Feb. 3, 1959 J. J. GIBSON 2,872,648

POWER DIVIDER

Filed Nov. 13, 1953 2 Sheets-Sheet 1

Fig_1

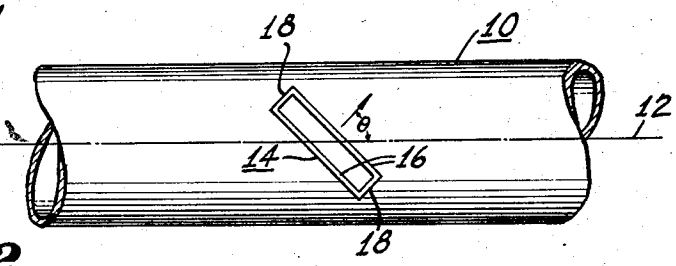
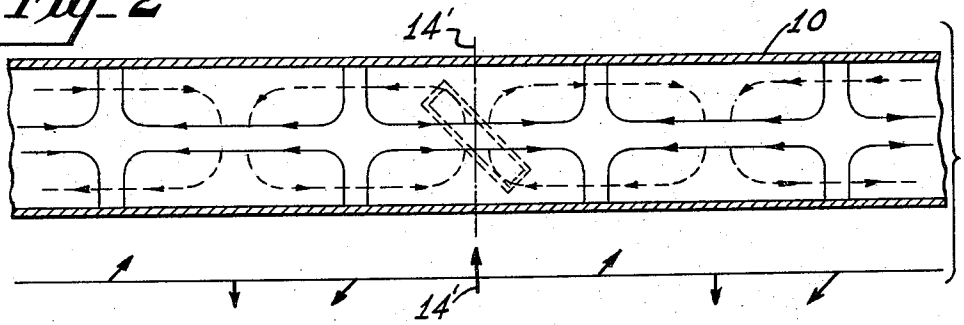


Fig_2



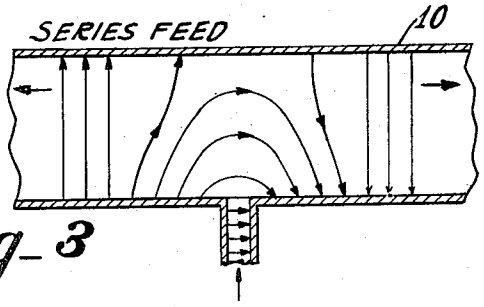


Fig_3

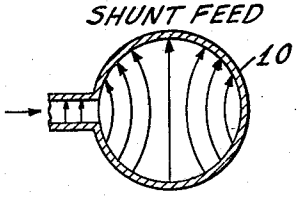


Fig_4

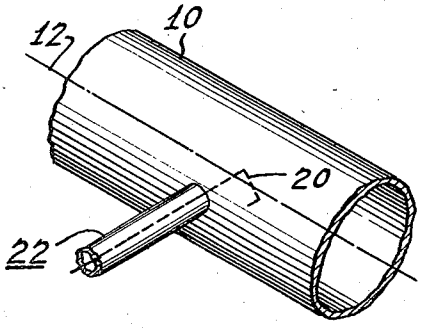


Fig_5

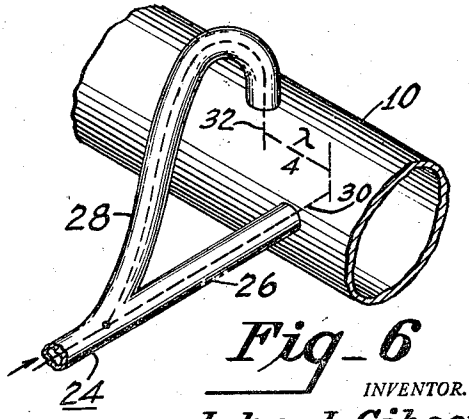


Fig_6

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POWER DIVIDER

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Fig_7

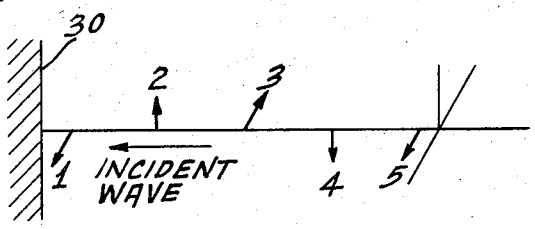
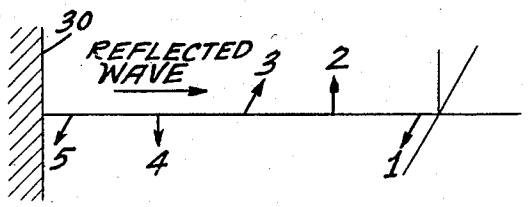


