

Aug. 22, 1961

W. L. WHIRRY  
MICROWAVE FILTER

2,997,673

Filed June 13, 1958

2 Sheets-Sheet 1

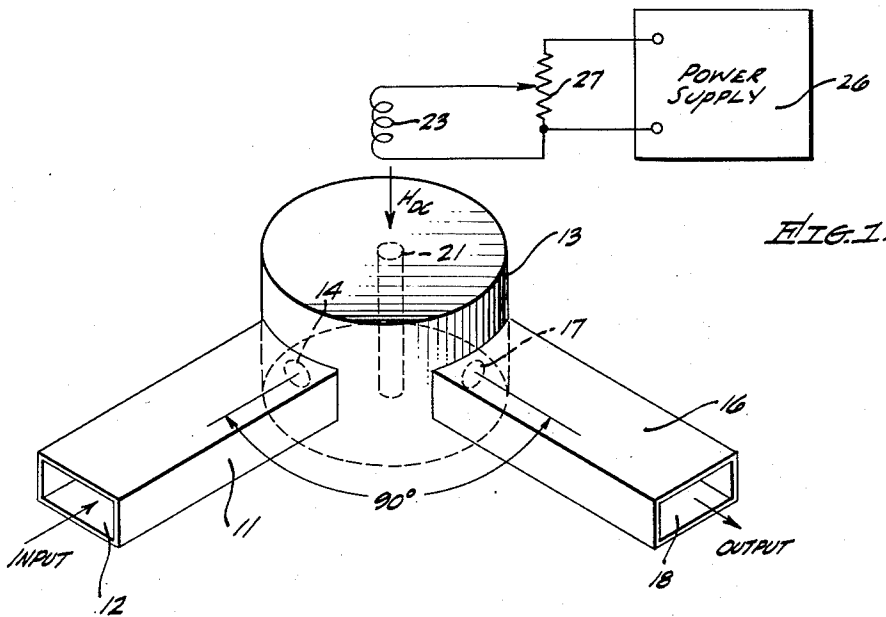


FIG. 1.

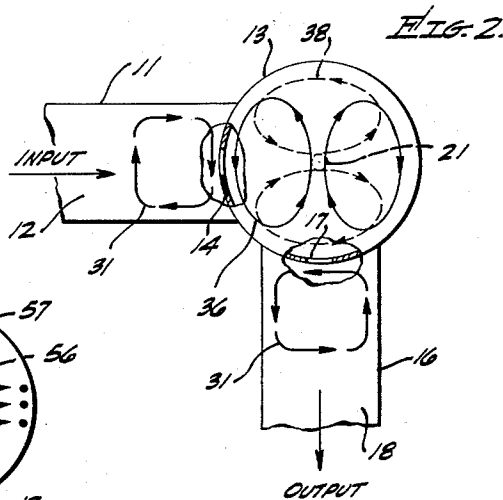


FIG. 2.

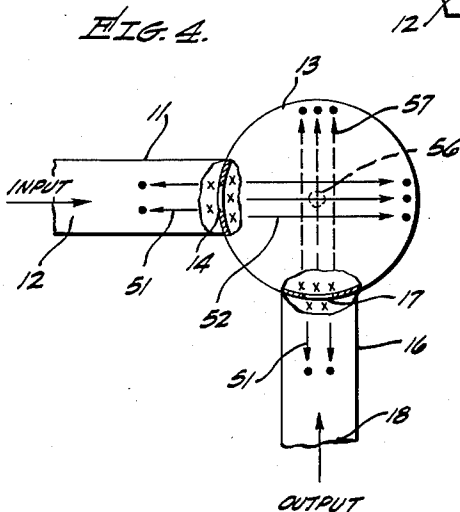


FIG. 4.

