

[54] **WAVEGUIDE FILTERS**

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[51] **Int. Cl.²**..... H01P 1/20; H01P 1/22; H01P 1/16

[58] **Field of Search**.... 333/22 R, 22 F, 73 R, 73 W, 333/81 R, 81 A, 81 B, 98 M

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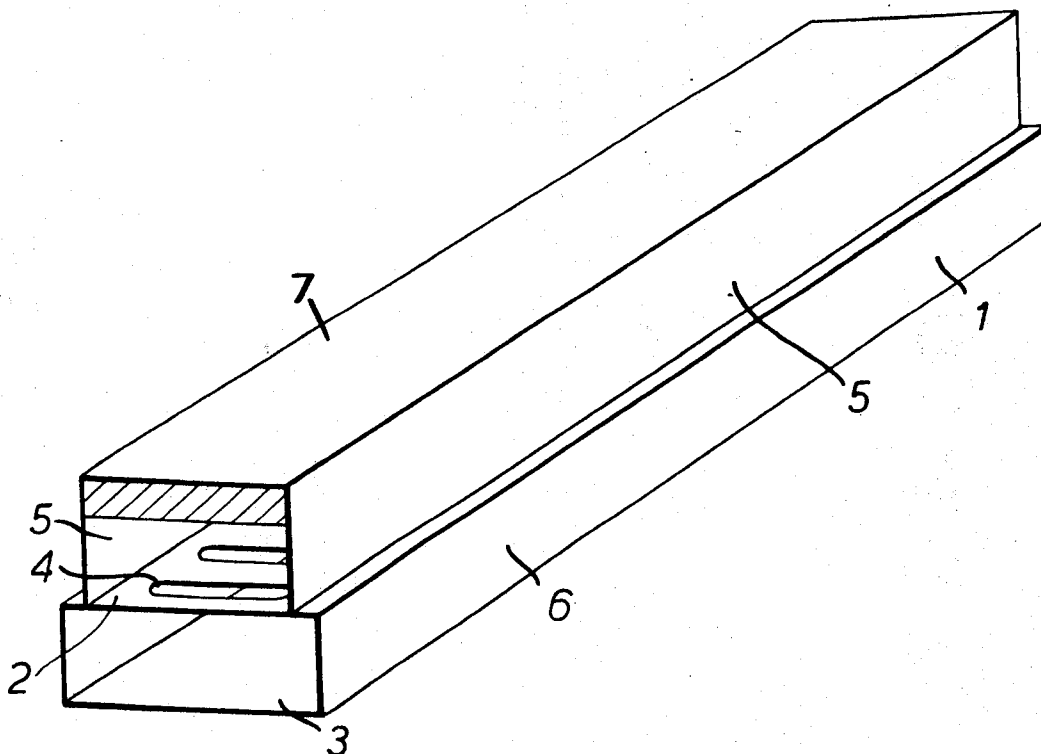
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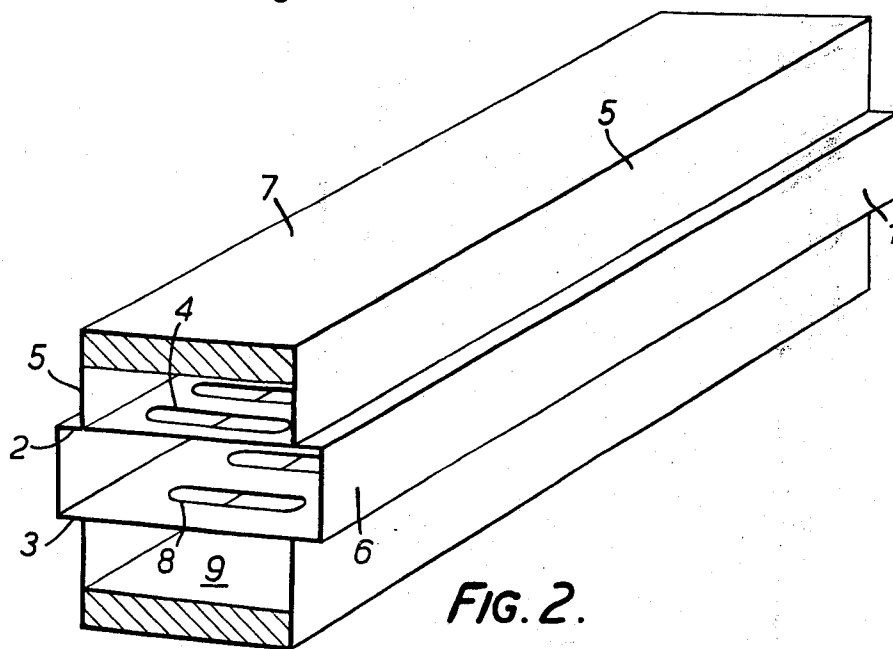
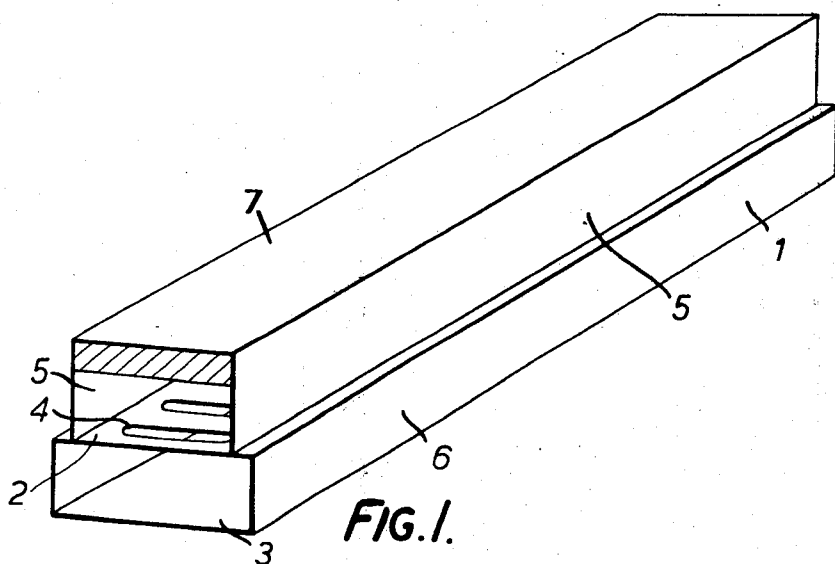
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ABSTRACT