Fig_8



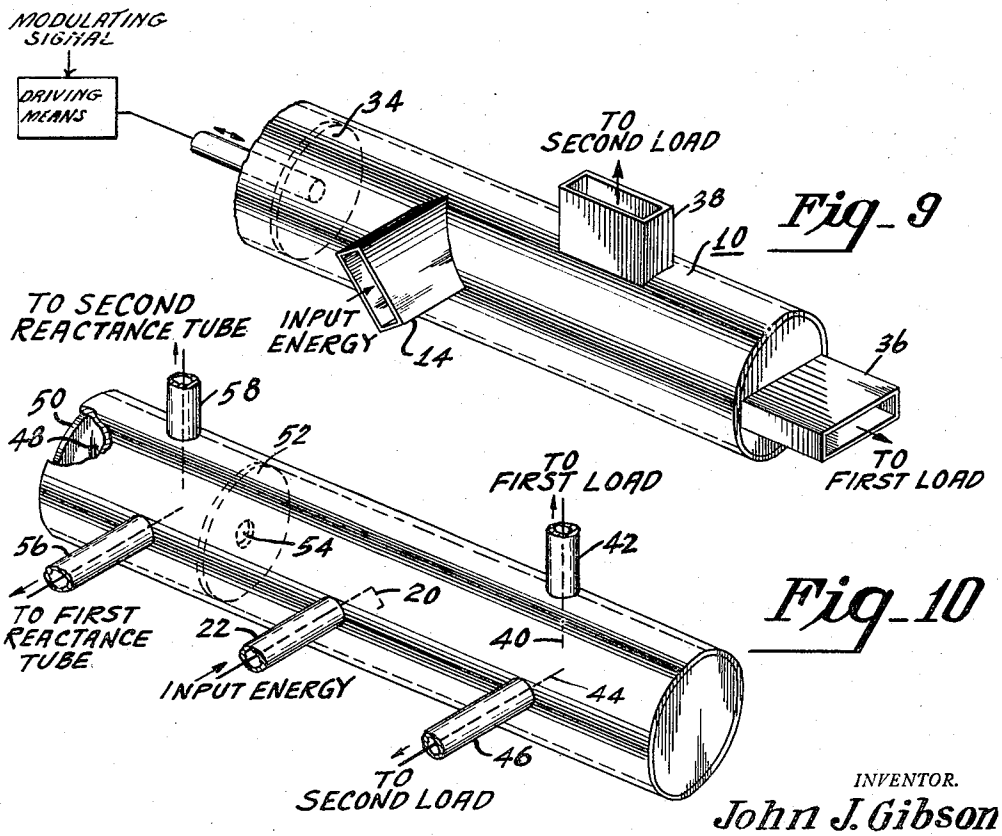


Fig_9

Fig_10

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POWER DIVIDER

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6 Claims. (Cl. 333—6)

This invention relates to power dividers for high frequency systems.

In the testing of components, it is often desirable to have available a means of varying the power from a source over wide limits. For example, in the testing of waveguide components for high-power carrying capacity, a variable power source is desirable. Further, certain systems of modulation, especially absorption modulation systems, may be employed in which the total power from the generator is constant, but the power radiated is modulated in amplitude by a variable division of the power from the generator between the radiation load or antenna and an absorption load. Furthermore, the power division in such systems must be responsive with a rapidity at least as great as the highest modulation frequency employed. Ordinarily, therefore, it is desirable that the power division may be varied over wide limits in response to electronic means.

It is an object of the present invention to provide an improved means of varying the output power division between two transmission lines.

Another object of the invention is to vary continuously the power output to a selected transmission line.

Still another object of the invention is to provide a variable power divider network of high-power handling capacity, responsive to electronic modulation, or to manual modulation.

A further object of the invention is to provide a compact power division network which will afford a power division responsive to a reactance variation.

A further object of the invention is to provide a novel power divider which is compact, the power division of which is readily and easily controlled either by electronic or manual means, and which is reliable in operation.