INVENTOR.  
WALTER L. WHIRRY,  
BY Robert H. Clay

ATTORNEY

Aug. 22, 1961

W. L. WHIRRY  
MICROWAVE FILTER

2,997,673

Filed June 13, 1958

2 Sheets-Sheet 2

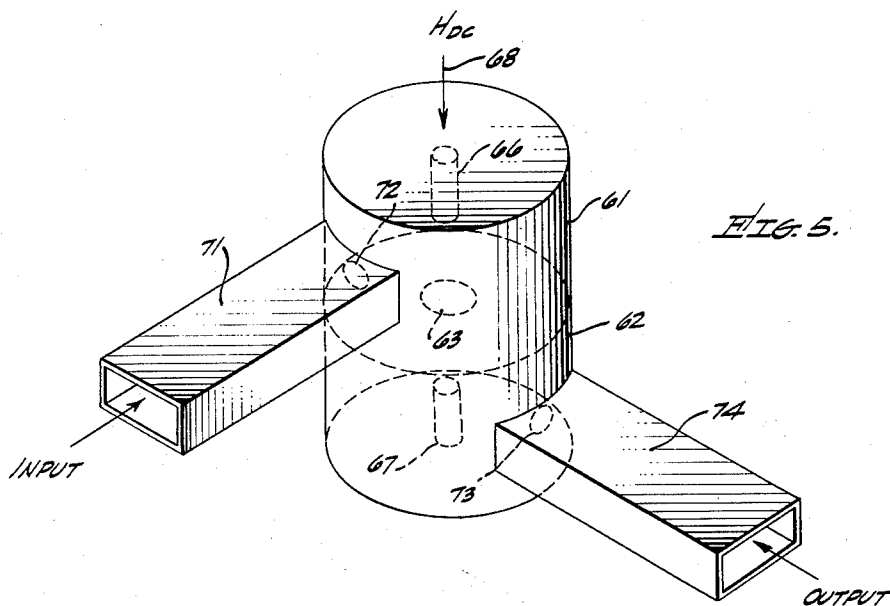


FIG. 5.

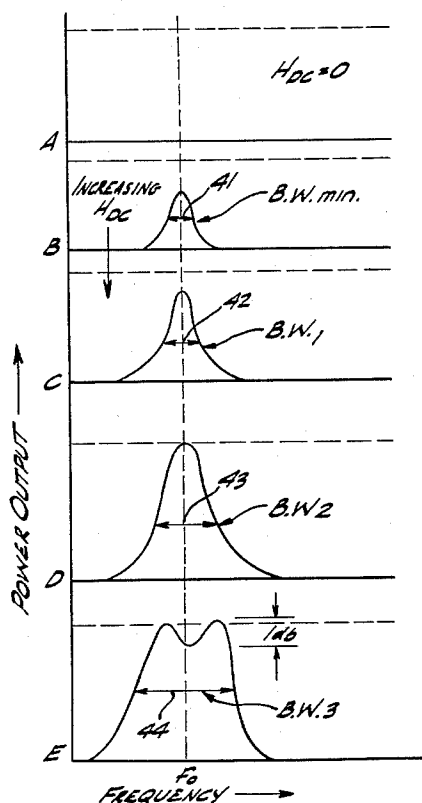


FIG. 3.

INVENTOR.  
WALTER L. WHIRRY,  
BY Robert H. Clay

ATTORNEY.

1

2,997,673

## MICROWAVE FILTER

Walter L. Whirry, Inglewood, Calif., assignor to Hughes Aircraft Company, Culver City, Calif., a corporation of Delaware

Filed June 13, 1958, Ser. No. 741,941

2 Claims. (Cl. 333-73)

The present invention relates to a microwave filter, and more particularly, to a variable bandwidth microwave filter.

For the most part, microwave filters are narrow band devices, and efforts to increase the bandwidth, as well as render them variable, have resulted in disadvantages. For instance, one type of broadbanding has been carried out by using a plurality of resonant cavities with switches to couple the cavities in certain grouping arrangements, and so provide different bandwidths to the system. Another system involves the use of movable irises in a waveguide to make up a variable band-pass cavity. A further system requires a resonant cavity having adjustable screws inserted through the wall which results in energy being coupled between two modes supported within the cavity, and thereby present a variable bandwidth dependent upon the degree of coupling between the two modes.

The foregoing examples of known variable bandwidth microwave filters each incorporate inherent disadvantages. The first mentioned system is bulky and substantially slow acting, while the latter two systems have moving parts requiring external mechanical actuators. Also, the latter systems are slow acting and have to be assembled so that the moving parts make good electrical contact with the wall of the associated conductive elements for proper operation.

In brief, the variable bandwidth microwave filter of the present invention comprises a single resonant cavity having an element of ferromagnetic material inserted therein and single input and output waveguides suitably coupled thereto. The two waveguides are coupled to the sidewall of the cavity thereby permitting suitable temperature compensation at the ends. Excitation of the cavity is in a mode such that the magnetic field is linearly polarized at the wall of the cavity. Under such a mode, the ferromagnetic element or rod couples energy into a second similar mode which is orthogonal and ninety degrees apart in time phase. This results in a circular rotating radio-frequency magnetic field coaxially within the cavity. The output waveguide is coupled ninety degrees about the circumference of the cavity with respect to the input guide. Now, by controlling the magnetization of the rod, the amount of coupling between the two modes is controlled with the result that the bandwidth is variable.