A waveguide filter has spaced slots in one or more broad walls of a waveguide the slots coupling into a parallel plate waveguide on the outside of the broad wall and formed by a pair of spaced conductive members closed by microwave absorptive load material. The slots act as a slow wave structure below a low pass cut-off frequency and do not transmit energy for absorption by the load material. Above the cut-off frequency the slot structure becomes fast wave and radiates like a slotted aerial structure into the load. The filter therefore acts as a low pass filter in this case. The parallel plate waveguide is not cut-off at the fundamental frequency but radiation is prevented by the slot geometry being slow wave. Less expensive physically smaller filters can be produced by this technique as compared with well known leaky wall filter structures.

27 Claims, 5 Drawing Figures





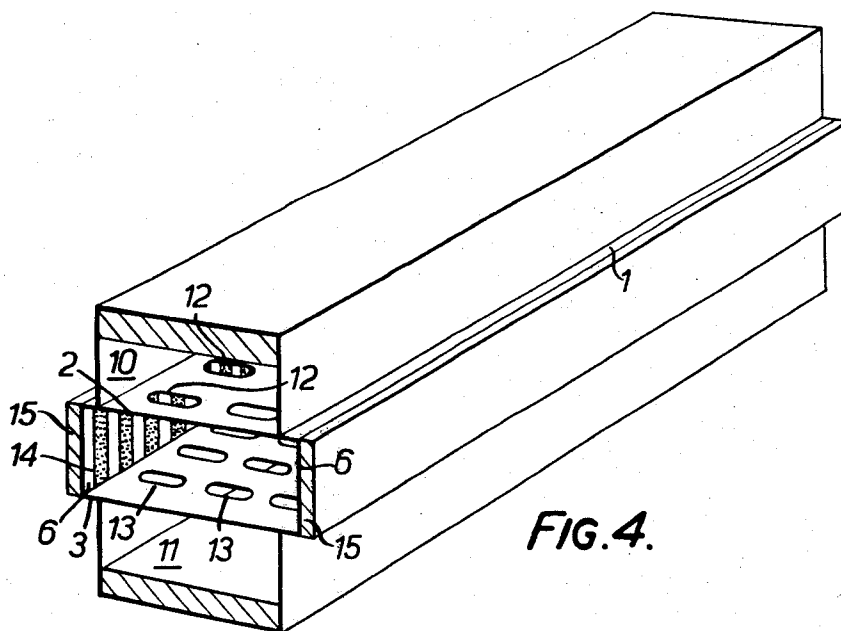


FIG. 4.

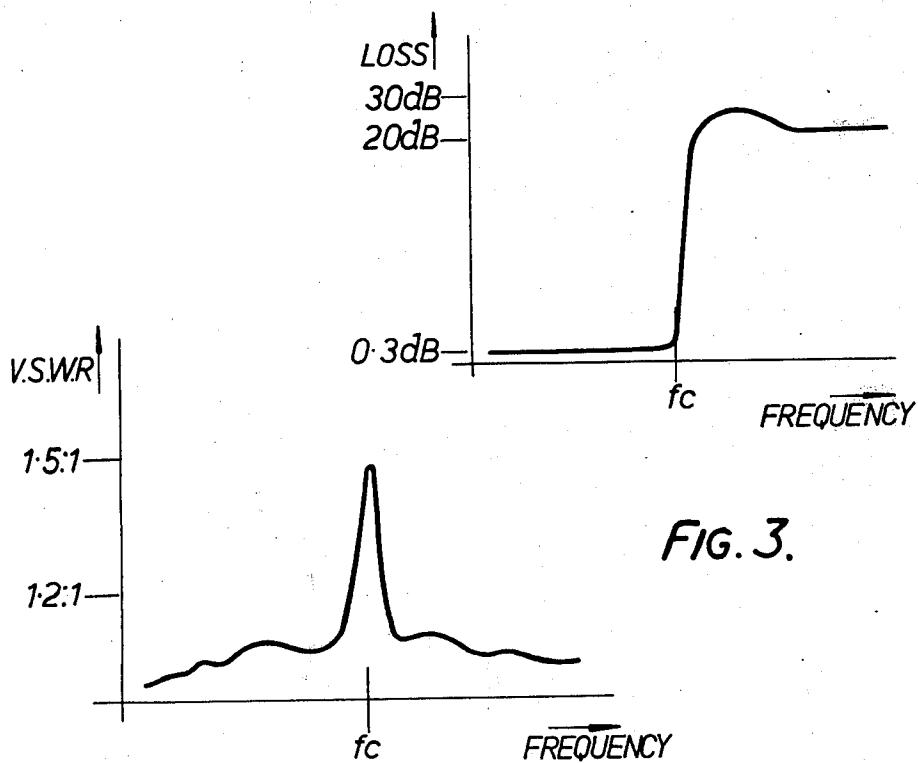


FIG. 3.

