Sept. 23, 1958 J. EPSTEIN 2,853,682

WAVEGUIDE FILTER

Filed Dec. 1, 1954 2 Sheets-Sheet 1

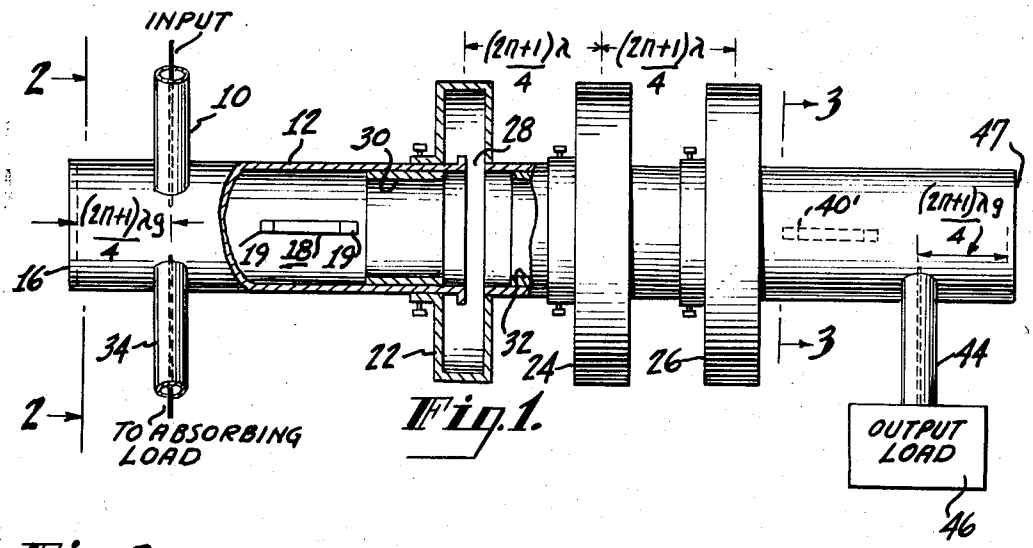


Fig. 1.

Fig. 2.

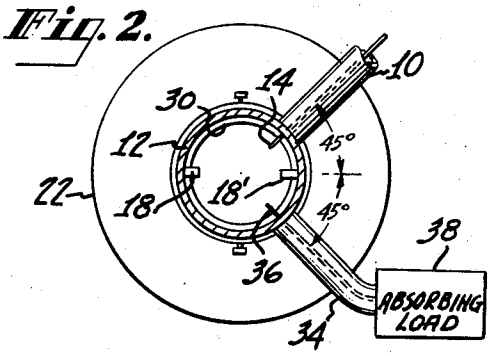
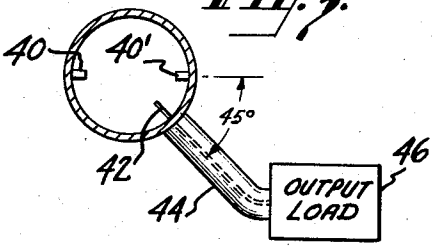


Fig. 3.



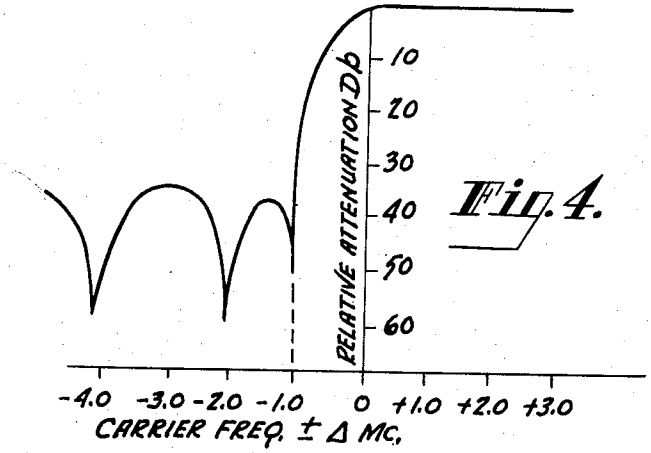


Fig. 4.

