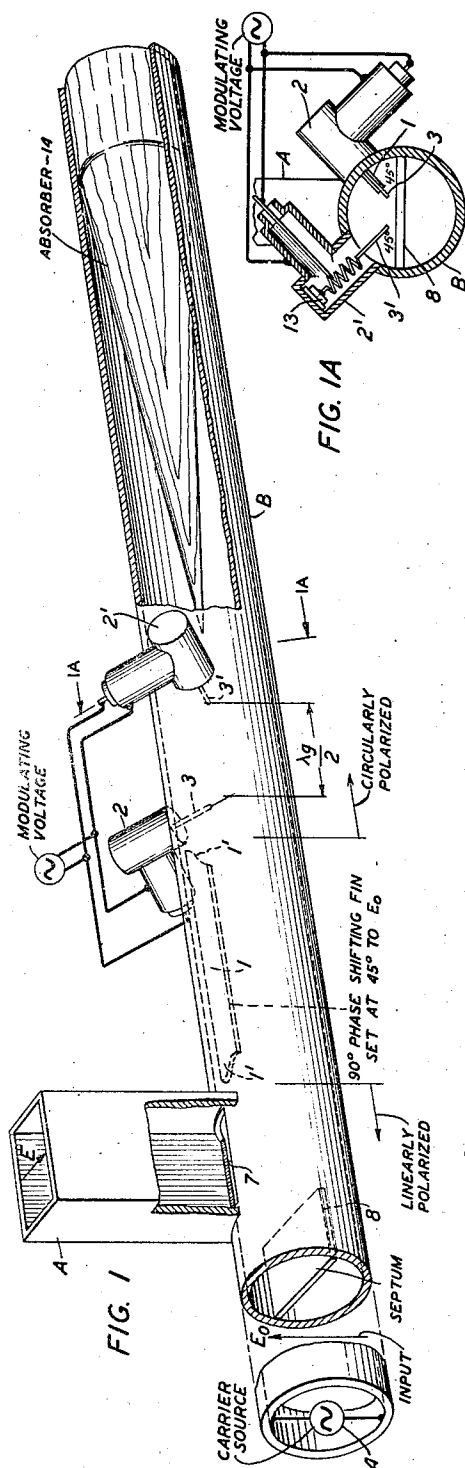
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2,458,579

