Feb. 12, 1952 W. D. LEWIS ET AL 2,585,563

WAVE FILTER

Filed Sept. 17, 1949

FIG. 1

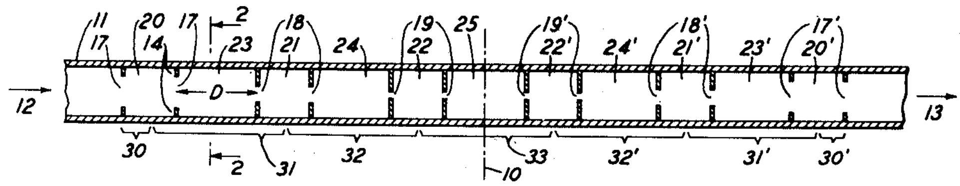


FIG. 2

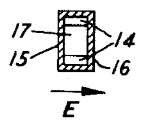


FIG. 3

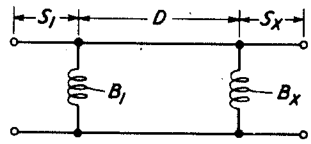


FIG. 4

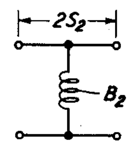


FIG. 5

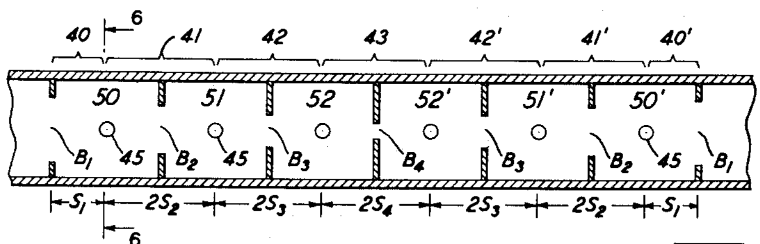


FIG. 6

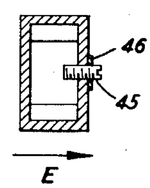
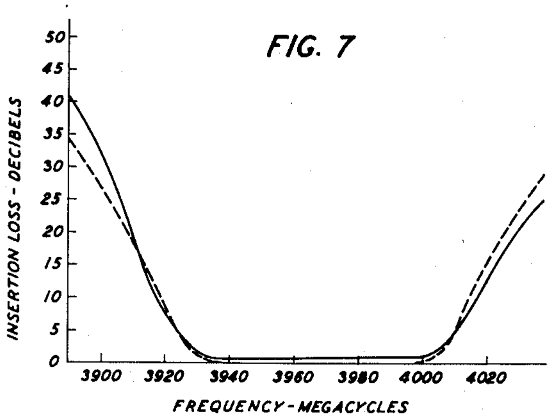


FIG. 7



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WAVE FILTER

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Application September 17, 1949, Serial No. 116,342

5 Claims. (Cl. 178—44)

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This invention relates to wave transmission networks and more particularly to microwave filters.

Objects of the invention are to simplify the construction and reduce the size and cost of microwave filters of the type comprising susceptive discontinuities longitudinally spaced in a wave guide.

The application of William W. Mumford, Serial No. 24,257, filed April 30, 1948, now Patent No. 2,540,488, discloses a microwave filter comprising a plurality of resonant chambers connected in tandem by interposed sections of wave guide. Each chamber is formed by a pair of susceptive discontinuities located at the respective ends of a section of wave guide. The filter is of the maximally-flat type, that is, it has a substantially constant insertion loss and a reflection coefficient which is substantially zero over as wide a band of frequencies as possible. In order to provide such a characteristic the band widths passed by the different chambers increase progressively from the center to both ends of the filter. This tapering of the band widths is accomplished by controlling the susceptances of the different pairs of discontinuities which form the resonant chambers. If the filter has N resonant chambers it will thus require 2N discontinuities and N—1 connecting sections of line.

The microwave filter in accordance with the present invention is the electrical equivalent of the maximally-flat prototype filter just described but requires only N+1 susceptive discontinuities and is considerably shorter in length. The derivation of the new structure is based upon the equivalence of a section of wave guide with a single centrally-positioned discontinuity to a connecting section with half of a resonant chamber, including a discontinuity, at each end thereof.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings in which like reference characters designate similar or corresponding parts and of which:

Fig. 1 is a longitudinal sectional view of the prototype microwave filter comprising resonant chambers connected by sections of wave guide;

Fig. 2 is a cross-section of the filter of Fig. 1 taken at the line 2—2;

Fig. 3 is a schematic circuit of a portion of the filter of Fig. 1 comprising a connecting section with half of a resonant chamber at each end thereof;

Fig. 4 is a schematic circuit of a simplified filter section, equivalent to the one shown in Fig. 3, comprising a section of wave guide with a single susceptance at the center;

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Fig. 5 is a longitudinal sectional view of a microwave filter in accordance with the invention comprising a plurality of sections of the type represented by Fig. 4;

Fig. 6 is a cross-sectional view of the filter of Fig. 5 taken at the line 6—6; and

Fig. 7 gives the theoretical and measured insertion loss-frequency characteristics of the filter of Figs. 5 and 6.

