

May 30, 1961

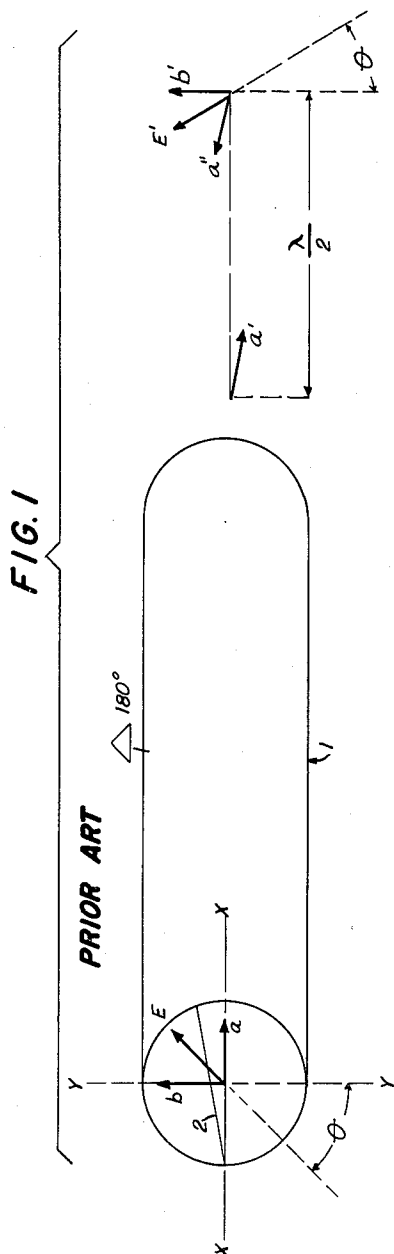
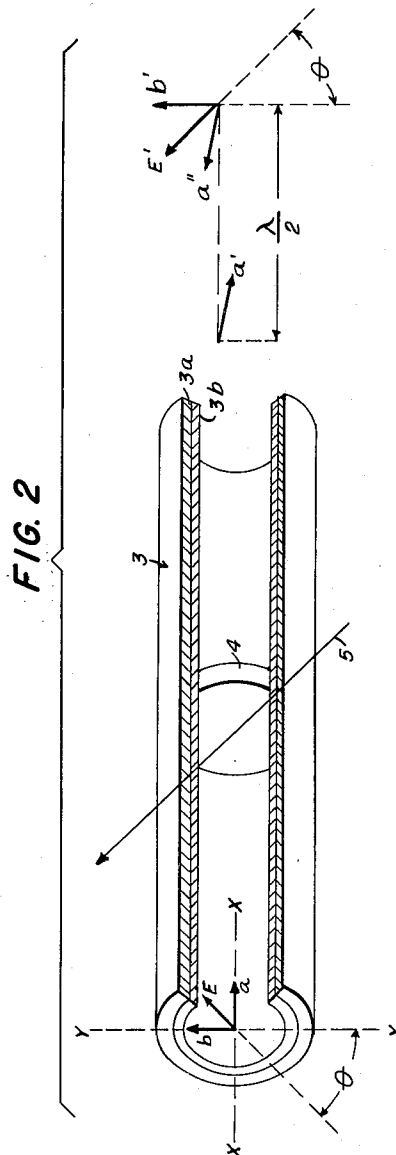
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2,986,710