MICROWAVE MODULATOR

Filed April 26, 1945

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

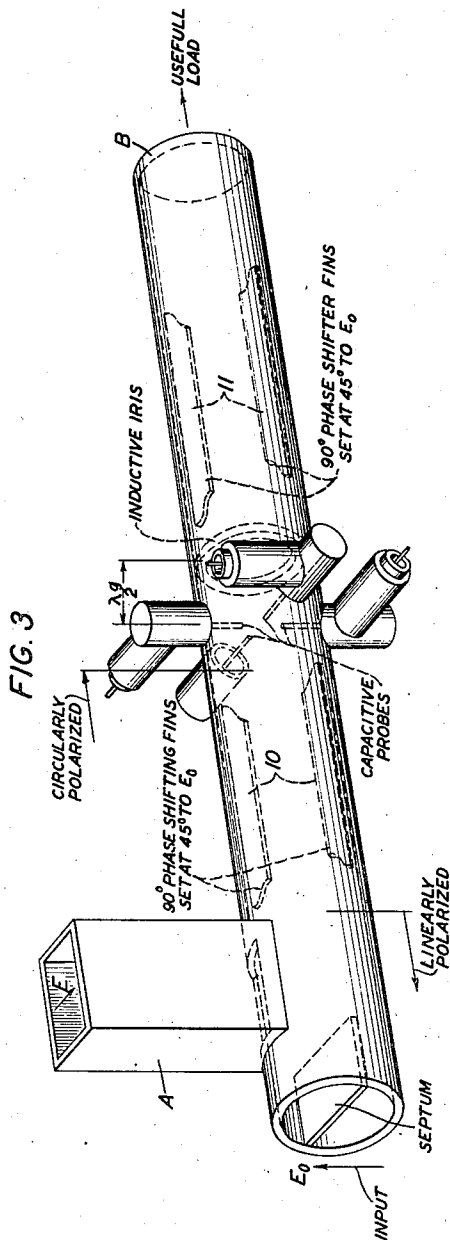


FIG. 1B

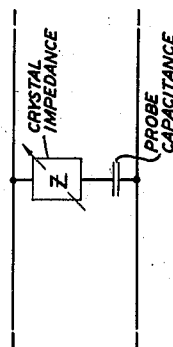
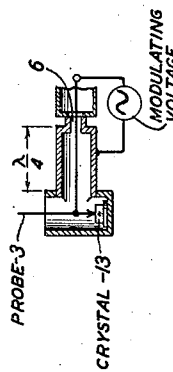


FIG. 4



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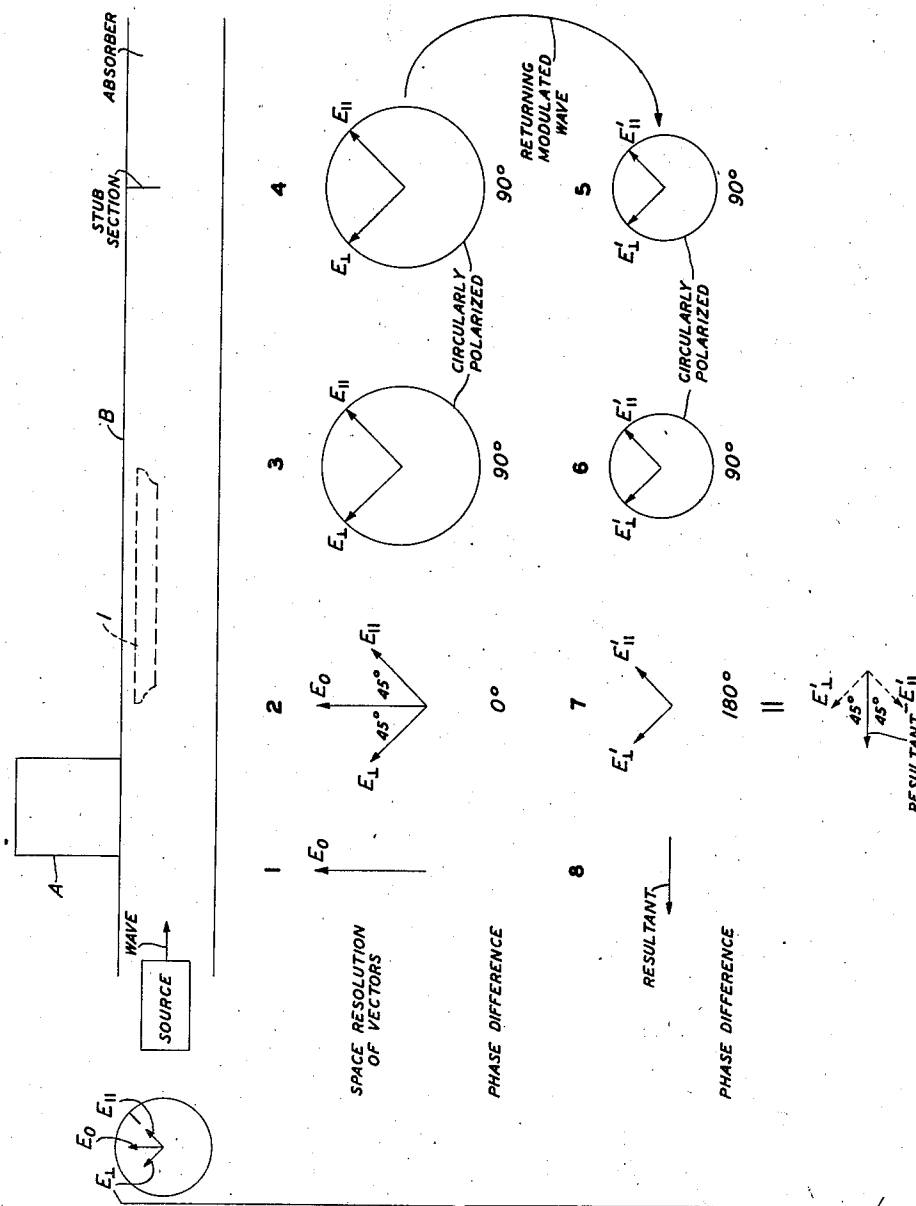
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MICROWAVE MODULATOR

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3 Sheets-Sheet 3



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MICROWAVE MODULATOR

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Application April 26, 1945, Serial No. 590,367

38 Claims. (Cl. 179—171.5)

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This invention relates to microwave power dividers and modulators.

