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[54] **MICROWAVE FILTER**
6 Claims, 5 Drawing Figs.

[52] U.S. Cl. 333/73

[51] Int. Cl. H03h 7/10

[50] Field of Search..... 333/10, 81;
333/73, 73 (W)

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ABSTRACT: A microwave bandstop filter of the type in which a plurality of resonant cavities are coupled by irises at intervals to a connecting waveguide. According to the invention the intervals are made three-quarters wavelength and the connecting guide section between each pair of irises is provided with a particularly chosen characteristic impedance which eliminates undesirable responses of the connecting sections without introducing further discontinuities to the structure.

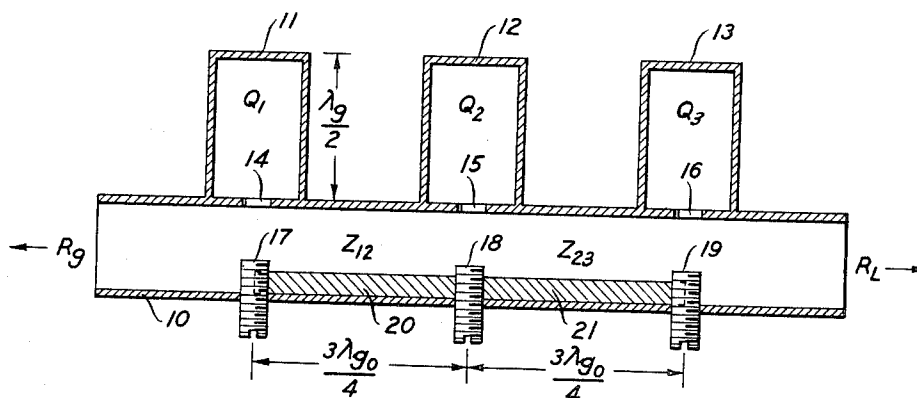


FIG. 1

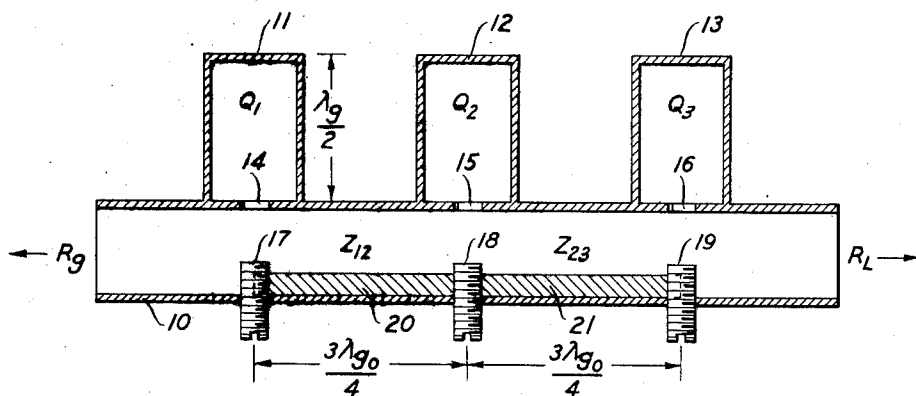


FIG. 2

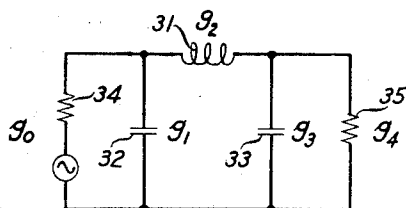


FIG. 3

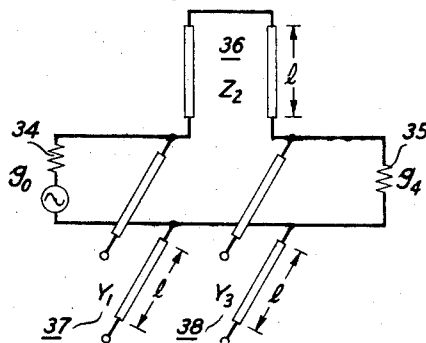


FIG. 4

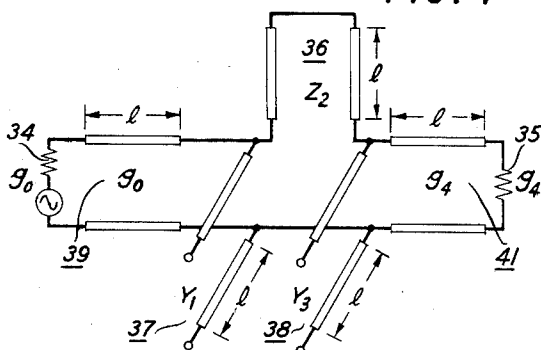
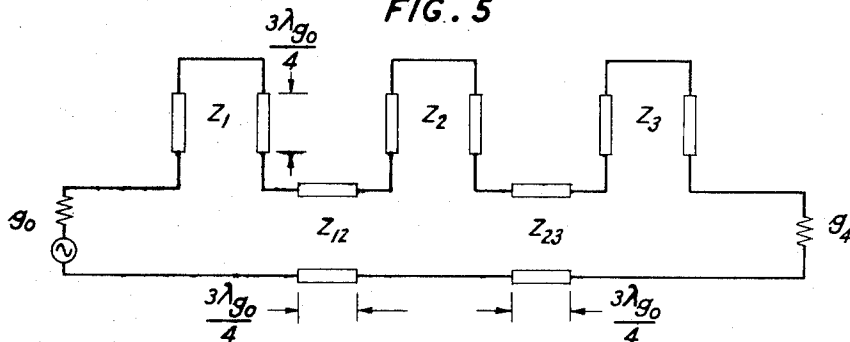


FIG. 5



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MICROWAVE FILTER

BACKGROUND OF THE INVENTION

Since its original disclosure by A. G. Fox in Pat. Nos. 2,432,093, Dec. 9, 1947, and 2,588,226, Mar. 4, 1952, extensive use has been made of the basic microwave filter comprising a plurality of conductively bounded resonant cavities coupled at points spaced by an odd multiple of one-quarter wavelengths along a conductively bounded rectangular waveguide. Control of the resonant frequency and Q of the cavities provided a large variety of band-pass and bandstop filters with numerous useful cutoff characteristics. In the early years of the art the cavities were spaced one-quarter wavelength and it was satisfactory to neglect the effects of each section of the connecting waveguide between the cavities.

Later, it was found that for physically realizable bandstop filters in waveguide, some larger multiple of quarter wavelength spacing should be used in order to prevent the coupling of higher order modes between adjacent cavity irises from degrading the performance of the filter. The effects of the longer connecting sections then become too large to ignore for present