A still further object of the invention is to provide a novel power divider, the power division ratio of which is variable by varying the input signal frequency.

In general, it is found preferable to use the principles of power division between two transmission lines rather than attenuation by variable absorption in the conventional manner. The unwanted power is diverted into a transmission line feeding a matched and preferably fixed load, which may readily absorb high power, and the remaining undiverted power is passed on to the device under test (or vice versa).

In accordance with the invention, a waveguide is employed in which there exist two similar orthogonal modes of wave propagation in space quadrature at the operating frequency. These two modes are fed from a generator at an intermediate point in the waveguide in such a way that a circularly-polarized wave is transmitted in opposite directions along the longitudinal axis of the waveguide from the point of feed. The two circularly-polarized waves are polarized in a like sense, i. e., both right-handed or both left-handed waves. Reflection substantially without loss is secured from one side of the feed point, as by a reflecting termination, or a reactance tube coupling. The reflected wave returns to join the

other wave from the feed point and combines with that other wave into a plane wave. The orientation of the polarization of the plane wave depends upon the phase of the reflection, or upon an equivalent reactance effect. The two loads are coupled respectively to the two modes of propagation, and thus derive power from the plane wave in a proportion dependent on the polarization of the wave. The reactance may be either a reactance tube, as mentioned, or a variable reactance termination such as a plunger manually positionable, or a frequency-sensitive device such as a cavity resonator.

The foregoing and other objects, advantages, and novel features of the invention will be more fully apparent from the following description when taken in connection with the accompanying drawing, in which like reference numerals refer to similar parts, and in which:

Figure 1 is a side elevational view of a type of feed suitable to provide the circularly-polarized modes in a circular waveguide progressing away from the point of feed;

Figure 2 is a diagram schematically illustrating instantaneous polarization vectors and currents on the waveguide walls in the arrangement of Figure 1;

Figure 3 is a longitudinal cross-sectional view and Figure 4 is a transverse cross-sectional view of the waveguide of Figure 1 showing instantaneous electric vectors of two different types of coupling for the purpose of explaining more fully the coupling illustrated in Figure 1;

Figures 5 and 6 are perspective views of two different couplings equivalent to the coupling of Figure 1;

Figures 7 and 8 are diagrams illustrating the effect on the sense of circular polarization of reflection from the plunger of Figure 7;

Figure 9 is a perspective view of one arrangement according to the invention employing a reflecting plunger as a reactance element; and

Figure 10 is a perspective view of another embodiment of the invention employing a reactance tube device.

Referring to Figure 1, a circular hollow-pipe waveguide **10** having a longitudinal axis **12** is fed from a rectangular hollow-pipe waveguide **14**. The longitudinal axis of the rectangular waveguide **14** is at right angles to the axis **12** of the circular hollow-pipe waveguide. The rectangular waveguide has broad walls **16** and narrow walls **18**. The narrow walls **18** are at an angle (θ) with respect to the circular guide axis **12**. The coupling resulting from the intersection between the rectangular waveguide **14** and the circular waveguide **10** excites two orthogonal $TE_{1,1}$ modes in the circular waveguide **10**. In effect, one of these $TE_{1,1}$ modes is series fed from the rectangular guide **14**, and the other is shunt fed from the rectangular guide **14**. This may be understood from Figures 3 and 4, where the rectangular slot at the intersection of the rectangular waveguide **14** with the circular waveguide **10** is analogued as two slots, one of which is vertical as viewed in Figure 1 and one of which is horizontal as viewed in Figure 1, thus resolving the slot at the intersection into two slots one of which has its length or longitudinal dimension parallel to the axis **12** and one of which has its longitudinal dimension normal to the longitudinal axis **12** of circular waveguide **10**. The resolved slot having its length or long dimension normal to the circular waveguide axis **12** is shown in Figure 3 as viewed in a section taken in a horizontal plane. It will be apparent that the $TE_{1,1}$ mode excited by the series feed thus illustrated in Figure 3 is in phase opposition on different sides of the slot. On the other hand, the slot portion resolved along the length of the circular waveguide axis **12** excites a $TE_{1,1}$ mode on one side of the coupling which is in phase with that on the other side of the coupling. Furthermore, it may be shown that assuming rather narrow slot dimensions and a matched coupling,