REFLECTION TYPE SINGLE SIDEBAND MODULATOR

Original Filed Aug. 27, 1953

4 Sheets-Sheet 1



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4 Sheets-Sheet 2

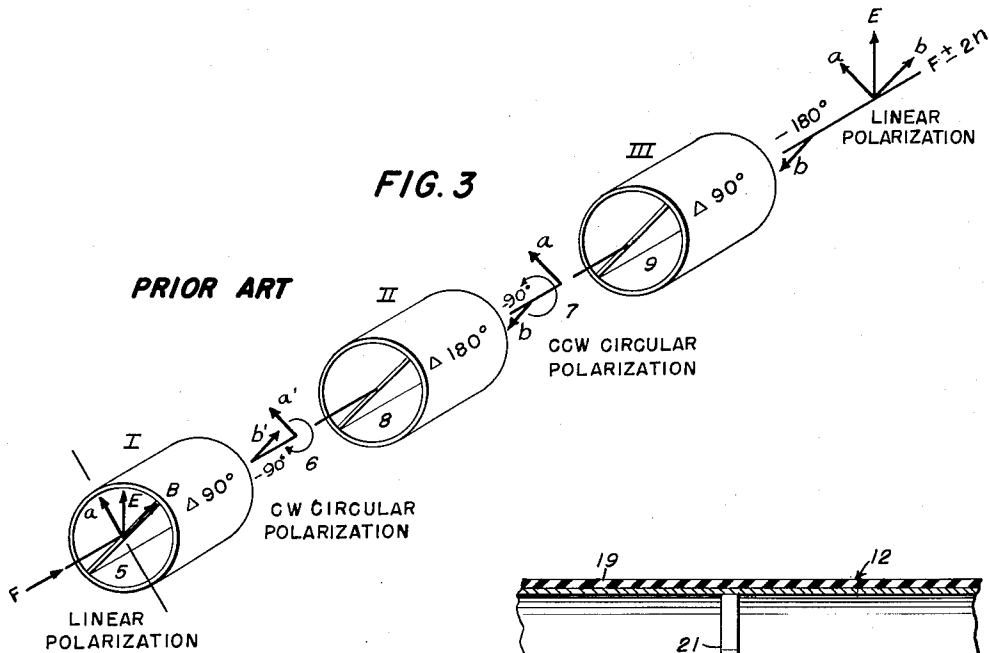
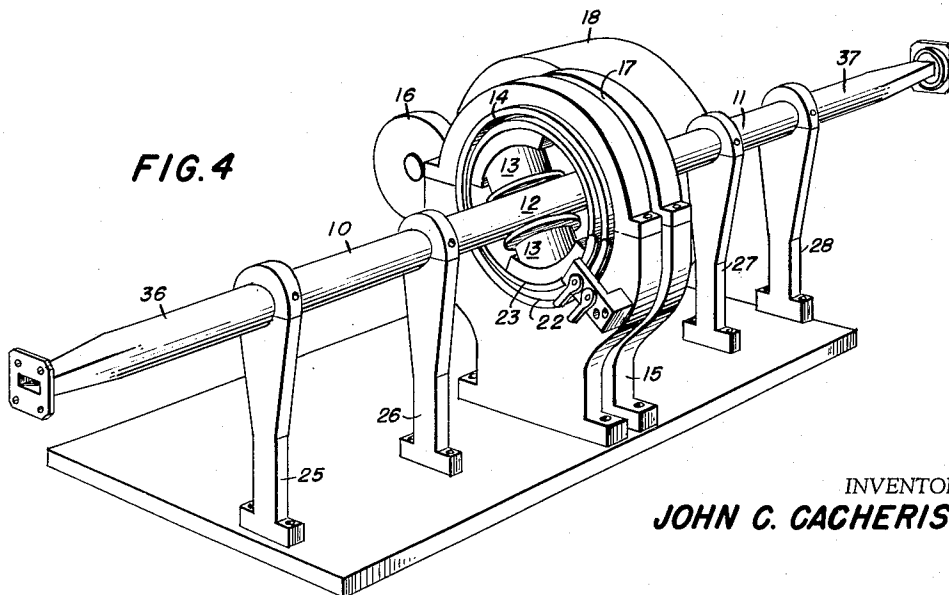