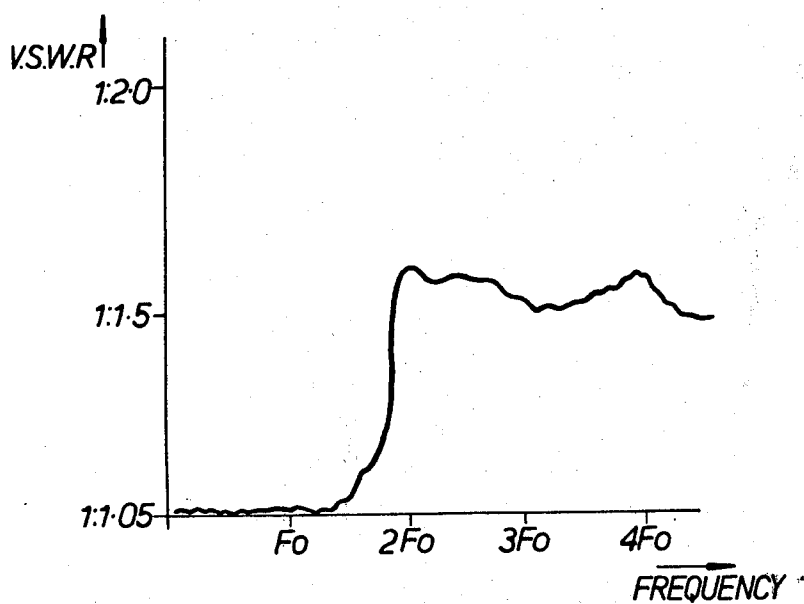
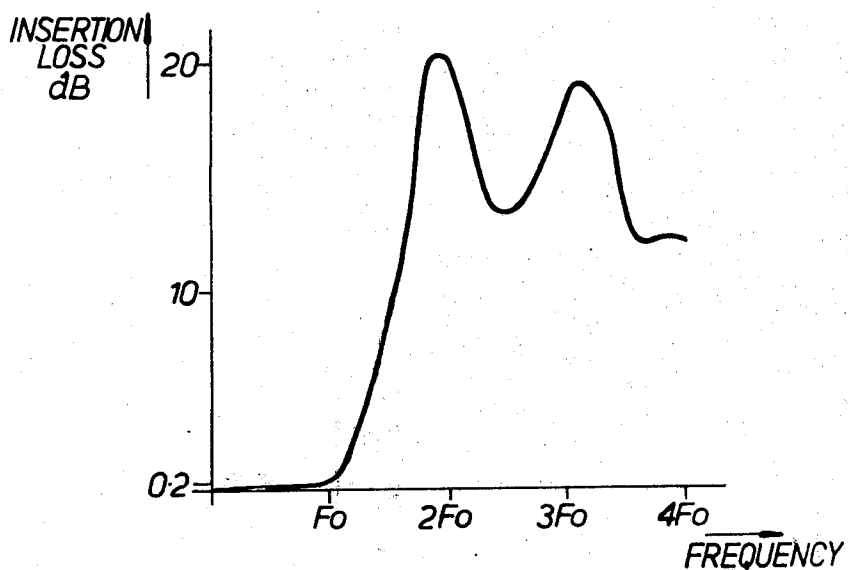


FIG. 5.

WAVEGUIDE FILTERS

This invention relates to waveguide filters of the absorptive type. Waveguide filters have been constructed using lengths of what is known as a "leaky wall filter". A leaky wall filter usually consists of a length of rectangular waveguide having resonant slots cut into broad or narrow walls or both, each slot coupling into a length of waveguide extending perpendicular to the slotted wall and usually 'cut off' to fundamental frequencies for which the main waveguide is designed and the additional lengths of waveguide containing individual matched loads.

Such leaky wall filters are extremely bulky, having typical cross-sectional dimensions several times those of the waveguide into which it is to be coupled. The construction is also mechanically complex and this size and complexity results in the filters being costly to produce.

This invention seeks to provide waveguide filters in which the above mentioned disadvantages are reduced.

According to this invention a waveguide filter comprises a length of rectangular waveguide provided with in one broad wall, a plurality of spaced slots extending substantially perpendicularly to the longitudinal axis of the waveguide; a pair of spaced conductive members presenting surfaces substantially parallel to the narrow walls of the waveguide arranged on the outside of the slotted wall to form a parallel plate waveguide; and microwave absorptive material on the same side of the waveguide as said spaced members and spaced from the slotted wall and arranged to absorb energy transmitted through the slots during operation of the device; the spacing and dimensioning of the slots being such that a substantial proportion of waves propagating through the rectangular waveguide in any TE_{mn} mode, where $M \neq 0$, at frequencies greater than a predetermined frequency is transmitted through the slots into the parallel plate waveguide and is attenuated by absorption by said material.