It is therefore an object of the present invention to provide a new and improved microwave filter having a variable bandwidth.

Another object of the invention is to provide a microwave filter having a variable bandwidth between a single input and a single output without moving parts.

A further object of the invention is to provide a microwave filter wherein the bandwidth is variable in accordance with the degree of magnetization of a ferromagnetic element.

A still further object of the invention is to provide a simple, compact and light weight microwave filter of variable bandwidth.

Other objects and advantages of the present invention will be apparent from the following description and claims considered together with the accompanying drawings, in which:

FIG. 1 is a perspective view of one embodiment of the

2

variable bandwidth microwave filter of the present invention;

FIG. 2 is a plan view of the filter of FIG. 1 showing a mode of excitation;

FIG. 3 is a series of bandwidth characteristics of the filter for various degrees of magnetization of the ferromagnetic rod of FIG. 1;

FIG. 4 is a plan view of the filter of FIG. 1 showing a second mode of excitation; and

FIG. 5 is a two-cavity embodiment of the filter of FIG. 1.

Referring to FIG. 1 in detail, there is illustrated a microwave filter according to the present invention having a rectangular waveguide 11 with an input port 12 for coupling to a source of microwave energy (not shown) and exciting a cylindrical resonant cavity 13 at the resonant frequency thereof through a suitably disposed sidewall coupling aperture 14. A rectangular waveguide 16 is coupled to cavity 13 by another suitably disposed sidewall aperture 17 that is displaced ninety degrees with respect to input aperture 14 and serves as an output coupling at port 18.

For operation as a microwave filter a rod 21 of ferromagnetic material, such as a ferrite, is suitably mounted within cavity 13 on the axis thereof and is magnetized by a movable, permanent magnet or, as shown in FIG. 1, an electromagnet 23. The electromagnet 23 is suitably energized by a conventional direct current power supply 26 with a variable element included in the circuit, such as potentiometer 27. Where substantially high values of static magnetic field are desired, the rod 21 may be substantially small and positioned at one end of cavity 13, but where smaller values of field are desired, a longer rod is used, as shown in FIG. 1.

An example of modes of excitation during operation is shown in FIG. 2 and reference is made to such figure for consideration with the following description. Input energy at port 12 is propagated through waveguide 11 in a transverse electric mode, such as a  $TE_{10}$ -mode, having a plane polarized magnetic field 31. When the frequency of input energy at port 12 is far off the value of the resonant frequency of cavity 13, a high impedance is presented at aperture 14 by the cavity and the energy is reflected. As the frequency of such input energy approaches the value of the resonant frequency of cavity 13, an increasing amount of energy is coupled into the cavity to excite a mode, which for the particular cavity shown in FIGS. 1 and 2 is a transverse magnetic mode 36, such as the  $TM_{110}$  type, and is maximized about the value of resonant frequency. Because of the ninety degree displacement between the two apertures 14 and 17, none of the energy of the cavity mode 36 is coupled through aperture 17 for propagation by waveguide 16 to output port 18.

The foregoing has been set forth with respect to zero magnetization of the ferromagnetic material of rod 21. Now, when a substantially low value of static magnetization, indicated as  $H_{DC}$  in the drawings, of rod 21 is established by a suitable setting of potentiometer 27 across power supply 26, a portion of the energy of the magnetic field 36 is coupled by the rod into a second similar magnetic field mode 38 which is orthogonal and ninety degrees apart in time phase. Since the second field 38 is orthogonal to the first field 36, and there is a ninety degree spacing between apertures 14 and 17, such latter aperture 17 is electromagnetically coupled to the second field and an output is produced at port 18.

As the frequency of the input energy is increased from a value below the resonant frequency to a value above, the output at port 18 increases to a maximum at the resonant frequency and then decreases. With an increase in magnetization of rod 21, the amount of power

coupled into the second field 38 and thus to the output port 18 is increased, as is the spread of frequencies that excite cavity 13. Now, it is well known that when an axial magnetic field is applied to ferromagnetic material disposed in a cavity, such combination of magnetized rod 21 and cavity 13 results in a splitting of the resonant frequencies for clockwise and counter-clockwise directions of rotation of the radio-frequency magnetic field in the cavity. The difference between the two resonant frequencies increases as the degree of magnetization is increased.