A general object of the invention is to partition the energy derived from a microwave source into separable components, linearly and circularly polarized, respectively, and to controllably vary the relative energies of the components without reaction upon the source.

A principal object of the invention is to reflectively modulate a carrier microwave propagated through a wave guide, without affecting the frequency, amplitude or phase stability of the carrier source.

Another principal object is to convert a linearly polarized wave into a circularly polarized wave, and to reflectively modulate the latter without reaction upon the wave source.

Another principal object of the invention is to segregate from the carrier wave and to separately propagate a modulated wave, by virtue of their mutually perpendicular linear polarizations, without affecting the stability of the carrier source.

A further object of the invention is to modulate a circularly polarized wave in a wave guide.

Another object of the invention is to reflectively modulate, in a wave guide, a circularly polarized carrier wave and to linearly polarize the resultant modulated wave without reaction upon the carrier source.

Other objects and advantages will be apparent from the specification taken in connection with the accompanying drawings, wherein:

Fig. 1 shows a perspective view of a wave guide modulation system;

Fig. 1A shows a typical cross-sectional view thereof taken along 1A;

Fig. 1B is an equivalent circuit diagram of a stub section;

Fig. 2 shows a preferred modification of the wave guide modulation system;

Fig. 2A shows the corresponding typical cross-sectional view taken along 2A;

Fig. 3 shows a controllable power divider for linearly polarized waves; and

Fig. 4 represents a stub element with the modulating crystal and probe element associated therewith; and

Fig. 5 is an explanatory diagram for Fig. 1 depicting polarization states and electric force components.

Microwave modulator circuits have heretofore suffered from a lack of stability in the generating source, resulting often from the reaction of the associated circuits upon the generator, altering its frequency, amplitude, or phase.

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In accordance with this invention modulation is accomplished without reaction upon the carrier source. This result is effected in three stages:

(1) A linearly polarized carrier is converted by a 90-degree phase shifter, into a circular polarization prior to modulation.

(2) By means of probes and crystals, the carrier is reflectively modulated in accordance with the modulating signal.

(3) The reflected modulated waves are converted by a second 90-degree phase shift, into a linear polarization, perpendicular to the original carrier, whereby separation therebetween is effected without reaction on the source.

Applicant's modulation system incorporates certain novel and useful characteristics, as will become apparent from the following detailed description and appended claims.

The term "reflective modulation" as used in this specification, may be defined as a modulation, produced by a material or substance, whose reflectivity characteristic for microwaves, can be varied in accordance with a modulating current or voltage, whereby the amplitude of the carrier is thereby varied as a function of the signal.

Linear polarization as applied herein may be defined as a state of the field, wherein the electric vectors have, practically speaking, a fixed direction, as contrasted with a random distribution of orientations.

Circular polarization is defined herein as a state of the field, wherein the electric vectors are resolvable into mutually perpendicular, linearly polarized components of equal amplitude, differing 90 degrees in time phase.

The term "dominant wave" defines the mode, having the lowest possible cut-off frequency, capable of propagation in a predetermined pipe.

Referring to Fig. 1, a carrier wave is applied to the main cylindrical wave guide B as a linearly polarized, dominant microwave, having its electric vector E_0 perpendicular to the cylinder axis. The linear polarization may be effected in any well-known manner, such as by the use of opposed, spaced diametral connections from the microwave oscillator to the guide as disclosed in United States patent to G. C. Southworth 2,106,771 patented February 1, 1938, or in the association of a square guide with a circular guide, as in the United States patent to A. E. Bowen 2,129,669 patented September 13, 1938, or by the use of an extended probe, as in the United States patent to W. L. Barrow 2,255,042 patented September 9, 1941, or in various other manners, familiar to those skilled in the microwave art. The source 4 of microwave

oscillations shown schematically in Fig. 1 may be any of the well-known types, such as the Barkhausen-Kurz, the velocity variation, the magnetron, the spark gap discharge, etc.