INVENTOR.
JESS EPSTEIN
BY J. C. Whittaker
ATTORNEY

Sept. 23, 1958 J. EPSTEIN 2,853,682

WAVEGUIDE FILTER

Filed Dec. 1, 1954 2 Sheets-Sheet 2

Fig. 5.

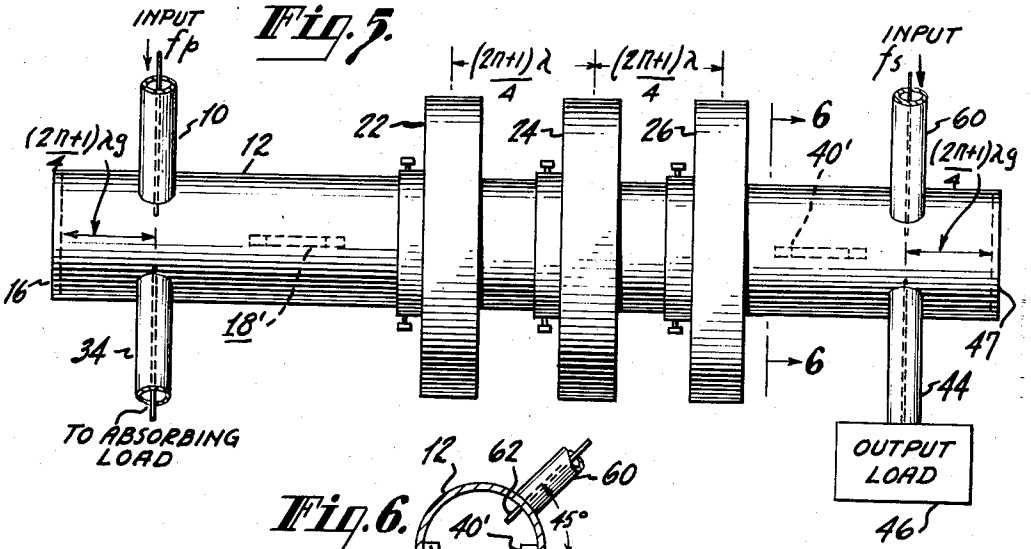


Fig. 6.

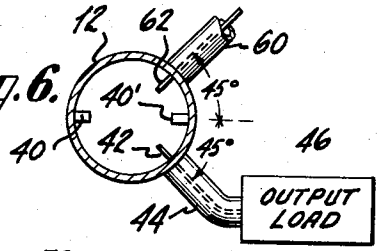


Fig. 7.

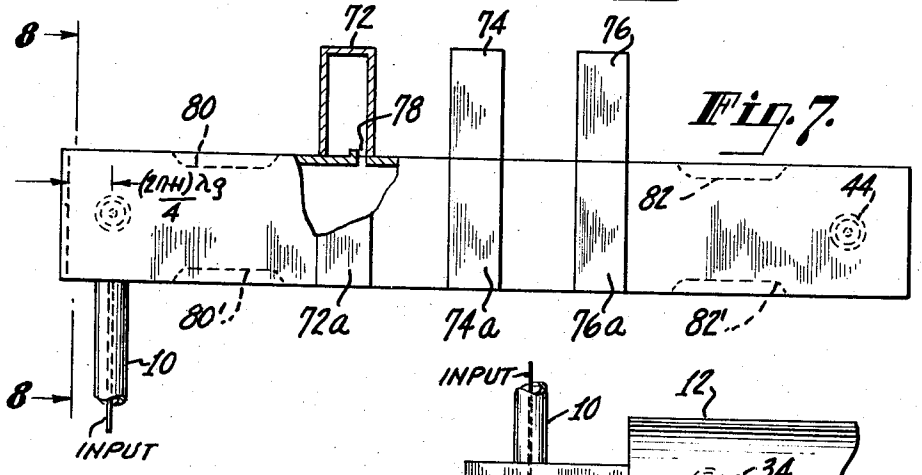


Fig. 8.