Also, in connection with the foregoing, it is readily apparent that both apertures 14 and 17 couple to either direction of rotation of the radio-frequency magnetic field. The result of such characteristics of the described device is to spread the lower and upper values of frequency in which cavity 13 is excited. Eventually, as the degree of magnetization of rod 21 is increased, the difference between the two values of resonant frequency becomes so great that the separation is noted at output port 18 by two peaks of power separated by lower values.

The above described operation may be more readily understood by reference to FIG. 3 wherein a series of frequency response characteristics are illustrated by plotting frequency versus power output at various values of magnetization of rod 21. Thus, for zero magnetization of rod 21, FIG. 3A shows that there is zero output at port 18 for all frequencies. By applying a low value of magnetization to rod 21, excitation of cavity 13 commences and as shown in FIG. 3B, at a value of frequency quite close to the resonant frequency  $f_0$  of cavity 13, without the ferromagnetic material, increases to a substantially low value of power and then decreases in the same manner. FIGS. 3C and 3D illustrate frequency response curves, similar to that of FIG. 2B, for increasing values of magnetization, and it is seen that the frequency spread of excitation of cavity 13 is increased as well as the amplitude of the power output.

For a still greater increase in the magnetic field energization of rod 21 to a value where the two resonant frequencies are considerably different, the aforementioned peaked power output at port 18 is obtained as shown in FIG. 3E. Thus, as indicated in FIGS. 3B-E by the double arrows 41 to 44 and labeled  $BW_{min}$  to  $BW_3$ , respectively, as the static magnetic field of rod 21 is increased, the bandwidth as conventionally measured, also increases thereby readily providing a variable bandwidth characteristic to the microwave filter of the present invention.

The mode of excitation of cavity 13 is not limited to that illustrated in FIG. 2 and may readily be accomplished as shown in FIG. 4 for operation in a manner similar to that set forth in the preceding paragraphs. In this latter drawing, the same reference numerals indicate like elements with respect to FIG. 1. Thus energy propagated within waveguide 11 in a transverse electric mode 51, such as the  $TE_{10}$ -mode, is coupled to cavity 13 in a transverse electric mode, as for example, the  $TE_{111}$ -mode which has a magnetic field 52 parallel to the longitudinal dimension of the cavity wall. With a transverse electric mode, a disc 56 of ferromagnetic material is mounted at one end of cavity 13 in place of the rod 21 of FIGS. 1 and 2, to prevent disturbance of the electric field of the cavity mode. By establishing a static magnetic field axially through the cavity 13, the ferromagnetic disc 56 then couples energy into a second magnetic field 57 having the orthogonal and ninety degree time phase difference as previously set forth with respect to the filter of FIGS. 1 and 2. The operation of the cavity, together with the waveguides 11 and 16 with the foregoing modes of excitation, is the same as described above to provide a variable bandwidth microwave filter. Also, by applying the same principles square cavities may

be used in place of the cylindrical resonant cavities illustrated in the drawing.

While the bandwidth of the filters described so far have been measured to be variable by a factor of about 2 for conditions varied as between those illustrated by FIGS. 3B and 3D and of about 3 as between FIGS. 3B and 3E, where a dip of substantially 1 decibel is permitted between peaks, there are occasions where a greater factor of bandwidth variation is desired. To obtain such greater factor of bandwidth variation, two resonant cavities 61 and 62 are cascaded by providing a central coupling aperture 63 through adjacent ends of the two cavities as shown in FIG. 5.

Each of the two cavities 61 and 62 respectively contains a ferromagnetic rod or disc 66 and 67 which are magnetized as indicated by field arrow 68 to establish a greater difference between resonant frequencies in one cavity than in the other. By suitable proportionment of relative sizes of the ferromagnetic rods 66 and 67, a single static magnetic field producing device may be utilized to control operation of the cavities. Input energy is coupled to one cavity 61 by a waveguide 71 and sidewall coupling aperture 72 while the output is coupled from the other cavity 62 by a sidewall coupling aperture 73 and waveguide 74.

With the foregoing structure and relationships, cavities 61 and 62 support, for example,  $TM_{110}$ -modes and aperture 63 couples to the circularly polarized magnetic field of input cavity 61 to excite a similar mode in output cavity 62. Sidewall coupling aperture 73 is ninety degrees from the input coupling aperture 72 in the manner of FIGS. 1 and 2 and operation is similar to that described for such figures with a resultant greater bandwidth variation.