The propagation of the carrier wave in the wave guide proceeds in a forward direction from left to right, unaffected by the presence of the septum 8, whose plane is perpendicular to E_0 . The linearly polarized wave E_0 , incident upon the 90-degree phase shifting section, is converted during its passage therethrough into an emergent circularly polarized wave by the phase shifting action of the internal metallic fin 1, which extends radially thereto. The fin is set at an angle of 45 degrees (see Fig. 1A) to the direction of E_0 , to afford a resolution of the electric force vector E_0 into equal and mutually perpendicular components, viz. $E_{\parallel}$ parallel to the fin and $E_{\perp}$ perpendicular to the fin, (as illustrated in Fig. 5).

The details of the construction of the 90-degree phase shift section, the proportioning of the fin 1, the underlying theory and mode of operation thereof are fully set forth in the United States application of W. A. Tyrrell, Serial No. 590,365 filed April 26, 1945. Fundamentally, as disclosed in said application, the fin affects the wave velocity and therefore the phase of the component $E_{\perp}$ parallel thereto, while its relative action on the component $E_{\parallel}$ perpendicular thereto is practically nil. As further disclosed in said Tyrrell application, the length of the fin is proportioned to provide the desired relative 90-degree phase shift between the components, whereby the conversion to circular polarization is achieved, as illustrated in Fig. 5. In addition, provision is made for impedance matching of the fin to the guide by means of terminations 1' of reduced or tapered cross-section.

The nature of the conversion from the linearly polarized state to the circularly polarized state by the 90-degree phase shift section has been represented diagrammatically in Fig. 5. The vector diagram 1 shows the source, the direction of propagation of the input wave, and the direction of the unresolved vector E_0 . Vector diagram 2 shows E_0 resolved spacially into its components $E_{\parallel}$ and $E_{\perp}$ with respect to the plane of the fin. The phase coincidence between $E_{\parallel}$ and $E_{\perp}$ is represented on the diagram by a phase difference of 0 degrees. Vector diagram 3 shows the state of the emerging wave as a circularly polarized microwave field. Here the spacial relation between the components is still unchanged but a relative difference of 90 degrees in time phase therebetween has been introduced by the action of the phase shift section. The circular polarization is schematically represented by a circle passing through the vector end points. Vector diagram 4 depicts the circularly polarized state of the microwave field in the region of the modulating stub sections.

Modulation of the circularly polarized waves in accordance with signal variations, is accomplished in the modulating stub sections 2, 2' (Fig. 1) by varying the reflection produced by a modulating crystal contained therein.

The pair of coaxial line stub sections 2, 2' are located beyond the phase shift section and spaced a distance approximately $\lambda_g/2$ apart (where λ_g equals the wavelength in the guide) to eliminate the possibility of disturbing interactions therebetween.

Each stub section is provided with a modulating crystal 13 and a coupling or pick-up probe 3

in contact therewith, as shown in greater detail in the cross-section view of Fig. 4. The microwaves are picked up by the probe and applied to the crystal over the longitudinal coaxial line section of the stub. The modulating voltages are applied to the crystal from the terminals and over the connections shown in Fig. 4. In order to provide highly efficient operation of the crystal at the microwave frequency and to permit the transfer of modulating voltage thereto without disturbing the microwave propagation, a $\lambda/4$ coaxial line (where λ =microwave length in air) terminated by a coaxial by-pass condenser 6 is connected transversely to the longitudinal, coaxial section of the stub.

Referring to Fig. 1, the crystals 13 and probes 3 and 3' should be identical structurally and electrically in order to provide equal reflections respectively for the components $E_{\parallel}$ and $E_{\perp}$ of the circularly polarized microwave field. The relative 90-degree angular disposition between probes 3 and 3' is illustrated in Fig. 1A.

The desired behavior of the reflecting probes could be obtained by making them coplanar. However, in such an arrangement, a mutual coupling or interaction therebetween would supervene and tend to introduce undesirable effects. Spacing the probes a distance of $\lambda_g/2$ apart, renders negligible the interaction and preserves the desired relative phase relationships between the components $E_{\parallel}$ and $E_{\perp}$.