FIG. 5



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4 Sheets-Sheet 3

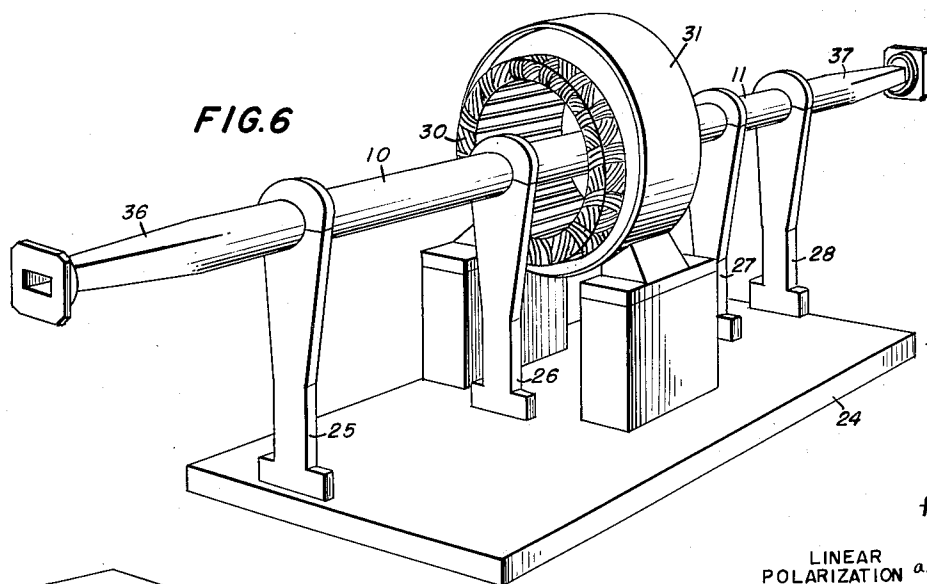
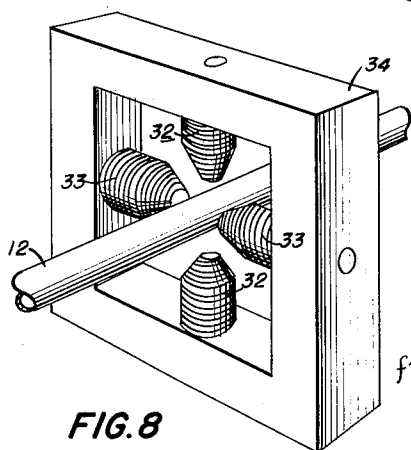
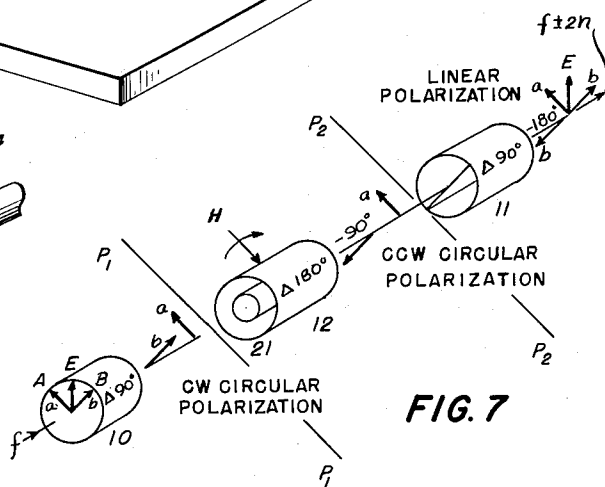
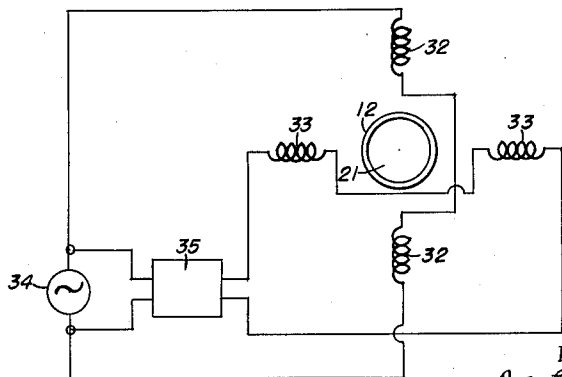