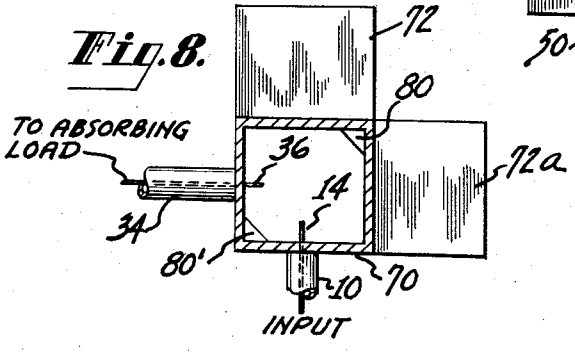


Fig. 9.

INVENTOR.
JESS EPSTEIN
BY J. C. Whittaker
ATTORNEY

United States Patent Office 2,853,682 Patented Sept. 23, 1958

2,853,682

WAVEGUIDE FILTER

Jess Epstein, Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application December 1, 1954, Serial No. 472,317

19 Claims. (Cl. 333—6)

The present invention relates to electromagnetic wave filters and in particular to improved waveguide filters.

It is an object of the present invention to provide an improved waveguide filter operative in the ultra high frequency and microwave regions.

It is another object of the present invention to provide an improved waveguide filter of extremely high power handling capacity.

It is still another object of the present invention to provide an improved vestigial sideband filter especially suitable for use in a television transmission system.

Still another object of the present invention is to provide an improved vestigial sideband filter of much simpler structure than existing vestigial sideband filters.

Yet another object of the present invention is to provide an improved waveguide filter having constant input resistance.

A more specific object of the present invention is to provide an improved waveguide filter adapted to couple two separate generators of different frequencies to a common load such as, for example, both a picture frequency generator and a sound frequency generator to a television system radiating means.

A typical embodiment of the present invention includes a main waveguide dimensioned to support the propagation of a given mode of linearly polarized wave energy in a band of frequencies. This band includes certain desired frequency components and certain undesired frequency components. Positioned along the length of the main waveguide are a plurality of cavity resonators, each coupled to the waveguide and each tuned to a different, undesired frequency. The entire filter is series resonant at the desired frequency. Located between the input means and the cavity resonators is a circular polarizer, whereby linearly polarized energy travelling from the input means toward the cavity resonators is converted to circularly polarized wave energy. The circularly polarized wave energy at the undesired or reject frequencies is reflected back from the cavity resonators and reconverted to linearly polarized wave energy by the circular polarizer. This reflected, linearly polarized energy is in space quadrature with the input linearly polarized wave energy and may be extracted from the waveguide by a suitably positioned device such as a probe extending into the guide. In one form of the invention, the probe leads to a dissipating load which substantially fully attenuates energy at the undesired frequencies.

The energy at the desired frequency passes through the waveguide substantially unaffected by the cavity resonators. Beyond the cavity resonators a second circular polarizer reconverts this circularly polarized energy to linearly polarized energy. An output means including a suitably positioned probe located at the output end of the waveguide extracts this energy from the waveguide and passes it to an output load such as an antenna or the like.

In one form of the invention the main waveguide may

be circular and the cavity resonators cylindrical and symmertically disposed about the circular waveguide. In another form of the invention the main waveguide may be rectangular and the cavity resonators also rectangular. The input and output means may include coaxial lines, waveguides or broad band transition means between the input and output transmission lines and the main waveguide.

Another embodiment of the invention is especially adapted for connecting two different generators to a common load. One of the generators is coupled to the main waveguide at one end thereof and the other at the other end thereof. As in the embodiment above described, one or more cavity resonators located along the length of the guide (between the input and output end thereof) may be tuned to certain reject frequencies in the band associated with the first of the generators. Another of the cavity resonators may be tuned to a second input frequency associated with the other generator. A circular polarizer is located between each generator input and the cavity resonators.

The desired frequency components produced by the first generator are transmitted down the guide and changed from linearly to circularly polarized waves and then from circularly polarized waves to linearly polarized waves. An output probe connected to a common output load picks up this output energy. The undesired frequency components produced by the first generator are reflected back from the cavity resonators to an absorbing load as in the embodiment discussed above.