The modulating voltages may be in the audio, radio or ultra-high frequency range and may be continuous or pulsating in character. They are applied to the crystals over parallel paths (not shown) from the terminals shown in Fig. 4.

The crystals may be silicon, germanium, iron pyrites, Carborundum, zinc sulphide, or any other materials effective in the microwave range.

Modulation involves the pick-up of the corresponding microwave components $E_{\perp}$ and $E_{\parallel}$ by the corresponding probes 3 and 3' parallel thereto and their application to the appropriate modulating crystals which, as is well known, have a non-linear characteristic.

The reflective coefficient k_0 of the crystal is variable and changes in accordance with the modulating voltage applied thereto. As a consequence, the circularly polarized microwaves applied to the crystals, are variably reflected and directed toward the useful load A under the control of the modulating voltage.

Little or no modulated power is taken out at the useful load A when the crystals are operated under the condition of maximum impedance Z (Fig. 1B). As impedance Z decreases, increased reflection occurs and more power appears in A, until finally a maximum of power may be withdrawn therefrom.

Waves, which are not withdrawn at the useful load A, are either absorbed in the crystals or in the tapered cylindrical absorber of wood 14 or the like, shown in Fig. 1.

The stub sections may, if desired, assume various positions arising from rotational displacements by rotational angle θ about the principal guide axis, as occurs in Fig. 2, for example, without altering the essential characteristics of the modulation impressed on the circularly polarized microwave field.

Referring to the diagrammatic showing of Fig. 5, the returning modulated wave, as a consequence of the reflective modulation is shown in vector diagram 5 as circularly polarized with com-

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ponents $E'_{\parallel}$ and $E'_{\perp}$, equally reduced in amplitude and still 90 degrees out of time phase.

Vector diagram 6 shows the resolution of the returning circularly polarized wave into perpendicular components at the input to the 90-degree phase shift section.

In its return passage through the 90-degree phase shift section, the wave suffers another 90-degree time phase shift in the parallel component $E'_{\parallel}$, relative to the perpendicular component $E'_{\perp}$.

Accordingly, upon emergence from the phase shift section, the wave is characterized by a parallel component $E'_{\parallel}$ displaced a total of 180 degrees in phase for the to and fro passage, and by a perpendicular component $E'_{\perp}$ with relatively unchanged phase, as depicted in vector diagram 7. The resultant electric force vector of the emerging wave is compounded from $E'_{\perp}$ and the dotted vector ($-E'_{\parallel}$), as illustrated in vector diagram 7, these components being phase coincident.

By comparing vector diagram 7 and vector diagram 2, it will be obvious that the resultant electric force vector of the emerging wave is linearly polarized and perpendicular in direction to the original input vector E_0 . The perpendicularity arises from the 45-degree angle relationships shown in Fig. 5.

The perpendicularity between the emerging resultant vector and E_0 permits the efficient separation and segregation of the modulated wave from the original carrier E_0 . The returning modulated wave, as it approaches the original source, is effectively reflected and launched into the branch rectangular guide A by means of the diametral septum 8, acting like a reflecting wall to electric force components parallel thereto. The entrance into the side chamber A is constituted by a rectangular slot 7.

The transverse septum 8 is a thin metallic plate, having its plane perpendicular to E_0 . Since the resultant emerging vector was also shown to be perpendicular to E_0 , it follows that the resultant will lie parallel to the septum. The length of the septum may be $\lambda_g/2$ or greater for the complete reflection of the resultant vector or modulated wave into chamber A, wherein it is propagated as a dominant wave E.

Propagation of the modulated wave into the source, is effectively prevented by the transverse septum 8, which divides the main guide diametrically into two semi-circular sections. The effect of the division is to shift the critical wavelength of these sections to a value beyond cut-off, thereby to render impossible the propagation of the modulated wave therethrough and into the source. For the original input wave, whose polarization is perpendicular thereto, the septum has no effect on its forward propagation nor on its cut-off frequencies.