FIG. 9

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REFLECTION TYPE SINGLE SIDEBAND MODULATOR

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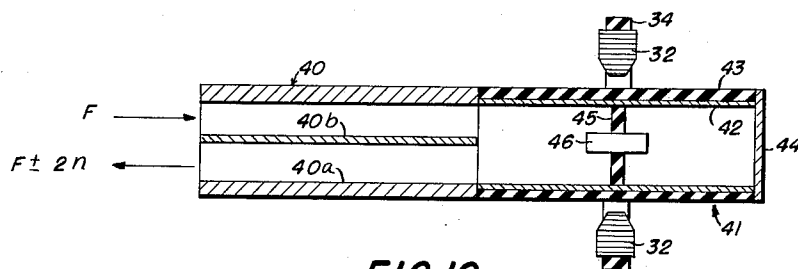


FIG. 10

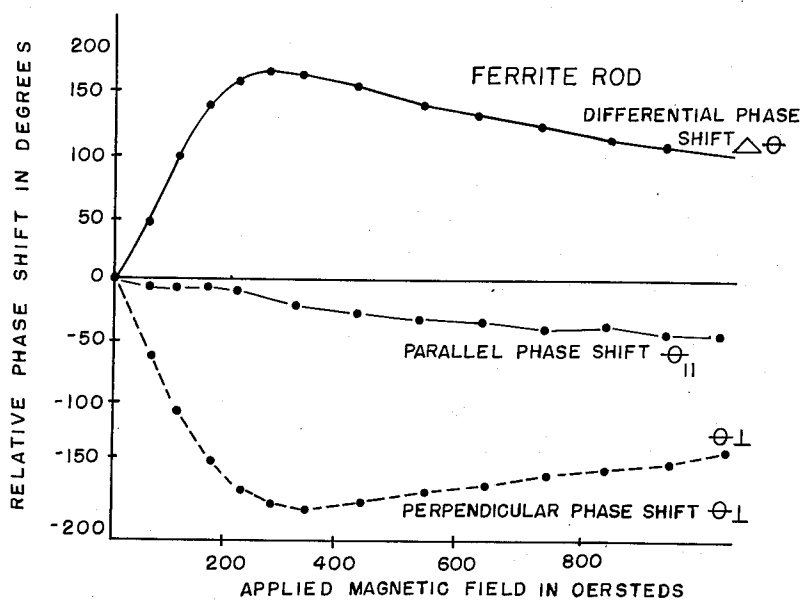


FIG. 11

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2,986,710

REFLECTION TYPE SINGLE SIDEBAND MODULATOR

John C. Cacheris, Bethesda, Md., assignor to the United States of America as represented by the Secretary of the Army

Original application Aug. 27, 1953, Ser. No. 377,004. Divided and this application Apr. 9, 1958, Ser. No. 727,509

2 Claims. (Cl. 332-51)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment to me of any royalty thereon.

This invention relates to single sideband modulators in general, and more particularly to a single sideband modulator of the reflection type.

The present invention is a division of copending application Serial No. 377,004 filed August 27, 1953, now abandoned, entitled "Single Sideband Microwave Modulator Using Ferrites" in the name of John C. Cacheris.

One object of this invention is to provide an improved microwave single sideband modulator.

Another object is to provide a single sideband modulator for microwaves wherein high frequency shift of the microwave carrier is obtained.

A further object of the invention is to provide a single sideband modulator employing a ferrite in combination with a transverse rotating magnetic field to obtain a frequency shift of the microwave carrier.

The specific nature of the invention, as well as other objects, uses, and advantages thereof, will clearly appear from the following description and from the accompanying drawing, in which:

Figure 1 is a schematic diagram of a conventional waveguide half-wave differential phase-shift section.

Figure 2 is a perspective view of the differential phase-shift section incorporated in the invention.

Figure 3 is a schematic diagram of a conventional single sideband modulator for microwave signals.

Figure 4 is a perspective view of one embodiment of the invention.

Figure 5 is a fragmentary cross sectional view showing the mounting of the ferrite in a waveguide section.

Figure 6 is a perspective view of another embodiment of the single sideband modulator of the invention.

Figure 7 is a schematic diagram of the operation of the single sideband modulator illustrated in Figures 4 and 6.

Figure 8 is a fragmentary view illustrating another means for creating a rotating transverse magnetic field about the half-wave section containing the ferrite.