Preferably the microwave absorptive material covers the gap between said spaced parallel surfaces.

Preferably the spacing of the spaced members is less than the dimension of the broad wall of the waveguide.

Preferably again the slots are spaced by substantially one half wavelength of the TE_{10} mode in the parallel plate waveguide at said predetermined frequency.

For best attenuation of frequencies above the predetermined frequency, the length of each slot should be substantially one half wavelength at the predetermined frequency.

If all the slots are of the same length then an abrupt change in impedance caused by the slots will cause a large voltage standing wave ratio due to reflections when the waves encounter the slots. It is preferred therefore to reduce the lengths of the slots progressively from the centre slot at least towards the front end of the filter but preferably towards both ends.

In the preferred embodiment of the filter, slots are also provided in the other broad wall of the waveguide; two further spaced conductive members, similar to said spaced members, are positioned on the outside of this broad wall and further microwave absorptive material is arranged similarly to said absorptive material to absorb energy transmitted through the slots, the slot spacings and the slot dimensions being the same but the lon-

gitudinal slot positions in one wall being mid-way between the slot positions in the other wall.

A filter in accordance with the invention can be adapted to act as a harmonic filtering arrangement passing frequencies in a band about a fundamental frequency and extending up to a predetermined frequency without substantial attenuation and attenuating harmonic frequencies of said fundamental frequency. In such cases the spacing of the slots is chosen to be a half-wavelength at said predetermined frequency and the length of the slots is chosen to be substantially one half wavelength at the harmonic frequency at which maximum attenuation is required.

Preferably in such a harmonic filter, as in said preferred embodiment slots are provided on both broad walls but the lengths of the slots in one wall are a half wavelength at one harmonic frequency and the slots in the other wall are a half wavelength at another harmonic frequency.

As the frequency of desired maximum attenuation increases, the length of each slot will decrease and in order to provide better attenuation of higher modes which occur at the higher frequencies it is preferred, at each slot position, to provide a plurality of individual longitudinally aligned slots across the whole width of the broad wall, there being as many slots as the width of the broad wall allows.

The filtering arrangement in accordance with the invention so far described only provide good attenuation of waves travelling in broad wall modes i.e. TE_{M0} modes.

To provide attenuation of other modes the rectangular waveguide can be provided with a plurality of spaced elongate slits in at least one narrow wall extending substantially parallel to the minor axis of the waveguide and microwave absorptive material positioned closely adjacent the outside of the waveguide and arranged to cover each slit, the spacing and dimensioning of the slits being such that a predetermined frequency band propagating in any TE_{M0} mode where M is any integer is passed along the waveguide without substantial attenuation and all other modes are attenuated by absorption by said material. Preferably the width of each slit is less than twice the thickness of the material forming the waveguide.

Advantageously each slit extends the full width of the narrow wall.

Preferably again the slits are equally spaced by two slit widths. Better attenuation is achieved if both narrow walls are provided with slits and associated microwave absorptive material.

Conveniently the microwave absorptive material comprises a single layer of ferrite loaded silicon rubber.

Where the filter is required to have a high power handling capability the microwave absorptive material may be formed from a base of ceramic material loaded with a material capable of absorbing energy in the operating frequency range of the filter.

Preferred loading materials are ferrite and carbonyl iron powder.

The invention will now be further described, by way of example, with reference to the drawings accompanying the Provisional Specification in which,

FIG. 1 is a schematic illustration of a low pass filter in accordance with this invention.

FIG. 2 shows a modification of the filter of FIG. 1.

FIG. 3 shows graphs of attenuation and voltage standing wave ratio (V.S.W.R.) against frequency for the filter of FIG. 2.

FIG. 4 is a schematic illustration of a harmonic filtering arrangement in accordance with this invention and FIG. 5 shows graphs of attenuation and V.S.W.R. against frequency for the filtering arrangement of FIG. 4.