Accordingly, as the source energy is variably partitioned between modulated energy, which flows out into the useful load A, and absorbed energy, by means of the modulating voltage control, the source itself remains constant and unchanged, and free from disturbing reaction effects.

The preferred modification, illustrated in Fig. 2, is better adapted for broad band work and high power than the system of Fig. 1. To this end, it is provided with a pair of coplanar fins 21 and 21' in the phase shift section, and four coplanar modulating stub sections. The probes form collinear pairs which are mutually perpendicular

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to each other. The symmetry of the probe arrangement cancels or nullifies any interaction tendencies therebetween.

In order to produce zero reflection at some desirable value of crystal impedance, such as at one extreme or the other of its range of variation, an inductive iris 5 of the correct size may be used, spaced approximately $\lambda_g/2$ away from the plane of the probes. When the crystal impedance is caused to vary to the opposite extreme under the influence of the modulating voltage, the power withdrawn at the useful load A will be at its maximum.

The arrangement of the probes and fins with respect to the main cylinder axis will be apparent from the cross-sectional view of Fig. 2A.

The operation of the system shown in Fig. 2 is essentially similar to that described in connection with Fig. 1, corresponding parts performing the same operations in both instances.

Whereas the systems of Figs. 1 and 2 have been described as modulators, they may with small modification be utilized as power dividers, variably partitioning source energy in the microwave range into separable waves of like or unlike polarizations. Thus, the systems of Figs. 1 and 2 may be modified for use as power dividers, by removing the absorber 14, and permitting radiation to issue from the open end. The unabsorbed and transmitted circularly polarized waves will propagate from the open end, while linearly polarized waves are drawn off through side chamber A. The microwave crystals 13, under the control of a variable control voltage, determine the proportioning of source energy as between the separable circularly and linearly polarized waves.

As a power divider, the modification shown in Fig. 3 is capable of partitioning the energy from a microwave source into separable linearly polarized components. For this purpose, a second pair of 90-degree phase shifting fins 11 is provided in the guide beyond the modulating section for converting the forwardly propagating circularly polarized waves into linearly polarized waves. By applying a variable voltage to the modulating crystals in parallel, the power ratio of the separable linearly polarized components may be varied correspondingly. The characteristic curves representing the energy versus the applied modulating voltage for the separated waves, will be mutually complementary, neglecting the energy dissipated in the modulating crystals.

Although the present invention has been described with reference to specific embodiments thereof, it may be embodied in various other forms within the spirit and scope of the appended claims.

What is claimed is:

1. In a wave guide modulator for microwaves, a cylindrical wave guide, a source connected thereto for propagating a linearly polarized carrier wave therein, means in said guide adapted to convert the carrier wave into a circularly polarized wave, means for reflectively modulating the circularly polarized wave without reaction upon the carrier source, and a branching wave guide connected to said cylindrical guide between said source and polarization converting means for segregating and propagating the linearly polarized, modulated wave in a direction perpendicular to said cylindrical guide's principal axis.

2. A microwave modulator comprising a source of linearly polarized carrier waves, means adapted to convert said linearly polarized waves

into circularly polarized waves and conversely, means for variably reflecting and thereby modulating said carrier in accordance with a signal voltage and means for segregating the modulated waves without reaction upon the carrier source.

3. A microwave modulator comprising a cylindrical wave guide, means in said guide for producing a circularly polarized carrier wave, means for reflectively modulating said carrier in accordance with signal variations, and means connected to said guide for removing a linearly polarized, modulated wave therefrom.

4. A modulator comprising a source of linearly polarized carrier waves, means adapted to convert said waves into circularly polarized waves and conversely, and means for variably reflecting and modulating said waves, without reaction upon said source.

5. In combination, a source of linearly polarized carrier waves, a cylindrical wave guide, a differential 90 degree phase shifter and polarization rotator connected thereto and comprising a loaded section of wave guide, a modulator, and a rectangular branching guide connected to said cylindrical guide between said source and said modulator, whereby linearly polarized, modulated waves may be segregated and propagated therein.

6. A wave guide modulator comprising a source of linearly polarized carrier waves, a cylindrical wave guide, means adapted to produce therein circularly polarized waves and a modulating crystal connected to said cylindrical guide and adapted to variably reflect said circularly polarized waves in accordance with modulating signals.