day design standards. With this problem in mind it has been proposed by B. M. Schiffman and G. L. Matthaei, for example, in an article "Exact Design of Band-Stop Microwave Filters" in the Jan. 1964 IEEE Transactions, MT&T, at page 6, to interpose a plurality of quarter-wave transformer sections between each cavity. While theoretically sound, physical realization of this approach is impractical since the complicated configuration introduces further discontinuities to a structure which already has more unavoidable discontinuities than can readily be controlled.

SUMMARY OF THE INVENTION

In accordance with the invention, it has been discovered that a simple, single reduction of the waveguide height dimension in a three-quarter wavelength long region between a given pair of resonant cavities so proportioned to produce in this region a specified value of characteristic impedance based upon the parameters of the cavities themselves, will eliminate the undesirable effects. No discontinuities are introduced between the cavities, and the only discontinuities in the connecting guide physically coincide with and therefore electrically tune with the inherent discontinuities of the cavity coupling iris and capacitive matching screw usually associated with the iris.

When the principles of the invention are applied to a typical three-cavity, maximally flat (structurally symmetrical) filter, the structure in accordance with the invention reduces to a single slab of conductive material one and one-half wavelengths long and of a specified thickness, extending in the connecting rectangular guide adjacent to a wide wall and centered therein across from the irises of the resonant cavities. The principles of the invention may be extended to filters having an arbitrary number of cavities both symmetrical and unsymmetrical.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a cross-sectional view of an illustrative three-cavity filter in accordance with the invention;

FIG. 2 is a schematic of a typical lumped element prototype filter having a characteristic desired for FIG. 1;

FIGS. 3 through 5 represent sequential transmission line substitutions to derive an equivalence between FIG. 1 and FIG. 2.