Figure 9 is a wiring diagram of the rotating transverse magnetic field producing means of Figure 8.

Figure 10 is a cross sectional view of an improved form of the single sideband modulator of the invention comprising a reflection system.

Figure 11 is a graph showing the relative phase-shift of the microwave in the reflection system of Figure 10 as a function of the applied magnetic field. $\theta_{\parallel}$ is the phase-shift obtained when the magnetic vector of the microwave is parallel to magnetic field transverse to the direction of propagation and the ferrite element. $\theta_{\perp}$ is the phase-shift obtained when the said magnetic vector is perpendicular to the magnetic field. $\Delta\theta$ is the differential phase-shift obtained and is equal to $\theta_{\parallel} - \theta_{\perp}$.

Figure 1 schematically shows a conventional waveguide half-wave section whereby rotation of polarization of a dominant wave is obtained. The waveguide section is indicated by 1 having a dielectric slab 2 extending

2

internally therethrough. A linearly polarized wave represented by the vector E introduced from the left of waveguide section and polarized at angle θ to the X axis of the section has two mutually perpendicular components represented by vectors a and b . The component a along the X axis is retarded 180° with respect to component b , along the Y axis. Therefore as the wave emerges from the section, a' lags b' by 180° or one half wavelength. At the position of b' the X axis component will be pointed in the opposite position from a' as indicated by a'' . Vector addition of the components a'' and b' will give the resultant linearly polarized wave E' polarized at angle θ clockwise from the Y axis. Therefore the effect of a half-wave differential phase-shift section is to cause a rotation of the angle of polarization in the direction of Y axis by 2θ , that is, the section will cause a rotation of the angle of polarization at twice the angle of input polarization and in the opposite direction.

In Figure 2 there is shown the differential phase-shift section which is incorporated in the invention wherein a linearly polarized dominant wave is caused to travel through the waveguide section 3 whereby rotation of the polarization of the dominant wave and a differential phase-shift between the two components of the dominant wave is obtained through the use of a ferrite 4 positioned in the waveguide intermediate its ends and subjected to a transverse magnetic field as indicated by the arrow 5. The waveguide section 3 comprises a plastic tubular member 3a provided with a silvered inner surface 3b. The position of the introduced wave and emergent wave and components are indicated by the vectors shown at each end of the waveguide and are identical to those shown in Figure 1.

Ferrites are ferromagnetic dielectrics having a resistivity intermediate between that of metallic alloys and that of good electrical insulating materials. Because of their high resistivity, ferrites propagate microwaves with relative ease and their magnetic properties may be varied by an applied D-C. field.

The theory of the behavior of a saturated ferromagnetic material such as a ferrite magnetized in an arbitrary direction with respect to the direction of propagation shows that an infinitely large ferromagnetic medium which is homogeneously magnetized in the Y-direction becomes doubly refracting when plane electromagnetic waves are propagated in the Z-direction. For two linearly polarized waves with H-vectors parallel and perpendicular to the applied magnetic field, the indices of refraction are given by:

$$\eta_{\parallel}^2 = \epsilon$$

$$\eta_{\perp}^2 = \frac{\epsilon(\mu^2 - \alpha^2)}{\mu}$$

If damping and crystal-anisotropic field are ignored, μ and α are given by

$$\mu = \frac{\gamma^2 H_e B_e - \omega^2}{\gamma^2 H_e - \omega^2}$$

and

$$\alpha = \frac{4\pi M \omega}{\gamma^2 H_e^2 - \omega^2}$$

where

ϵ is the dielectric constant of the medium

γ is the gyromagnetic ratio of the electron

B_e is the effective flux density ($B_e = H_e + 4\pi M$)

H_e is the effective internal magnetic field

M is the magnetization of the medium

ω is the angular microwave frequency

$$\eta_{\parallel}^2 = \epsilon$$

and

$$\eta_{\perp}^2 = \epsilon \left[\frac{\gamma^2 B_e^2 - \omega^2}{\gamma^2 H_e B_e - \omega^2} \right]$$