Also, the two  $TM_{110}$ -mode cavities of FIG. 5 may be utilized in a different manner to achieve similar variable broadband characteristics. With such cavity modes, the coupling aperture 63 between cavities 61 and 62 is centered near the wall ninety degrees from the input waveguide aperture 72 to electromagnetically couple to a single mode of the input cavity 61. A single mode is then excited in the second cavity 62 and the ferromagnetic material 67 couples a portion of the energy into a second similar, but orthogonal mode. This, then, permits the output aperture 73 and waveguide 74 to be positioned in linear alignment with respect to input waveguide 71 and aperture 72. Operation is then substantially the same as set forth in the preceding paragraphs.

A simple, compact and lightweight microwave filter has been described, which requires no moving parts to provide a variable frequency bandwidth at the output thereof. Also, changes in the bandwidth of the output may be rapidly accomplished by a simple electrical adjustment of the strength of the static magnetic field applied to the ferromagnetic material of the filter.

While the salient features of the present invention have been described in detail with respect to a particular embodiment, it will be readily apparent that numerous modifications may be made within the spirit and scope of the invention, and it is therefore not desired to limit the invention to the exact details shown except insofar as they may be defined in the following claims.

What is claimed is:

1. A variable bandwidth microwave filter comprising a first resonant cavity having ferromagnetic material mounted on a center line thereof, variable means disposed adjacent said cavity for establishing a magnetic field along said center line, input means coupled to said cavity for exciting a first mode having a magnetic field component linearly polarized at the walls of said cavity whereby a second similar mode is excited in said cavity through said ferromagnetic material, said second mode being orthogonal and ninety degrees apart in time phase with respect to said first mode, a second resonant cavity mounted end-to-end along said center line with respect to said

5

first cavity and having a different amount of ferromagnetic material subject to said magnetic field, coupling means extending between circularly polarized magnetic field components of said first cavity to similarly excite said second cavity, and output means electromagnetically coupled to a magnetic field component parallel to the wall of said second cavity.

2. A variable bandwidth microwave filter comprising a first cylindrical cavity having a ferromagnetic element axially mounted therein, means disposed adjacent said first cavity for establishing an axial static magnetic field through said element, a first rectangular waveguide terminated at an input sidewall aperture of said first cavity and having the broadwalls thereof disposed transverse to the axis of said first cavity for exciting in such cavity a first transverse magnetic mode having a linearly polarized magnetic field component at the ends of said first cavity, a portion of said first mode being coupled by said element to a second similar mode that is orthogonal and ninety degrees apart in time phase with respect to said first mode, a second cylindrical cavity mounted end-to-end with respect to said first cavity and having a ferromagnetic element of different size axially mounted therein subject to said axial static magnetic field, a coupling aperture communicating between said first and second cavities at the adjacent ends thereof to electromagnetically couple to at least one of said modes of said first cavity to excite two modes that are orthogonal and ninety de-

6

grees apart in time phase with magnetic field components parallel to the cylindrical wall in said second cavity, a second rectangular waveguide terminated at an output aperture of said second cavity and having the broadwalls thereof disposed transverse to the axis of said cavities for excitation by the linearly polarized magnetic field of one of said two modes in said second cavity, and means for varying said static magnetic field means to control the degree of coupling between modes in each of said cavities and thereby the frequency bandwidth of the output.

#### References Cited in the file of this patent

##### UNITED STATES PATENTS

|    |           |                |               |
|----|-----------|----------------|---------------|
| 15 | 2,632,808 | Lawson         | Mar. 24, 1953 |
|    | 2,759,099 | Olive          | Aug. 14, 1956 |
|    | 2,810,890 | Klopfenstein   | Oct. 22, 1957 |
|    | 2,825,765 | Marie          | Mar. 4, 1958  |
| 20 | 2,944,232 | Beljers et al. | July 5, 1960  |

##### FOREIGN PATENTS

|           |        |               |
|-----------|--------|---------------|
| 1,099,724 | France | Mar. 23, 1955 |
|-----------|--------|---------------|

##### OTHER REFERENCES

- 25 Article I, Ferrite-Tunable Microwave Cavities, by C. Nelson. Proceedings of the IRE, October 1956, pages 1449-1455 relied upon.