DETAILED DESCRIPTION

In FIG. 1 a three-cavity filter has been selected to illustrate the principles of the invention. As shown in cross section, the filter comprises a section of rectangular conductively bounded waveguide 10 and three, approximately one-half wavelength long cavities 11, 12 and 13 coupled through a wide wall of

guide 10 by means of irises 14, 15 and 16 at points spaced three-quarters of a guide wavelength. Capacitive tuning screws 17, 18 and 19 are located in the wide wall opposite each of the irises 14, 15 and 16 respectively. To this extent the structure is conventional and well known in the art.

In accordance with the invention, the characteristic impedance of guide 10 in the region extending from iris 14 to iris 15 (or from screw 17 to 18) is reduced to a value designated Z_{12} by restricting the narrow cross-sectional dimension of guide 10 by conductive slab 20, and in the region between irises 15 and iris 16 (or screws 18 and 19) to a value designated Z_{23} by conductive slab 21. In the form illustrated, screws 17, 18 and 19 extend through holes in slabs 20 and 21 and the end of each slab is considered to coincide with the diameter of a screw.

In order to illustrate the principles of the invention and to specify the impedance values Z_{12} and Z_{23} in accordance with the invention, a procedure familiar to the filter design art will be applied in which one starts with the lumped element low pass prototype filter having the desired transmission characteristic, derives the transmission line equivalent of the prototype and finally makes corrections necessary to describe the distributed parameter form of the cavities. For a further discussion of this approach and a justification of its validity, reference may be had to standard text books such as "Microwave Transmission Circuits" by G. L. Ragan, Radiation Laboratory Series, Vol. 9, McGraw-Hill, New York 1951, or to published articles such as "Microwave Band-Stop Filters With Narrow Stop Bands" by L. Young, G. L. Matthaei and E. M. T. Jones, IRE Transactions on MTT, Vol. 10, pp 416-427, Nov. 1962.

In FIG. 2 a typical low-pass prototype circuit is shown comprising a series inductance 31, a pair of shunt capacitors 32 and 33, a source impedance 34 and a load impedance 35. The values g_0, g_1, g_2, g_3 and g_4 , referred to in the foregoing literature as "g" values, are the normalized element values giving the frequency response desired.

The transmission line equivalent of FIG. 2 is shown in FIG. 3 in which a shorted stub 36 of characteristic impedance Z_2 and of length l has been substituted for the inductive element 31, and the open line stubs 37 and 38 of characteristic admittance Y_1 and Y_3 and the same length l have been substituted for the capacitive elements 32 and 33, respectively, using the frequency transformation:

$\omega = A \tan \beta l$ (1) where ω is the normalized prototype frequency variable, A is the bandwidth constant, l is the length of the stubs and β is their propagation constant. Selecting

$$l = \frac{3\lambda_{g0}}{4} \quad (2)$$

in accordance with the invention, where λ_{g0} is the band center frequency wavelength, and applying the transformation of equation (1) to each of the characteristic impedances, they become:

$$Y_1 = g_1 A; Z_2 = g_2 A; \text{ and } Y_3 = g_3 A \quad (3)$$

where

$$A = \omega_1 \cot \left(\frac{3\pi}{2} \frac{\lambda_{g0}}{\lambda_{g1}} \right) \quad (4)$$

in which ω_1 is the band edge frequency (3 db. point, for example, of the prototype filter) and λ_{g1} is the desired band edge guide wavelength corresponding to ω_1 .

In FIG. 4 a transmission line section 39 having a length l , now

$$\frac{3\lambda_{g0}}{4}$$

and the same impedance g_0 as the generator, has been inserted preceding the stubs 36 and 37 of FIG. 3, and a transmission section 41 of the same length having the same impedance g_4 as the load, has been inserted following the stubs 36 and 38. Neither addition changes the amplitude transmission characteristic of the network.