The effective permeability of the wave whose H-vector is parallel to the D.-C. field H_a is one since $\eta^2 = \mu_e$. It is independent of the magnitude H_a . The effective permeability of the wave whose H-vector is perpendicular to the D.-C. field is given by

$$\mu_{\perp} = \frac{\gamma^2 B_e^2 - \omega^2}{\gamma^2 H_e B_e - \omega^2}$$

The perpendicular permeability becomes infinite when $\omega^2 = \gamma^2 H_e B_e$, not when $\omega^2 = \gamma^2 H_a^2$ as for the medium magnetized in the direction of propagation. This is in agreement with Polder's theory. In simplification thereof let:

$$\mu_{\perp} = 1 + \Delta\mu_{\perp}$$

then

$$\Delta\mu_{\perp} = \left[\frac{\gamma^2 B_e^2 - \omega^2}{\gamma^2 H_e B_e - \omega^2} - 1 \right]$$

$$\Delta\mu_{\perp} = \left[\frac{\gamma^2 B_e^2 - \gamma^2 H_e B_e}{\gamma^2 H_e B_e - \omega^2} \right]$$

If $\gamma^2 H_e B_e$ is much smaller than ω^2 , the above equation can be simplified to

$$\Delta\mu_{\perp} = \frac{\gamma^2 H_e B_e - \gamma^2 B_e^2}{\omega^2}$$

and

$$\mu_{\perp} = \left[1 + \frac{\gamma^2 H_e B_e - \gamma^2 B_e^2}{\omega^2} \right]$$

Therefore the differential phase-shift of the wave with its magnetic vector parallel to H_a , with respect to the wave whose magnetic vector is perpendicular to H_a , is given by

$$\Delta\theta = \omega l (\epsilon\mu_0)^{1/2} [\mu_{\parallel}^{1/2} - \mu_{\perp}^{1/2}]$$

$$\Delta\theta = l (\epsilon\mu_0)^{1/2} \left[\frac{\gamma^2 B_e^2 - \gamma^2 H_e B_e}{\omega} \right]$$

Although the theory has been derived for a saturated infinite medium with no losses, it appears that the analysis approximates the waveguide case since double refraction has been observed experimentally.

Frequency shifts of a few hundred cycles per second of a microwave carrier have been accomplished by means of differential half-wave phase-shift section rotated between two stationary quarter-wave differential phase-shift sections of circular waveguide as schematically shown in Figure 3 wherein I and III indicated the quarter-wave differential phase-shift sections ($\Delta 90^\circ$) and II indicates the half-wave differential phase-shift section ($\Delta 180^\circ$). Section I is oriented at 45° with respect to the electric vector E of the microwave from the rectangular waveguide (not shown). The input to section I which is a linearly polarized microwave may be resolved into equal orthogonal components as indicated by vectors *a* and *b*. Component *a* parallel to the A axis travels faster than the component *b* parallel to the B axis which is delayed by a thin dielectric strip 5 so that the two components have a differential phase-shift of 90° . The output of section I consists of the two vectors *a* and *b* in quadrature in space and time. This emerging signal is a circularly polarized wave which is rotating at microwave frequency, the direction of rotation is from the leading to the lagging component or clockwise as indicated by the arrow 6. Section II is a half-wave differential phase-shift section which delays the *b*-component by an angle of 180° , as described in connection with Figure 1. Therefore, at the output of Section II, the direction of rotation of the circular node will be reversed as indicated by the counterclockwise arrow 7. If the rotating circularly polarized

input wave to section II is considered stationary and if this section is rotated clockwise through an angle of 90° , the emerging wave is rotated through an angle of 180° . Thus the output rotates through twice the angle of rotation of section II. Section III is a quarter-wave differential phase-shift section which reconverts the counterclockwise-rotating circularly polarized waves to linearly polarized wave. The dielectric strips of section II and III are indicated by reference numerals 8 and 9, respectively. To summarize, section I converts the incident linearly polarized waves into circularly polarized wave. Section II rotates the instantaneous orientation of the circularly polarized waves and thereby shifts the phase of the output thereof. Section III reconverts the circularly polarized waves to linearly polarized waves. Furthermore, continuous mechanical rotation of section II at a constant speed will produce a continuous change in phase which causes a fixed increase or decrease in the frequency of the transmitted waves as indicated in Figure 3 by $F \pm 2n$ where *n* is the number of revolutions per second of section II.