Taking up the figures in greater detail, Figs. 1 and 2 show the prototype maximally-flat microwave filter of the type disclosed in the above-mentioned Mumford application. The filter is symmetrical about the transverse center line 10 and comprises a rectangular wave guide 11 with six pairs of susceptive discontinuities longitudinally spaced therein to form six chambers, resonant at the mid-band frequency f_0, and five interconnecting sections. There are thus required twice as many discontinuities as resonant chambers. Electromagnetic wave energy from a suitable source is fed in at one end, as indicated by the arrow 12, and the filtered energy is extracted at the other end, as indicated by the arrow 13, and utilized in an appropriate load device.

Each of the discontinuities is in the form of an inductive iris formed by a transverse partition 14 with a central aperture 17 extending between the wider sides 15, 16 of the guide in the direction of the electric field E, as shown in Fig. 2. The susceptance of the iris is determined by the width of the aperture 17 in a direction perpendicular to the vector E. There are six pairs of these irises 17, 18, 19, 19′, 18′ and 17′ forming six resonant chambers 20, 21, 22, 22′, 21′ and 20′ connected by the five sections 23, 24, 25, 24′ and 23′. Each of the resonant chambers has a length approximately equal to half a wavelength λ_g within the guide 11 and each connecting section has a length approximately equal to three quarters λ_g. All of the chambers are resonant at f_0 but their band widths increase from the center of the filter to each end to provide a maximally-flat characteristic. This is accomplished by increasing the width of the apertures, and thus decreasing the susceptance of the different pairs of irises, as the ends of the filter are approached from the center. Thus, the iris 18 is larger than 19, and 17 larger than 18.

The microwave filter in accordance with the invention, one embodiment of which is shown in Figs. 5 and 6, is derived from the prototype of

Fig. 1 by replacing a number of two-iris sections by equivalent one-iris sections. To see how this is done, consider the filter of Fig. 1 divided into seven sections **30**, **31**, **32**, **33**, **32'**, **31'** and **30'** by transverse planes through the centers of the resonant chambers **20**, **21**, **22**, **22'**, **21'** and **20'**, respectively. The end sections **30** and **30'** are used, unchanged, as the end sections **40** and **40'** of the filter of Fig. 5. Each comprises a section of wave guide of length S_1, equal to half of the length of the chamber **20**, and an iris having a normalized susceptance B_1 connected at the outer end thereof.

Each of the intermediate sections in Fig. 1 consists of a connecting line with half of a resonant chamber at each end thereof. Thus, the section **31**, as shown schematically in Fig. 3, is made up of a central section of line of length D equal to the length of the connecting guide **23**, a normalized susceptance B_1 at the left end thereof, a normalized susceptance B_x equal to that of the iris **18** at the right end thereof, a section of line of length S_1 to the left of B_1 and a section of line of length S_x, equal to half the length of the chamber **21**, at the right of B_x. In accordance with the invention, the filter section shown in Fig. 3 is replaced by the equivalent one shown in Fig. 4 comprising a line of length $2S_2$ with a normalized susceptance B_2 at the center thereof. Two of these sections appear in Fig. 5, next to the end sections, as sections **41** and **41'**. In like manner the sections **32**, **33** and **32'** in Fig. 1 are replaced in Fig. 5 by the equivalent sections **42**, **43** and **42'** which comprise sections of guide of length $2S_3$, $2S_4$ and $2S_3$, respectively, with centrally positioned irises having normalized susceptances B_3, B_4 and B_3, respectively. When the seven sections are connected in tandem, as shown, there are thus formed the six chambers designated **50**, **51**, **52**, **52'**, **51'** and **50'**. Due to the symmetry of the structure about the central susceptance B_4, the chambers **50**, **51** and **52** are identical to the chambers **50'**, **51'** and **52'**, respectively.

Between each two adjacent irises there is provided a tuning screw **45**, with lock nut **46**, for adjusting the chamber defined by the irises and the connecting guide.

It will be noted that the filter of Fig. 5 requires only seven irises to provide a structure which is the electrical equivalent of the prototype filter with twelve irises shown in Fig. 1. Furthermore, the former is considerably shorter in length than the latter since the six chambers are directly coupled together and do not require connecting sections of wave guide.