The input wave applied by the second generator is changed to a circularly polarized wave, reflected back from the cavity tuned to its frequency and reconverted to a linearly polarized wave travelling in the same direction and having the same plane of polarization as the wave of desired frequency components from the first generator. It is therefore also applied to the common load. The undesired frequency components, if any, of the second wave are passed through the waveguide to the other input end thereof and attenuated by the absorbing load.

The invention will be described in greater detail by reference to the following description taken in connection with the following drawing in which:

Fig. 1 is a view, partially in cross-section, of a typical embodiment of the present invention;

Fig. 2 is a cross-sectional view along line **2—2** of Fig. 1;

Fig. 3 is a cross-sectional view along line **3—3** of Fig. 1;

Fig. 4 is a graph of the performance of the filter of Figs. 1–3;

Fig. 5 is a plan view of a second embodiment of the invention;

Fig. 6 is a cross-sectional view along line **6—6** of Fig. 5;

Fig. 7 is a view, partially in cross-section, of a third embodiment of the invention;

Fig. 8 is a cross-sectional view along line **8—8** of Fig. 7; and

Fig. 9 is a plan view of a modified input coupling means usable with the embodiments of Figs. 1 and 5.

Throughout the figures similar reference numerals refer to similar elements.

Referring now to the drawing and in particular to Figs. 1–3, input coaxial line **10** supplies its energy to circular waveguide **12**. The waveguide is dimensioned to operate in its dominant (TE_{11}) mode. The end of coaxial line **10** extending into waveguide **12** is formed as a coupling probe **14** which excites the waveguide to propagate linearly polarized waves toward the cavity resonators. The input means is spaced an odd number of guide quarter

wave-lengths, at the frequency it is desired to transmit down the waveguide, from the input end **16** of the waveguide. Thus, looking toward the input end **16** from input probe **14** the input end apepars as an open circuit and substantially all wave energy is transmitted to the right.

Circular polaizing means **18**, **18'** comprise a pair of quarter wave fins tapered at the ends **19**, **19** thereof for matching purposes. These convert the linearly polarized wave travelling from the input means **10** into a circularly polarized wave. Although shown as a pair of fins, it will be appreciated that other circular polarizing devices such as metal or dielectric rods or a dielectric slab may be used instead. The theory of operation of circular polarizing devices is well known and need not be discussed in detail here.

Located along the axial length of circular waveguide **12** are a plurality of cavity resonators **22**, **24**, **26**, each coupled to the waveguide by means of an annular coupling aperture one of which, **28**, is shown. These cavity resonators are tuned to different frequencies in the input frequency band which it is desired to reject. The susceptance slope of the cavities may be varied by adjusting cavity dimensions and the widths of the annular coupling apertures. The filter is made series resonant for a desired frequency in the input band by means of a plurality of transformers, one located in front of each cavity resonator. Two such transformers **30**, **32** are shown.

Each cavity resonator may be provided with a plurality of equiangularly spaced tuning slugs located in a side wall of the cavity resonator for tuning out electrical and mechanical dissymmetries in the resonators. For the sake of drawing simplicity these are not illustrated.

Referring again to Fig. 1, the input linearly polarized wave is converted to a circularly polarized wave by polarizer **18**. Cavity resonators **22**, **24** and **26** are tuned to reject frequencies f_1, f_2 and f_3 respectively, in the input frequency band. These resonators therefore appear as open circuits to these frequencies and the energy at these frequencies is reflected back from the cavity resonators toward circular polarizers **18**, **18'**. The circular polarizer reconverts the circularly polarized waves at frequencies f_1, f_2, f_3 to linearly polarized waves having a direction of polarization in space quadrature with that of the input wave.

Coaxial line **34** is electrically coupled to waveguide **12** by means of coupling probe **36** which is at an angle of 45° with respect to the common axis of fins **18**, **18'**. Preferably probe **36** is spaced an odd number of guide quarter wavelengths from the short-circuited end **16** of the waveguide at approximately the average reject frequency. Thus, the wave energy at the rejected frequencies looking from coupling probe **36** toward short-circuited end **16** sees an open circuit and is substantially fully transmitted into the coaxial transmission line **34**.

In a preferred form of the invention, line **34** may be terminated in an absorbing load **38** made of Bakelite, ferrous metal or some other energy dissipating means for substantially fully dissipating the rejected wave energy. If, however, it is desired to utilize the rejected frequencies, the coaxial line **34** may be terminated in a utilization device.