Single sideband modulators of this type have the disadvantage incurred by the mechanical rotation of the half-wave section which limits the frequency shift to approximately 200 c.p.s. whereas the sideband modulator of the invention employing ferrite material in the half-wave section produces frequency shifts of the order of 20 kc. in transmission through the phase changer without appreciable loss of power.

Figure 4 shows a form which my invention may take. The same general configuration as employed by prior art is used, namely two quarter-wave differential phase-shift sections ($\Delta 90^\circ$) 10 and 11 and a half-wave differential phase-shift section ($\Delta 180^\circ$) 12. The section 12 contains a ferrite 21 positioned intermediate its ends. A two pole winding 15, energized by direct current, creates a magnetic field transverse to the direction of wave propagation in the section 3. The two pole winding is mounted on a ring 14 which is rotatably mounted by means of bearings in housing 15 and rotated about section 12 by means of a friction disk 16 in contact with ring 14 through the groove 17 in the housing. The disk is driven by motor 18. The half-wave differential phase-shift section 12 comprises a waveguide made of linen 19 with a thin coating of silver 20 on the interior surface thereof as shown in the fragmentary view, Figure 5. For the purpose of illustration the waveguide sections are shown supported on a base 24 by means of arms 25 to 28 inclusive, and also the housing 15. A disk shaped ferrite 21 is shown affixed within member 12, although a ferrite of any geometric configuration may be used. The silver coating is sufficient to carry microwave propagation through the guide, but does not cause large eddy currents usually experienced by rotating a magnetic field through a copper guide. The rectangular-to-round waveguide transitions 36 and 37 couples the modulator to the microwave transmission system in which it is used. Current is provided the winding 13 through slip rings 22 and 23. The winding is arranged so that the ferrite in the waveguide section is in alignment with the winding. The rotating transverse magnetic field is created when the two pole winding 13 mounted on ring 14 is energized by direct current and the ring 14 rotated through means of motor 18 about the portion of the half-wave section 12 containing the ferrite 21 which becomes double refracting when subjected to a magnetic field. The combination of the double refracting ferrite and waveguide with the transverse rotating magnetic field produces a continuous change in phase which is the equivalent to a frequency shift.

In Figure 7 is shown a schematic diagram of the operation of the single sideband modulator illustrated in Figures 4 and 6 wherein the waveguide sections thereof are indicated by the reference numerals 10, 11 and 12. The quarter-wave section 10 converts the incident linear-

ly polarized wave into circularly polarized waves. Section 12 contains the ferrite 21 with a rotating transverse magnetic field H_a thereabout adjusted for 180-degree differential phase-shift therethrough and section 11 reconverts the circularly polarized waves to linearly polarized waves. The effect of continuous rotating of section 12 by means of the rotating transverse magnetic field in combination with the ferrite will cause a fixed increase or decrease in the frequency of the circularly polarized microwave therein. The plane-polarized wave fed into section 10 emerges circularly polarized in, say, a clockwise direction. Hence, the vector E in the plane P_1 performs f rotations per second, f being the carrier frequency of the incoming energy. If an observer were located in section 12 and if section 12 rotates counterclockwise, the observer will see a frequency $f+n$, n being the number of revolutions per second of section 12. Due to the action of section 12, the observer will see $f+n$ counterclockwise rotations of the E vector in the plane P_2 . Since section 12 itself rotates, that is the rotating transverse magnetic field about produces the effect of rotating section 12, the vector E in plane P_2 as seen from section 11 rotates $f+2n$ times a second. Energy with a frequency $f+2n$, therefore, emerges from the device.