Design formulas for evaluating the susceptances of the irises and the lengths of wave guide for the different sections of a directly-coupled filter of the type shown in Fig. 5, to make it the lectrical equivalent of the prototype maximally-flat filter of Fig. 1, will now be presented. In the general case there will be N chambers (in Fig. 5 $N=6$) formed by $N+1$ filter sections each comprising a length of wave guide and an iris. The filter will thus comprise two end sections of wave guide each of length S_m, one or more intermediate sections of wave guide each of length $2S_m$, an iris having a normalized susceptance B_1 connected at the outer end of each of the end sections, and an iris having a normalized susceptance B_m connected at the center of each of the intermediate sections. The subscript m denotes the number of the section counted from the nearer end of the filter, and in Fig. 5 is one for the end sections **40** and **40'**, two for the next sections **41** and **41'**, three for the sections **42** and **42'**, and four for the central section **43**. The required formulas are:

$$B_1^2=\frac{4}{\pi}\left(\frac{\lambda_0}{\lambda_g}\right)^2\frac{f_0}{\Delta f}\sin\frac{\pi}{2N} \qquad (1)$$

$$|B_m|=B_1^2\frac{\sqrt{2}\sqrt{\cos\frac{\pi}{N}-\cos\frac{2(m-1)\pi}{N}}}{2\sin\frac{\pi}{2N}} \qquad (2)$$

$$S_m=\frac{\lambda_g}{4\pi}\operatorname{arc}\cot\frac{B_m}{2} \qquad (3)$$

where N is one less than the total number of sections, λ_0 is the mid-band free space wavelength, λ_g is the mid-band wavelength in the guide, f_0 is the mid-band frequency, and Δf is the band width to the three-decibel insertion loss points. The vertical lines on each side of B_m indicate that its absolute value is given by Equation 2.

The solid-line curve of Figure 7 shows the insertion loss in decibels plotted against the frequency in megacycles for a seven-section (six-chamber) microwave filter of the type shown in Fig. 5 having a mid-band frequency f_0 of 3970 megacycles and a band width Δf of 80 megacycles built as a unit in a rectangular brass wave guide having internal dimensions of 1.872 inches by 0.872 inch. The chambers were first adjusted individually for minimum insertion loss by means of the tuning screws **45**. A wave-guide bridge and a scanning oscillator were then used in a final adjustment to reduce standing waves in the transmission band.

For comparison, the broken-line curve of Fig. 7 shows a calculated theoretical characteristic which neglects dissipation and therefore shows lower insertion loss in the band. Otherwise, the measured curve is in good agreement with the calculated curve. The agreement between the two curves becomes closer as the ratio of the band width Δf to the mid-band frequency f_0 decreases.

Although Fig. 5 shows for illustrative purposes a filter having five intermediate sections it is to be understood that either more or less may be used. The invention is of particular importance in designing highly discriminative filters with four or more intermediate sections.

What is claimed is:

1. A wave filter comprising two end sections of wave guide each of length S_m, at least four intermediate sections of wave guide each of length $2S_m$ connected in tandem therewith, an iris having a normalized susceptance B_1 connected at the outer end of each of said end sections, and an iris having a normalized susceptance B_m connected at the center of each of said intermediate sections, where

$$B_1^2=\frac{4}{\pi}\left(\frac{\lambda_0}{\lambda_g}\right)^2\frac{f_0}{\Delta f}\sin\frac{\pi}{2N}$$

$$|B_m|=B_1^2\frac{\sqrt{2}\sqrt{\cos\frac{\pi}{N}-\frac{2(m-1)\pi}{N}}}{2\sin\frac{\pi}{2N}}$$

$$S_m=\frac{\lambda_g}{4\pi}\operatorname{arc}\cot\frac{B_m}{2}$$

N is one less than the total number of said sections, the subscript m denotes the number of the associated section counted from the nearer end of the filter, λ_0 is the mid-band free space wavelength, λ_g is the mid-band wavelength in the sections of guide, f_0 is the mid-band frequency, and Δf is the width of the transmission band to the three-decibel insertion loss points, each of said sections of wave guide comprising a hollow conductor adapted to convey therethrough electromagnetic microwave energy above a critical frequency.

2. A filter in accordance with claim 1 which includes tuning means associated with each of said sections.

3. A filter in accordance with claim 2 in which

said tuning means comprise a screw extending through a wall of the associated section of wave guide.

4. A filter in accordance with claim 1 in which said sections of wave guide are made of brass.

5. A filter in accordance with claim 1 in which the number of said intermediate sections is at least five.

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No references cited.