As already mentioned, the filter is series resonant at a frequency of interest in the input band. Energy at this frequency is converted from linearly to circularly polarized wave energy by circular polarizer **18**, **18'**. Cavity resonators **22**, **24** and **26** are tuned to frequencies lower than the frequency of interest and have substantially little effect on this frequency. Located in the waveguide near the output end thereof is a second circular polarizer **40**, **40'**. Again, although shown as a pair of tapered fins, the polarizer may consist of other types of polarizing devices well known in the art. This second circular polarizer converts the circularly polarized wave energy at the frequency of interest to linearly polarized waves having a direction of polarization which depends upon the angular position of fins **40**, **40'**.

The output means includes a coupling probe **42** which may be an extension of the inner conductor of coaxial line **44**. The output coupling probe is spaced an odd number of guide quarter wavelengths, at the frequency of interest, from the remote end **47** of the waveguide. Therefore, looking toward the remote end of the waveguide from coupling probe **42** the former appears as an open circuit and substantially all energy at the frequency of interest passes into coaxial transmission line **44** and thence to the output load **46**.

Fig. 4 is a graph of the performance of the filter system illustrated in Figs. 1–3. The curve dips at frequencies f_1, f_2, and f_3. In an embodiment of the invention actually constructed, the attenuation at the reject frequencies was greater than 50 db with respect to the frequency of interest, as clearly illustrated on the graph.

In the embodiment of the invention discussed above, the input and output means include coaxial transmission lines. It is to be understood that this is merely illustrative of the invention and is not meant to be limiting. Other input and output means such as waveguides may be employed and, if desired, broad band coupling means may be employed between the main waveguide and the input and output means. If it is desired to substitute waveguides for the coaxial lines, these would be coupled to the circular guide with their broad dimension parallel to the waveguide axis. One typical broad band matching device which may be employed instead of the input connection shown in Figs. 1–3 is illustrated in Fig. 9. This includes an input coaxial line **10** coupled to a rectangular waveguide **50** which is in turn coupled to the circular waveguide **12**. The coaxial line **34** leading to the absorbing load is shown by dashed lines. This line is spaced an odd number of guide quarter wavelengths from the short-circuiting end **16** of the waveguide.

Although in the embodiment of the invention discussed above three cavity resonators are employed, it is to be understood that the invention is not limited to the use of three resonators. For certain purposes a single cavity may be sufficient and for others it may be desirable to use two, four or more cavity resonators.

A second embodiment of the invention is shown in Fig. 5. This one is particularly adapted for coupling two generators having different carrier frequencies to a single load. For example, it is especially suitable for coupling the picture and sound transmitters of a television transmitting station to a single antenna. The input wave energy applied to coaxial line **10** includes the picture frequency f_p and certain other, lower frequencies it is desired to filter out of the system. Cavity resonators **22** and **24** are tuned to these undesired frequencies and, as in the embodiment of Fig. 1, wave energy at the undesired or reject frequencies is reflected back toward the input end **16** of the waveguide and substantially fully transmitted to the absorbing load connected to coaxial line **34**. The main waveguide **12** is series resonant at the picture frequency. The linearly polarized input wave energy at the picture frequency is converted to circularly polarized wave energy by polarizer **18**, **18'** (only **18** is shown). This circularly polarized wave energy travels down the waveguide and is reconverted to linearly polarized wave energy by circular polarizer **40**, **40'**. Output coupling probe **42** is at an angle of 45° with polarizer **40**, **40'** and receives the energy at the picture frequency.

Wave energy at the sound frequency f_s is applied to the second input coaxial line **60**. This line is coupled to waveguide **12** by means of coupling probe **62** (Fig. 6) positioned at an angle of 45° to the plane passing through **40**, **40'** and in space quadrature with output probe **42**. Cavity resonator **26** is tuned to the sound frequency and

therefore looks like an open circuit in series with the waveguide at the sound frequency.