that there is phase quadrature between the series-fed mode vectors illustrated in Figure 3 and the shunt-fed mode vectors illustrated in Figure 4 at any point in the guide removed from the point of coupling at the intersection of the circular and rectangular waveguides **10** and **14**. In Figure 4 the vectors in the $TE_{1,1}$ mode of the circular waveguide **10** are delayed in travel time along the circular waveguide **10** more than those of Figure 3, which are not delayed but immediately propagate in either direction from their slot. Because of the quadrature relationship, the waves travelling to the right and to the left of the intersection of the rectangular guide **14** and circular guide **10** as viewed in Figure 1 are elliptically polarized. By proper choice of the angle (θ) between the narrow walls **18** and the longitudinal axis **12** of the circular waveguide **10**, the amplitude of the two $TE_{1,1}$ modes may be made equal. Then, circularly polarized waves are excited which travel in both directions in the circular guide **10** from the intersection with the rectangular guide **14**.

Figure 5 shows another means of feeding the waveguide **10** to provide waves circularly polarized and travelling each away from the coupling on different sides thereof. The loop **20** of Figure 5 couples the coaxial line **22** to the circular waveguide **10**. However, the loop **20** is oriented at an angle between zero and 90 degrees with respect to the longitudinal axis **12** of the circular waveguide **10**. By suitable selection of the angle of the plane of the loop **20**, the desired circular polarization may be obtained.

Figure 6 shows still another method of securing the circularly polarized feed travelling in opposite directions from the coupling. In Figure 6 a source supplies a coaxial line **24** which is bifurcated into two coaxial lines **26** and **28** respectively. The latter two lines terminate in well-known probe couplings **30** and **32**, respectively, to the circular waveguide **10**. As viewed in Figure 6, the probe coupling **30** couples to the $TE_{1,1}$ mode of the circular waveguide **10** having its principal or largest electric vector in a horizontal direction; whereas the probe coupling **32** couples to the $TE_{1,1}$ mode having its principal electric vector in a vertical direction. The length of the sections **26** and **28** from the bifurcation of the coaxial transmission line **24** to the probe couplings **30** and **32** are equal. However, the probe couplings are spaced apart a quarter-wave length. The time of travel of one $TE_{1,1}$ mode toward the other therefore provides the phase quadrature or time quadrature requisite for circular polarization, whereas the orientation of the probe couplings provides the space quadrature requisite for circularization.

Returning to the coupling of Figure 1, and referring to Figure 2, the instantaneous current flow on the walls of the waveguide **10** and the instantaneous direction of the maximum radial electric field are indicated. A consideration of the position and direction of the maximum field strengths of the two modes shown in Figure 2, indicates that a right-handed circularly polarized wave travels in each direction away from the plane **14'**.

It is contemplated that the circularly polarized wave travelling in one direction from the coupling is to be reflected. Such reflection reverses the sense of polarization as indicated in Figure 7 and Figure 8. Figure 7 shows the position and direction of the maximum field strength of a circularly polarized incident wave advancing to the left as viewed in Figure 7. This wave of Figure 7 is polarized in the right-hand sense according to the usual convention by which, if the wave is observed at any particular point facing in the direction in which it is travelling, the vectors turn in a clock-wise direction at the operating frequency. After reflection on a reflecting metallic surface indicated as **30** in Figure 7, the reflected wave travels to the right as shown in Figure 8. After a certain time, the vector indicated as **1** in Figure 7 is instantaneously found in Figure 8 at some distance

to the right of the surface **30**. The vector **2** of Figure 7 which is farthest from the reflecting surface **30** at the moment for which the diagram is made, is the next farthest from the reflecting surface **30** at the time the diagram of Figure 8 is made. Thus the corresponding vectors **1**, **2**, **3**, **4**, and **5** of Figure 7 after reflection have the positions indicated in Figure 8. However, the reflected wave of Figure 8 is left-hand polarized according to the convention mentioned above. In other words, the circular polarization of the reflected wave is the reverse in sense of the circular polarization of the incident wave. Therefore, reflection reverses the sense of polarization of a circularly polarized wave.