7. A modulator comprising a cylindrical wave guide, a source of electromagnetic waves connected thereto, means in said guide adapted to provide circularly polarized waves, a non-linear element adapted to variably reflect and thereby modulate said waves in accordance with signal variations, and means adapted to segregate said modulated waves without reaction upon said source.

8. A microwave modulator comprising a source of linearly polarized waves, a cylindrical wave guide for propagating said waves, means therein adapted to circularly polarize said waves and a modulating substance having a variable reflectivity coefficient R_0 , adapted to reflect and thereby modulate said waves in accordance with signal variations, and means for segregating said modulated waves without reaction upon said source.

9. In a microwave modulator, a cylindrical hollow pipe, a source of linearly polarized carrier waves therein, a septum plate perpendicular to said polarization, means for converting said linearly polarized waves into circularly polarized waves, means for variably reflecting back and thereby modulating said circularly polarized waves, an absorber in said guide for transmitted waves, and means for effectively separating said modulated wave without affecting the impedance of said carrier source.

10. In a modulator for dielectrically guided microwaves, a cylindrical wave guide adapted to transmit a linearly polarized carrier wave, a metallic septum therein, perpendicular to said polarization, identical non-linear modulating elements connected to said guide and adapted to have their impedance characteristic vary in accordance with a modulating signal, mutually perpendicular probes connected to said elements, a source of modulating signals, and a branching wave guide connected to said cylindrical guide and adapted to segregate the modulated wave.

11. The method of transmitting radio signals

in a metallically bounded space which comprises producing a linearly polarized wave at microwave frequencies, deriving therefrom a circularly polarized wave, and modulating by reflecting the latter in accordance with signal variations.

12. The method of signaling which comprises generating a linearly polarized wave in the centimeter range, propagating the same in a metallically bounded space, circularly polarizing said wave, and then modulating by reflection the amplitude of the latter in accordance with a signal.

13. In combination, a source of linearly polarized carrier waves, a metallically bounded, hollow wave guide connected thereto, a reflecting modulator and a polarization rotator located between said source and said modulator, adapted to rotate the polarization of the modulated waves 90 degrees with respect to the carrier.

14. In combination, a source of linearly polarized waves, a symmetrical, hollow wave guide connected thereto, means for converting said linearly polarized waves to circular polarization, and means for variably reflecting waves of circular polarization in accordance with a modulating voltage.

15. In combination, a source of high frequency waves, a cylindrical wave guide connected thereto, means for producing a linearly polarized carrier wave therein, a circular polarizer in said guide, a crystal modulator and probe spaced from said circular polarizer, and means for segregating linearly polarized modulated waves without reaction upon said source.

16. In combination, a high frequency source, a cylindrical wave guide, means for establishing circularly polarized waves therein, and a modulator adapted to vary the amplitude thereof in accordance with signal variations.

17. A method of modulation at microwave frequencies comprising the steps of converting a linearly polarized dominant wave into a circularly polarized wave, modulating by variably reflecting the latter in accordance with signal variations, and segregating the modulated waves by converting them to linear polarization and rotating the converted polarization.

18. The method of signaling which comprises circularly polarizing an electromagnetic wave, variably reflecting and thereby modulating the same in accordance with signal variations.

19. The method of signaling which comprises circularly polarizing a linearly polarized microwave, modulating by reflecting the same in accordance with signal variations, and segregating a linearly polarized modulated wave by means of its polarization.

20. The method of signaling which comprises circularly polarizing a microwave, modulating the same in accordance with signal variations, converting the modulated wave into a rotated linearly polarized wave and segregating the converted modulated wave by means of its polarization.

21. The method of modulation which comprises polarizing electromagnetic energy, converting the same into a different state of polarization, modulating by reflecting the converted energy, and filtering the modulated energy by means of its polarization without reaction upon its source.

22. In combination, a source of microwaves, a hollow pipe wave guide connected thereto, means adapted to apply a dominant linearly polarized wave thereto, crystal modulators connected to said guide, a circular polarizer located between

said source and said crystal modulators, a pair of probes in said guide perpendicularly disposed to each other and connected to said crystal modulators, and means for producing a rotated linearly polarized modulated wave without reaction upon said source.