In operation, input wave energy at the sound frequency is converted by circular polarizer **40, 40'** to circularly polarized wave energy. The circularly polarized wave energy is reflected back from cavity resonator **26** toward the remote end **47** of the waveguide and polarizer **40, 40'** reconverts the circularly polarized wave energy to linearly polarized wave energy. The reflected, linearly polarized wave energy is in space quadrature with the incident, linearly polarized wave energy at the sound frequency. Therefore, output probe **42** is suitably oriented to couple this reflected wave to output load **46**.

For optimum performance probe **42** should be spaced an odd number of guide quarter wavelengths, at the sound frequency, from the remote end **47** of the waveguide. Also, the probe should be spaced an odd number of guide quarter wavelengths, at the picture frequency, from the remote end **47** of the waveguide. These requirements conflict; however, if the two input frequencies are relatively close together then the two spacings are substantially the same. In an embodiment of the invention actually constructed the picture and sound frequencies were within 1% of one another and the spacing between probe **42** and waveguide end **47** was adjusted to a guide quarter wavelength at the picture frequency. When so adjusted, there was practically no energy loss at the sound frequency. If the two input frequencies are relatively widely spaced from one another, it would be preferable to use a broad band transition section between the output load and the circular waveguide. For example, a transition section such as shown in Fig. 9 could be employed as could a number of other broad band devices known to those skilled in the art.

Summarizing the operation of the embodiment of Fig. 5, the picture frequency supplied to input means **10** is converted to circularly polarized wave energy, then converted back to linearly polarized energy and passed into the output load. Wave energy accompanying the wave energy at the picture frequency which it is desired to reject is reflected back from cavity resonators **22** and **24** and passed to the absorbing load connected to line **34**. Input energy at the sound frequency is supplied to coaxial line **60**. Cavity resonator **26** is tuned to the sound frequency and reflects all energy at this frequency back to the output load **46**. Any undesired frequencies accompanying the sound frequency pass into the absorbing load connected to line **34**.

As in the embodiments of Figs. 1–3, it is to be understood that although only three cavity resonators are shown, more or less may be employed according to the filter characteristics desired. Also, it is to be understood that the cavity resonators may include means for adjusting the susceptance slope of the cavities and for compensating for resonator dissymmetries. These are explained in more detail in the copending application mentioned above.

The embodiments of Figs. 1–3, 5 and 6, employ a circular main waveguide and annular, cylindrically shaped cavity resonators. If desired, the main cavity resonator may be rectangular and the cavity resonators also may be rectangular. An embodiment of the invention employing such components is illustrated in Figs. 7 and 8.

Referring now to Figs. 7 and 8, the filter includes a main square waveguide **70** and a plurality of pairs of rectangular cavity resonators **72, 72*a*; 74, 74*a*** and **76, 76*a***. Each cavity resonator is coupled to the waveguide by means of a slot perpendicular to the main waveguide axis, one of which, **78**, is shown in Fig. 7. As in the other embodiments of the invention, the width of the slot and cavity dimensions may be made adjustable in order to vary the susceptance slope of the cavities. For the sake of drawing simplicity, such means are not shown but it is to be understood that they may comprise a sleeve and set screw similar to the arrangement shown in Figs. 1 and 5, and tuning plungers mounted in the walls of the resonators or in the short-circuiting ends of the resonators.

The mode of operation of the filter of Figs. 7 and 8 is substantially the same as that of Fig. 1. An input wave including a desired frequency and certain other frequencies it is desired to reject is applied to input coaxial line **10**. Input probe **14** excites the waveguide in its dominant TE_{10} mode and the latter transmits linearly polarized wave energy toward the cavity resonators positioned along its length. Circular polarizer **80, 80'** located in opposite corners of the square waveguide convert the incident linearly polarized wave energy to circularly polarized wave energy. Wave energy at the undesired frequency components is reflected back from cavity resonators **72, 72*a*; 74, 74*a*** and **76, 76*a***. Circular polarizer **80, 80'** reconverts the reflected energy to linearly polarized energy and it is all substantially fully transmitted to the absorbing load via probe **36** and transmission line **34**. The filter is series resonant at the desired frequency. This desired frequency therefore passes through the waveguide being converted from linearly polarized energy to circularly polarized energy by polarizer **80, 80'**, and reconverted back to linearly polarized wave energy by polarizer **82, 82'** and thence passed via output coaxial line **44** to an output load (not shown).