Referring to Figure 9, a circular waveguide **10** has a coupling with a rectangular waveguide **14** such as discussed in connection with Figure 1. A source of electrical energy (not shown) may be connected to the waveguide **14** to supply energy thereto. In one direction along the circular waveguide **10** axis from the coupling of the waveguide **14**, and specifically to the left as viewed in Figure 9, a reflecting piston **34** is inserted to be manually, mechanically, or electrically longitudinally adjustable as desired. In the other direction from the coupling of waveguide **14** to the circular waveguide **10**, a pair of rectangular waveguides **36** and **38** are coupled to the hollow-pipe waveguide **10** in a fashion to be coupled solely to one or the other of two orthogonal $TE_{1,1}$ modes of the circular waveguide **10**. As shown in Figure 9, this is readily accomplished by employing one of the pair of rectangular waveguides **36**, having its longitudinal axis aligned with the longitudinal axis of waveguide **10**. The other rectangular waveguide **38** of the pair has its axis normal to the circular waveguide **10** axis and its broad walls normal to the broad walls of the first waveguide **36** of the pair and its narrow walls normal to the narrow walls of the first rectangular waveguide of the pair. As this pair of rectangular waveguides **36** and **38** couple respectively and independently to the two independent $TE_{1,1}$ modes, one of which has its principal electric vector in the direction parallel to the axis of the second waveguide **38** and the other of which has its principal electric vector normal to the broad walls of the waveguide **36**, the relative positioning of the pair of rectangular waveguides **36** and **38** affects only the matching. Means are known for suitably positioning the rectangular waveguides and for suitably coupling them to provide matched coupling to the respective $TE_{1,1}$ modes of the circular hollow-pipe waveguide **10**.

In operation of the embodiment of the invention illustrated in Figure 9, energy at the operating frequency from the source applied to the rectangular waveguide **14** is divided at the coupling to the circular waveguide **10**. Half the energy advances to the right and half to the left from the coupling as viewed in Figure 9 in circularly polarized waves each polarized in the same sense. The waves advancing in one direction, in this instance to the left, are reflected by the piston **34**. The reflected waves now travel to the right with a reversed sense of polarity. After the reflected waves pass the point of coupling of the rectangular waveguide **14** to the circular waveguide **10**, they combine with circularly polarized waves derived directly from the coupling. It is pointed out that neither the waveguide **14** nor any of the other feed systems mentioned herein absorb any energy from the reflected wave. Thus the polarized waves travelling to the right in the embodiment of Figure 9 are actually plane polarized, comprising a wave circularly polarized in the right-hand sense combined with a wave circularly polarized in the left-hand sense. As known, the combination of these two circularly polarized waves is a resultant plane polarized wave. The angle of polarization will depend upon the distance of the reflecting piston **34** from the coupling between the circular and rectangular waveguides **10** and **14**.

At one position, the plane polarization of the resultant

wave travelling to the right will be vertical. Accordingly, substantially all of the energy will be coupled to the first waveguide 36 of the pair and hence may be applied to a first load. When the reflecting piston 34 is displaced a quarter wavelength in the waveguide from this first position, the resultant wave advancing to the right is polarized with its electric vector horizontal, and substantially all of the energy is coupled to the second waveguide 38 of the pair and thence to a second load. Any desired ratio of coupling of the incident energy from the source with the first or second loads is readily secured, merely by properly positioning the piston 34. If desired, the piston may be mechanically or otherwise driven back and forth as shown to give a modulation at some specified frequency.

Figure 10 shows a different embodiment of the invention well suited for voice or other complex modulation of a high frequency wave. The input source may be coupled to a coaxial line waveguide 22 which in turn is coupled to the circular hollow-pipe waveguide 10 by coupling loop 20, as shown, for example, in Figure 5. A probe coupling 40 couples a coaxial line waveguide 42 to the circular waveguide 10 mode having its principal electric vector vertical. The first load is coupled to the coaxial line or waveguide 42 whereby the first load is connected to the $TE_{1,1}$ mode of circular waveguide 10 having vertical electric vectors. A similar probe 44 couples another coaxial line 46 to a second load, whereby the second load is connected to the $TE_{1,1}$ mode of the circular waveguide 10 orthogonal to the first or vertical electric vector mode. A resonant chamber 48 is formed in circular waveguide 10 by closing the end of the waveguide 10 with a solid reflecting plate 50. A second annular plate 52 has its outer edge conductively connected to the inner circumference of circular waveguide 10 and an aperture 54 resonant at the operating frequency. The two $TE_{1,1}$ modes in the circular waveguide 10 are coupled through the resonant aperture 54 to two similar modes in the chamber 48. A pair of coaxial lines 56 and 58 having probes normal to the longitudinal axis of the circular waveguide 10 and of the chamber 48 and also normal to each other are thus coupled to the two orthogonal modes of the circular waveguide 10. The coaxial line waveguides 56 and 58 couple first and second reactance tubes, respectively, to the chamber 48.