Recall that Kuroda's identity allows an interchange of an open stub of impedance Y and a connecting line of impedance Z , for a shorted stub of impedance

$$\frac{Z^2 Y}{1 + ZY} \quad (5)$$

and a connecting line of impedance

$$\frac{Z}{1 + ZY} \quad (6)$$

Applying the identity of equations (5) and (6) to line 39 and stub 37 and then again to line 41 and stub 38 of FIG. 4, FIG. 5 is obtained in which

$$Z_1 = \frac{g_0^2 Y_1}{1 + g_0 Y_1} = \frac{Ag_0^2 g_1}{1 + Ag_0 g_1} \quad (7)$$

$$Z_{12} = \frac{g_0}{1 + g_0 Y} = \frac{g_0}{1 + Ag_0 g_1} \quad (8)$$

$$Z_2 = Ag_2 \quad (9)$$

$$Z_3 = \frac{g_4^2 Y_3}{1 + g_4 Y_3} = \frac{Ag_3 g_4^2}{1 + Ag_3 g_4} \quad (10)$$

$$Z_{23} = \frac{g_4}{1 + g_4 Y_3} = \frac{g_4}{1 + Ag_3 g_4} \quad (11)$$

The network of FIG. 5 is now equivalent to that of FIG. 1 except for the practical differences between the resonant transmission line stubs of FIG. 5 and the resonant cavities of FIG. 1. It is easy enough to control the characteristic impedance of a transmission line stub to produce the desired values of Z_1 , Z_2 and Z_3 , but almost impossible in a cavity structure. On the other hand, the Q of a resonant cavity is readily varied by varying the size of its coupling iris. Therefore it is an obvious advantage to express the parameters of cavities 11, 12 and 13 of FIG. 1 by their loaded Q s. It is known that a one-half wavelength cavity of given loaded Q is equivalent to a short circuited three-quarter wavelength transmission line stub of characteristic impedance Z when

$$Q = \frac{3\pi}{2Z} \quad (12)$$

This expression is known to be sufficiently accurate for frequencies close to resonance as in most waveguide filters. Similarly, it is more convenient to express the load impedance R_l and generator impedance R_g directly rather than in their normalized equivalents g_0 and g_4 . Therefore, substituting equation (12) for each cavity impedance in equations (7) through (11) and multiplying all impedances by the factor R_g/g_0 , the following design equations are obtained for the structure of FIG. 1:

TABLE 1

$$\begin{aligned} Q_1 &= \frac{3\pi}{2R_g} \left(1 + \frac{1}{Ag_0 g_1}\right) & Z_{12} &= R_g (1 + Ag_0 g_1)^{-1} \\ Q_2 &= \frac{3\pi}{2R_g} \frac{g_0}{Ag_2} & Z_{23} &= R_g \frac{g_4}{g_0} (1 + Ag_3 g_4)^{-1} \\ Q_3 &= \frac{3\pi g_0}{2R_g g_4} \left(1 + \frac{1}{Ag_3 g_4}\right) & R_1 &= R_g \frac{g_4}{g_0} \end{aligned}$$

These equations define the respective Q s of a series of cavities in terms of prototype parameters for a given transmission characteristic, and in accordance with the invention, define the characteristic impedances Z_{12} and Z_{23} to be produced in the regions between cavities and coextensive with slabs 20 and 21. While these equations might appear to be complicated and difficult to apply to a physical structure, it should be recognized that once numerical values are obtained for Z_{12} and Z_{23} , design of a physical structure is merely a matter of causing the

height of the restricted guide produced by slabs 20 and 21 to bear the same ratio to the unrestricted height of guide 10 as do the desired impedances Z_{12} or Z_{23} to the characteristic impedance guide 10.

- 5 If the desired filter is symmetrical, as in the case in a maximally flat filter of the type most often desired, Q_1 and Q_3 and Z_{12} and Z_{23} are identical. Therefore, the slabs 20 and 21 are reduced to a single slab of conductive material of the required thickness one and one-half wavelengths long. If only a two-cavity filter is desired, the values of Q_1 , Q_2 and Z_{12} define the required parameters when

$$R_1 = R_g \frac{1}{g_0 g_3}$$

The principles of the invention may be extended to filters of four or more cavities. Following the same approach detailed with respect to FIGS. 2 through 5 for a five-cavity filter, for example, the following table of relationships may be obtained:

TABLE II

$$\begin{aligned} Q_1 &= \frac{3\pi}{2R_g} \left(2 + \frac{1}{Ag_0 g_1}\right) & Z_{12} &= R_g \left(\frac{1 + Ag_0 g_1}{1 + 2Ag_0 g_1}\right) \\ Q_2 &= \frac{3\pi}{2R_g} \left(\frac{1}{1 + Ag_0 g_1} + \frac{g_0}{Ag_2(1 + Ag_0 g_1)^2}\right) & Z_{23} &= R_g g_0 \left(Ag_2 + \frac{g_0}{1 + Ag_0 g_1}\right)^{-1} \\ Q_3 &= \frac{3\pi}{2R_g} \frac{1}{Ag_0 g_3} & Z_{34} &= R_g g_0 \left(Ag_4 + \frac{g_0}{1 + Ag_0 g_3}\right)^{-1} \\ Q_4 &= \frac{3\pi}{2R_g g_0} \left(\frac{1}{1 + Ag_3 g_0} + \frac{g_0}{Ag_4(1 + Ag_3 g_0)^2}\right) & Z_{45} &= R_g \frac{g_0}{g_6} \left(\frac{1 + Ag_3 g_0}{1 + 2Ag_3 g_0}\right) \\ Q_5 &= \frac{3\pi}{2R_g} \frac{g_0}{g_6} \left(2 + \frac{1}{Ag_3 g_6}\right) & R_1 &= R_g \frac{g_0}{g_6} \end{aligned}$$

In all cases it is understood that the above described arrangements are merely illustrative of a small number of the many possible applications of the principles of the invention. Numerous and varied other arrangements in accordance with these principles may readily be devised by those skilled in the art without departing from the spirit and scope of the invention.

I claim:

1. An electromagnetic wave filter having a predetermined transmission characteristic comprising a conductively bounded rectangular waveguide and a plurality of resonant cavities coupled to said guide each by one of a plurality of spaced irises, said guide cross section as defined by said conductive boundary being reduced in at least one dimension in the region of said irises to a dimension which remains uniform from the center of one iris to the center of an adjacent iris in order to include the wave transmission characteristics of said guide between said irises as a contribution to said predetermined transmission characteristic.

2. The filter according to claim 1 wherein said irises are spaced three-quarters of the guide wavelength of said wave energy in the center band of said filter.

3. The filter according to claim 1 wherein said cavities are approximately one-half the guide wavelength of said wave energy in the band of said filter.

4. The filter according to claim 1 having the same band edge frequency ω_c as a given lumped constant prototype filter of the type defined by a plurality of shunt capacitors interconnected by at least one series inductance and in which each component thereof is specified by a normalized g value giving the filter response desired, said filter including three cavities having loaded values of Q_1 , Q_2 , and Q_3 , separated by sections of waveguides of characteristic impedances Z_{12} and Z_{23} where

$$Q_1 = \frac{3\pi}{2R_g} \left(1 + \frac{1}{Ag_0 g_1}\right) \quad Z_{12} = R_g (1 + Ag_0 g_1)^{-1}$$

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$$Q_2 = \frac{3\pi}{2R_g} \frac{g_0}{Ag_2} \qquad Z_{23} = R_g \frac{g_4}{g_0} (1 + Ag_3g_4)^{-1}$$
$$Q_3 = \frac{3\pi g_0}{2R_g g_4} \left(1 + \frac{1}{Ag_3g_4}\right) \qquad R_1 = R_g \frac{g_4}{g_0}$$

wherein $A = \omega_1 \cot \left(\frac{3\pi}{2} \frac{\lambda_{g0}}{\lambda_{g1}} \right)$

R_l is a load impedance

R_g is a generator impedance, and g_0, g_1, g_2, g_3 and g_4 are normalized values of said lumped constant prototype filter.

5. The filter according to claim 1 wherein the narrow dimension of said guide cross section as defined by said con-

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ductive boundary is restricted to reduce the characteristic impedance of said guide between said irises.

6. Electromagnetic wave filter having a predetermined transmission characteristic comprising a conductively bounded waveguide having a given characteristic impedance, a plurality of resonant cavities coupled to said guide each by pedance of said guide being sharply reduced in a step at the transverse cross section of the center of one iris and remaining constant along a length of said guide to the transverse cross section of the center of an adjacent iris, the value of said reduced impedance being proportioned relative to the Q's of said cavities to make the transmission characteristics of said guide along said length of said predetermined transmission characteristic.

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