What is claimed is:

1. A waveguide filter comprising, in combination, a waveguide dimensioned to support the progagation of wave energy in a given frequency band; input means electrically coupled to said waveguide for exciting the propagation therein of linearly polarized wave energy in said band having a given polarization plane; a plurality of cavity resonators electrically coupled to said waveguide and spaced from one another along the length of said waveguide, each said cavity resonator being tuned to a different frequency within said band to reflect wave energy of the frequency to which said resonator is tuned back toward said input means; circularly polarizing means located in said waveguide between said input means and said plurality of cavity resonators for converting the linearly polarized wave energy travelling from said input means to said cavity resonators to circularly polarized wave energy and reconverting the circularly polarized wave energy reflected from said cavity resonators back toward said input means to linearly polarized wave energy having a polarization plane in space quadrature with said given polarization plane; and output means electrically coupled to said waveguide in space quadrature with said input means for receiving said reflected, linearly polarized wave energy.

2. A waveguide filter as set forth in claim 1, and further including second polarizing means located in said waveguide beyond said cavity resonators for converting the circularly polarized wave energy passed by said waveguide to linearly polarized wave energy; and second output means electrically coupled to said waveguide beyond said second polarizing means for receiving said passed, linearly polarized wave energy.

3. A waveguide filter comprising, in combination, a waveguide dimensioned to support the propagation of wave energy in a given frequency band; input means electrically coupled to said waveguide for exciting the propagation therein of linearly polarized wave energy in a given polarization plane at at least two frequencies within said band; output means coupled to said waveguide at a given angle to said input means and spaced a predetermined distance from said input means; reflector means coupled to said waveguide between said input means and said output means for reflecting wave energy at one of said frequencies and passing wave energy at the other of said frequencies; first circular polarizing means located in said waveguide between said input means and said reflector means for converting the linearly polarized wave energy travelling from said input means

to said reflector means to circularly polarized wave energy and reconverting the circularly polarized wave energy at said one frequency reflected from said reflector means back toward said input means to linearly polarized wave energy having a polarization plane in space quadrature with said given polarization plane; circular polarizing means located in said waveguide between said reflector and said output means for converting the circularly polarized wave energy at said other frequency passed by said reflector means to linearly polarized wave energy having a polarization plane at said given angle with said given polarization plane, whereby said plane polarized wave energy at said other frequency is transmitted to said output means.

4. A waveguide filter as set forth in claim 3, and further including means electrically coupled to said waveguide in the region of said input means for substantially dissipating the linearly polarized wave energy at said one frequency.

5. A waveguide filter as set forth in claim 4, said means for dissipating said wave energy including second output means coupled to said waveguide in space quadrature with said input means, said output means comprising a dissipating load.

6. A waveguide filter as set forth in claim 3, wherein said reflector means includes a cavity resonator tuned to said one frequency.

7. A waveguide filter as set forth in claim 4, wherein said waveguide comprises a circular waveguide and said reflector means comprises a hollow cylindrical cavity resonator of adjustable size tuned to said one frequency concentrically arranged about said circular waveguide.

8. A waveguide filter as set forth in claim 4, wherein said waveguide comprises a square waveguide and said reflector means comprises a pair of rectangular cavity resonators, each tuned to said one frequency, coupled to adjacent walls of said waveguide and extending radially outward therefrom.

9. A waveguide filter as set forth in claim 4, and further including a second reflector means coupled to said waveguide between said first and second polarization means for reflecting wave energy at a third frequency and passing wave energy at a fourth frequency, both within said given frequency band; and second input means electrically coupled to said waveguide in the region of said output means and in space quadrature with said output means for exciting the propagation along said waveguide of linearly polarized wave energy in said given polarization plane at at least said third and fourth frequencies, whereby said second polarization means converts said last-named linearly polarized wave energy into circularly polarized wave energy and reconverts the circularly polarized wave energy at said third frequency reflected from said second reflector means back toward said output means to linearly polarized wave energy having a polarization plane in space quadrature with said given polarization plane and said first polarizing means converts the circularly polarized wave energy passed by said second reflector means to linearly polarized wave energy having a polarization plane in space quadrature with said given polarization plane.