In operation, high frequency energy from the source is applied by the coaxial waveguide 22 to the coupling 20. By means of the loop coupling, circularly-polarized high-frequency energy is propagated in both directions from the coupling on the circular waveguide 10, to the right and to the left of the loop 20, as viewed in Figure 10. The circularly-polarized energy is coupled by the resonant aperture 54 to the chamber 48 where it remains circularly-polarized energy. The first and second reactance tubes should be connected to the coaxial lines 56 and 58 in such a manner that the energy coupled into the circular waveguide 10 by each line is in phase. This may be achieved by selecting reactance tubes having substantially the same characteristics and by making the lines 56 and 58 equal in length. The effect of the variation of the reactances is to vary the equivalent position of an equivalent short-circuit. In other words, the variation of the reactances coupled into the chamber 48 may be considered as the variation of the position of a short-circuit plunger such as 34, Figure 9. In other words, the change of phase of the signal is equivalent to the change of position of the plunger. Motion of the plunger is equivalent to changing the phase difference between the incident and reflected wave. Changing the reactance of the chamber 48 also is equivalent to changing the change in phase of the returned signal. The returned signal passes through the resonant aperture 54 travelling to the right, as viewed in Figure 10, and joins the circularly-polarized wave travelling to the right from the coupling loop 20. If the two reactance tubes do not equally affect the reactance of the chamber 48 by introducing the same amount of reactance and the same amount of change of reactance for change of signal, then the reflected wave is not circularly polarized, and to the extent which it is not circularly-polarized, operation of the embodiment is imperfect.

The resonant aperture 54 is circularly symmetrical in order to maintain the circular polarization and the same change of phase, that is the same modulation of the change of phase of the reflected signal for each of the orthogonal $TE_{1,1}$ modes. The resonant chamber 48 and the resonant aperture 54 magnify the change in reactance introduced by the reactance tubes through the transmission lines 56 and 58. It also may be noted that two variable reactances, such as the first and second reactance tube, must be employed connected to the transmission lines 56, 58. If only a single reactance tube were coupled to both of the lines, the direction of rotation of the reflected wave would be the same as that for the incident wave. Consequently, when the reflected wave travels to the right and rejoins the energy circularly-polarized and travelling to the right from the coupling 20, a linearly-polarized wave would not result.

In the embodiment of Figure 10 the linearly-polarized wave, which is the resultant of the circularly-polarized wave travelling to the right from the coupling means from the source, and the reflected wave which is circularly-polarized in an opposite sense, is coupled to the first and second loads in a proportion dependent upon the direction of polarization of the resultant linearly-polarized wave. This direction of rotation, however, depends again upon the amount of reactance introduced by the reactance tubes and the consequent phase relationship between the reflected wave and the incident circularly-polarized wave travelling to the right. Accordingly, one load may be an antenna or lead to a radiator, while the other load may be a matched absorbing load. In this fashion, the energy transmitted from the antenna is amplitude-modulated in accordance with signals applied to the reactance tubes. When the modulation is large, large amounts of energy are absorbed in the absorbing load, whereas when the instantaneous modulation is small, substantially all the energy is fed to the antenna.

If desired, the structure set forth in Figure 10 may be modified so that frequency modulated energy introduced into the circular waveguide 10 by the waveguide 22 is converted into amplitude-modulated energy. In such case the reactance tube transmission lines 56 and 58 may be omitted and the resonant chamber 48 is employed as a frequency-sensitive device. The reactance of the frequency-sensitive device changes with variations in the frequency of the signal in the waveguide 22. This results in corresponding changes in the polarization of the linearly polarized wave produced in the manner described above and in a variation in the power division ratio of the power divider. The above structure may be employed to derive amplitude-modulated energy from a frequency-modulated transmitter, as a balanced discriminator, or as a filter.