23. A microwave modulator comprising a source of linearly polarized waves, a hollow pipe wave guide connected thereto, crystals perpendicularly disposed with respect to said guide, a source of modulating voltage connected to said crystals and a polarization rotator connected between said source and said crystals and adapted to convert from linear to circular polarization and vice versa, and a reflecting septum adjacent said source for segregating the modulated waves having a linear polarization in quadrature to the source waves.

24. Means for modulating microwaves without changing the impedance of the source, comprising a source of incident linearly polarized waves, a cylindrical wave guide, an absorption modulator connected to said guide and adapted to have its absorption characteristic varied by a modulating voltage, and means for causing the modulated waves to be linearly polarized perpendicularly to the input wave.

25. Means for rotating the linear polarization of an electromagnetic wave through 90 degrees, comprising a section of wave guide pipe for converting the linear into a circular polarization, a reflector adapted to reflect equally the mutually perpendicular components of said circularly polarized wave, and means for converting the circular polarization into a linear polarization.

26. The method which comprises establishing a linearly polarized electromagnetic wave having a predetermined direction of polarization, propagating the two mutually perpendicular components into which such a wave can be resolved through a wave transmission path with mutually different phase velocities, partially reflecting the propagated components at a predetermined point in said path, and selectively abstracting the reflected components from said path at a point where the resultant of the two components is a linearly polarized wave having a direction of polarization that is perpendicular to said first-mentioned direction of polarization.

27. A microwave modulator comprising a cylindrical wave guide, a source of linearly polarized waves connected thereto, a conductive septum in said guide parallel to the axis of said guide, phase shifting means in said guide for transforming said waves to circular polarization, means for reflectively modulating said waves in accordance with a modulating signal, said phase shifter converting said modulated waves to a linear polarization, and a branching rectangular guide connected to said main guide for separately propagating said modulated waves without reaction upon said source.

28. A power divider comprising a source of linearly polarized microwaves, a main wave guide for propagating said waves, a rectangular wave guide communicating with said first guide and means for variably controlling the division of wave energy between said guides without reaction on said source.

29. The structure of claim 28, wherein said guides have principal axes perpendicular to each other.

30. The structure of claim 28, wherein said controlling means is a non-linear reactance.

31. The structure of claim 28, and reflecting means adjacent said rectangular guide, adapted to propagate therein a linearly polarized wave in quadrature phase relation to the waves in said main guide.

32. The structure of claim 28, wherein said means comprises a wave reflector in said main guide.

33. The structure of claim 28, wherein said means provides an impedance in said main guide.

34. The structure of claim 28, wherein a load is connected to said main guide beyond said controlling means.

35. A modulator comprising a source of incident linearly polarized waves, a metallicly shielded propagation medium for said waves connected to said source, a 90-degree polarization rotator located in said medium, an absorption modulator connected to said medium beyond said rotator, a modulating voltage source connected to said absorption modulator, and means between said source of incident waves and polarization rotator adapted to segregate the modulated waves, linearly polarized perpendicularly to said incident waves.

36. A power divider comprising a source of linearly polarized waves, a hollow pipe wave guide connected thereto, a phase shifting fin connected to the interior of said pipe, a non-linear device connected to said guide beyond said fin, a variable voltage source connected to said device, means for absorbing circularly polarized waves connected to said guide, and means located between said source and fin for segregating waves, polarized linearly and perpendicularly to said incident waves.

37. A power divider comprising a source of incident waves, polarized linearly, a pipe connected thereto, means in said pipe adapted to convert from linear to circular polarization and vice versa, an absorption modulator, connected to said pipe, beyond said polarization converting means, a source of variable voltage connected to said modulator for varying the energy distribution between the converted waves, and means connected to said pipe for separately propagating the converted waves.

38. A power divider comprising a source of incident linearly polarized waves, a pipe connected thereto for propagating said waves, means for reflecting and converting said waves into waves polarized linearly in quadrature to said incident waves, means for varying the relative energies of said polarized waves, and means connected to said pipe for separately propagating said quadrature polarizations.

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