10. A waveguide filter as set forth in claim 9, wherein said first and second reflector means comprise cavity resonators, one tuned to said first frequency and the other tuned to said third frequency.

11. A waveguide filter as set forth in claim 10, and further including means operatively associated with said cavity resonators for adjusting the susceptance slope of said resonators.

12. A waveguide filter as set forth in claim 10, wherein said waveguide comprises a circular waveguide and said cavity resonators comprise hollow cylindrical members concentrically arranged about said waveguide.

13. A waveguide filter as set forth in claim 4, and further including means for rendering said filter series resonant at said other frequency, said means including an impedance transformer located in said waveguide between said pair of polarizing means.

14. In combination, a length of waveguide, input means coupled to one end portion of said waveguide for introducing a first linearly polarized wave thereto having frequency components within a first frequency band; input means coupled to the other end portion of said waveguide for introducing a second linearly polarized wave thereto having the same direction of polarization as said first wave and having frequency components within a second frequency band; a pair of cavity resonators individually coupled to said waveguide between said two input means, one tuned to a frequency component in said first band and the other tuned to a frequency component in said second band; a pair of means for converting plane to circularly polarized waves, one located in said waveguide between said cavity resonators and one of said input means and the other located in said waveguide between said cavity resonators and the other of said input means; and an output means coupled to one end portion of said waveguide oriented to receive a linearly polarized wave having a direction of polarization in quadrature with that of the first and second waves.

15. In the combination as set forth in claim 14, said waveguide comprising a circular waveguide and said cavity resonator comprising annular cavity resonators concentric with the waveguide.

16. In the combination as set forth in claim 14, said waveguide being formed with coupling apertures therein for coupling said cavity resonators to said waveguide, and further including means for adjusting the effective size of said apertures.

17. In combination, a length of waveguide, input means coupled to one end portion of said waveguide for introducing a first linearly polarized wave thereto having frequency components within a first frequency band; input means coupled to the other end portion of said waveguide for introducing a second linearly polarized wave thereto having the same direction of polarization as said first wave and having frequency components within a second frequency band; a pair of cavity resonators individually coupled to said waveguide between said two input means, one tuned to a frequency component in said first band and the other tuned to a frequency component in said second band; a pair of means for converting plane to circularly polarized waves, one located in said waveguide between said cavity resonators and one of said input means and the other located in said waveguide between said cavity resonators and the other of said input means; and output means coupled to one end portion of said waveguide oriented to receive a linearly polarized wave having a direction of polarization in quadrature with that of the first and second waves; and a second output means coupled to the other end portion of said waveguide oriented to receive a linearly polarized wave having a direction of polarization in quadrature with that of the first and second waves.

18. In the combination as set forth in claim 17, further including a dissipating load connected to one of said output means.

19. A waveguide filter comprising, in combination, a waveguide dimensioned to support the propagation of wave energy in a given frequency band, input means electrically coupled to said waveguide for exciting the propagation therein of linearly polarized wave energy in a given polarization plane at at least two frequencies within said band, a cavity resonator coupled to said waveguide at a predetermined distance from said input means for reflecting wave energy at one of said frequencies and passing wave energy at the other of said frequencies, said cavity resonator being tuned to said one frequency, circularly polarizing means located in said waveguide between said input means and said cavity resonator for converting the linearly polarized wave energy traveling from

said input means to said cavity resonator to circularly polarized wave energy and for reconverting the circularly polarized wave energy reflected from said cavity resonator back towards said input means to linearly polarized wave energy having a polarization plane in space quadrature with said given polarization plane, and output means electrically coupled to said waveguide for receiving said reflected, linearly polarized wave energy.

References Cited in the file of this patent

UNITED STATES PATENTS

2,458,579	Feldman	Jan. 11, 1949
2,531,447	Lewis	Nov. 28, 1950
2,607,849	Purcell	Aug. 19, 1952
2,645,769	Roberts	July 14, 1953
2,686,901	Dicke	Aug. 17, 1954
2,713,151	Farr	July 12, 1955