Figure 6 illustrates another way of creating a rotating transverse field about section 12 containing the ferrite which comprises a three-phase winding 30 which when excited will produce a transverse magnetic field that rotates with speed dependent upon the frequency of the excitation source. The advantage to the use of this means of producing a rotating transverse field about section 12 is that the lack of moving parts greatly extends the upper limits of frequency shift possible in the device. The three-phase winding 30 is mounted in housing 31 affixed to base 24.

Another means for obtaining a transverse rotating field about section 12 is illustrated in Figure 8 wherein two pairs of coils 32 and 33 are disposed at right angles to each other about that portion of section 12 containing the ferrite in a frame 34 and excited by a 10 kc. generator as schematically shown in Figure 9. As before, the field applied to the ferrite is adjusted for a 180-degree differential phase-shift and is electrically rotated at 10 kc./sec. by the two pairs of coils 32 and 33, 90-degree out of phase. In Figure 9 the 10 kc. generator is indicated by 34 feeding the pair of coils 32 and the pair of coils 33, 90° out of phase through means of the phase changer 33.

An improved embodiment of the invention is shown in Figure 10 wherein the single sideband modulator for shifting the frequency, F , of the microwave introduced therein comprises a waveguide differential phase-shift section (Δ 90-degree) 40, coupled to a second differential phase-shift section (Δ 90-degree) 41. Section 40 is a typical Δ 90-degree section comprising a metallic waveguide member 40a having affixed therein a dielectric member 40b. Section 41, however, comprises a linen cylindrical member 43 provided with a coating of silver 42 on the inside surface thereof. One end has affixed thereto an electrical short circuit member 44 which may be in the form of a metallic disk 44 soldered to the end or if desired the short circuit member may comprise the disk 44 mounted on a threaded rod and adapted to be adjustably extended into the interior of member 43 in engagement with the silver coating 42. A Teflon disk 45

positioned in section 41 intermediate the ends thereof supports a ferrite rod 46. However, it is to be noted that a ferrite member of any geometrical configuration may be used in my invention. The numerals 32 and 34 represent the rotating magnetic field structure shown in Figure 8. The strength of the magnetic field is chosen so that section 41 provides a 90-degree differential phase-shift. In operation a linear polarized microwave of frequency F is introduced into Δ 90-degree section 40 with its electric vector oriented at angle 45° to the dielectric member 40a, so that the linearly polarized wave will be converted to a circularly polarized wave at the output of section 40. This circularly polarized wave then travels through section 41, passing through the ferrite rod 46 whereby a 90-degree phase differential is obtained. The short circuit 44 reflects the circularly polarized wave and causes it to travel back through section 41 in the opposite direction through the ferrite rod 46 whereby another 90-degree differential phase-shift is obtained, resulting in a total 180-degree differential phase-shift which is equivalent to a frequency shift of the microwave. This circularly polarized wave then passes back through Δ 90-degree section 40 wherein it is reconverted to a linearly polarized wave having a frequency of $F \pm 2n$, n being the revolutions per second of the rotating magnetic field.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement with the scope of my invention as defined in the appended claims.

I claim as my invention:

1. An improved single sideband modulator comprising in combination: a 90-degree differential phase-shift section having a first end and a second end, means applying a microwave signal of frequency f to said first end, a circular waveguide section having one end coupled to the second end of said 90-degree section, shorting means at the other end of said circular waveguide section, a ferrite member positioned intermediate the ends of said circular waveguide section, a housing having a multiphase winding positioned about said circular waveguide so that a rotating transverse magnetic field is applied to said ferrite member when said multiphase winding is excited, the strength of said magnetic field being chosen so that said microwave signal after passing through said ferrite member and being reflected by said shorting means back through said ferrite member in the opposite direction will have received a total 180-degree differential phase-shift, whereupon the microwave signal then passes into said second end of said 90-degree differential phase-shift section, the microwave signal obtained at said first end of said 90-degree differential phase-shift section thus having a frequency of $f+2n$ where n is the speed of rotation of said magnetic field.

2. The invention in accordance with claim 1, wherein said circular waveguide section comprises a non-metallic member having a metallic surface on the interior thereof, and wherein said ferrite member is a ferrite rod concentrically affixed in said circular waveguide section.

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