Thus, the invention discloses a combination for conveniently securing a desired power division between two loads, and one of which may conveniently be used as an absorber in an absorption modulation system. The invention contemplates a high-frequency source coupled to a hollow-pipe waveguide in a fashion to produce circularly-polarized waves travelling in both directions along the axis of the guide from the coupling. One of the circularly-polarized waves is effectively reflected, or changed in phase by a reactance, to join the other circularly-polarized wave, the resultant being a linearly-polarized wave. A coupling is provided to each of the two independent modes in the waveguide to which the two loads are respectively coupled. The power division between the loads depends upon the angular orientation of the resultant linearly-polarized wave, which is resolved into two components each of which is coupled inde-

pendently. Therefore, the power division depends in turn upon a reflection reactance. The reactance may be a simple piston or plunger, the position of which is varied to vary the reactance. If desired, the reactance may include a pair of reactance tubes, driven in phase by a modulating or power-dividing signal, independently reflecting in phase the two independent modes of propagation of the birefrigerent waveguide.

What is claimed is:

1. A waveguide circuit comprising, in combination, a circular waveguide dimensioned to support propagation of circularly polarized wave energy in a given frequency band; input means electrically coupled to said waveguide at a location intermediate the ends thereof for exciting circularly polarized waves therein having a given polarization sense, said circularly polarized waves being excited by said input means to travel down said circular waveguide in opposite directions with respect to said input means; a pair of output means in space quadrature relation electrically coupled to said waveguide on one side of said input means; a variable reactance device located in said waveguide on the other side of said input means for reflecting incident circularly polarized wave energy from said input means back toward said input means in a polarization sense opposite said given polarization sense, whereby said reflected wave energy combines with the input energy at said input means to form a linearly polarized wave propagated toward said output means having a direction of polarization which is a function of the value of reactance of said variable reactance means; and modulating means coupled to said variable reactance device for varying its effective reactance in accordance with a modulating signal, whereby the direction of polarization of said plane polarized energy also varies in accordance with said modulating signal.

2. A waveguide circuit as set forth in claim 1, wherein said variable reactance device includes a cavity resonator tuned to a frequency in said band, formed with a coupling aperture between said resonator and said waveguide tuned to said frequency within said band to permit the coupling of circularly polarized wave energy from said waveguide into said resonator and from said resonator into said waveguide, and said modulating means including means for varying the reactance presented by said resonator in accordance with a modulating signal.

3. A waveguide circuit as set forth in claim 2, said modulating means including a pair of probes in space quadrature extending into said cavity resonator, each said probe being adapted to be coupled to a reactance tube, whereby, the application of said modulating signal simultaneously to both of said reactance tubes equally affects the space quadrature components of the circularly polarized wave energy in said cavity resonator.

4. A waveguide circuit as set forth in claim 1, wherein said variable reactance device comprises a tuning plunger providing a short circuit across said circular waveguide, and means for varying the position of said plunger in the axial direction of said waveguide in accordance with a modulating signal.

5. A waveguide circuit comprising, in combination, a circular waveguide dimensioned to support the propagation of circularly polarized wave energy in the $TE_{1,1}$ mode in a given frequency band; input means electrically coupled to said waveguide at a location intermediate the ends thereof for exciting circularly polarized waves in the $TE_{1,1}$ mode therein that have a given polarization sense, said circularly polarized waves being excited by said input means to travel away from said input means in opposite directions in said circular waveguide; a pair of output means in space quadrature relation electrically coupled to said waveguide on one side of said input means; a variable reactance device located in said waveguide on the other side of said input means for reflecting incident circularly polarized wave energy from said input means back toward said input means in a polarization sense opposite said given polarization sense, whereby said reflected wave energy combines with the input energy at said input means to form a linearly polarized wave propagated toward said output means having a direction of polarization which is a function of the value of reactance of said variable reactance means; and modulating means coupled to said variable reactance device for varying its effective reactance in accordance with a modulating signal, whereby the direction of polarization of said plane polarized energy also varies in accordance with said modulating signal.

6. A waveguide circuit comprising, in combination, a waveguide dimensioned to support the propagation of circularly polarized wave energy in a given frequency band; input means electrically coupled to said waveguide at a location intermediate the ends thereof for exciting equal amplitude waves therein in space and phase quadrature relation; said equal amplitude waves being excited by said input means to travel in opposite directions in said waveguide with respect to said input means; a pair of output means in space quadrature relation electrically coupled to said waveguide on one side of said input means; a variable reactance device located in said waveguide on the other side of said input means for reflecting incident circularly polarized wave energy from said input means back toward said input means; and modulating means coupled to said variable reactance means for varying said reactance in accordance with a modulating signal.

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