Referring now to FIG. 1 of the drawings, the low pass filter shown comprises a length of rectangular waveguide 1 dimensioned to propagate a selected frequency band in the TE_{10} mode. The waveguide 1 has broad walls 2 and 3 and narrow walls 6 and is provided in broad wall 2 with a number of equally spaced slots 4. On the outside of the broad wall 2 and arranged parallel to the narrow wall 6 are arranged a pair of spaced parallel plates 5 running the entire length of the waveguide 1. The plates 5 form a parallel plate waveguide which is closed by layer 7 of ferrite loaded silicon rubber spaced from the broad wall 2 and acting as a microwave absorptive load. If high power handling capability is required the microwave absorptive material 5 may be formed by a ceramic base loaded with a suitable microwave absorber such as ferrite or carbonyl iron powder. The plates 5 are spaced by a distance slightly less than the broad wall dimension of the waveguide 1 and the slots are spaced by one half wavelength of the TE_{10} mode in the parallel plate waveguide at the predetermined frequency at which attenuation is required to commence. Additionally the slots 4 are of length equal to one half wavelength at a frequency just inside the range where attenuation begins the slots thus being resonant at this frequency.

In operation, provided that the spacing of the slots 4 is less than one half wavelength of signals passing through the waveguide 1, the slotted structure performs as a slow wave structure and little energy is coupled by the slots 4 into the load 7. As the frequency of the propagating signals increases the spacing of the slots will eventually equal one half wavelength of the signals and the structure will become fast-wave resulting in considerable radiation of energy into the ferrite loaded silicon rubber absorptive material load 7. Maximum energy transfer into the load 7 occurs at a frequency when the slot lengths equal one half wavelength of the propagating signals, which for the present low pass filter is required to be just after the commencement of attenuation.

If all the slots 4 were of the same length then at the resonant frequency of the slots signals would experience an abrupt change of impedance to propagation which would result in a large reflected signal. To reduce this effect the slots may be reduced in length towards one or preferably both ends of the filter such that maximum attenuation occurs in the centre of the length of the filter.

A second method of reducing the effect of reflection by the slots is shown in FIG. 2 where like parts to those of FIG. 1 bear like reference numerals.

Referring to FIG. 2, a second set of slots 8 is provided in the other broad wall 3 of the waveguide 1, of spacing identical to those in wall 2 but each slot in the second set 8 being mid-way between two slots in the first set such that signals in guide 1 effectively see slots one quarter wavelength apart at the frequency at which attenuation commences. On the outside of wall 3 is a parallel plate waveguide generally designated 9 which is

identical to that on the outside of wall 2 and will not be described further. Reflections due to the two sets of slots will destructively interfere and therefore result in reduced voltage standing wave ratio. Both sets of slots may also be reduced in length towards either end of the filter as previously described. The resulting frequency-attenuation curve and frequency-V.S.W.R. curve are both shown in FIG. 3 which requires no explanation.

Low pass filters incorporating this invention may be designed having a rejection band which commences within the fundamental frequency band in which only the TE_{10} mode will propagate and for which the waveguide 1 is designed.

The filter described so far can be adapted to perform as a harmonic filtering arrangement and such an adapted filter is shown in FIG. 4.

In FIG. 4 the broad wall 2 of the waveguide 1 is provided with spaced slots 12 and associated parallel plate waveguide and load generally designated 10. Using the same design considerations as previously described, the slots 12 are spaced such that attenuation commences at a frequency just above the fundamental frequency band of the TE_{10} mode in the waveguide 1. The length of each of the slots 12 is chosen such that maximum attenuation occurs at a desired harmonic frequency which for the purposes of the present example is assumed to be the second harmonic. The slots being one half wavelength long at the second harmonic frequency are sufficiently small that they may be grouped in twos across the width of the wall 2 each group of two slots having aligned lengths. By providing slots in groups of two, improved attenuation is given especially in TE_{M0} modes where M is an even integer across the width of the wall 2.

Slots 13 are also provided on the broad wall 3 together with parallel plate waveguide 11. The slots 13 have the same spacing as the slots 12 but are resonant at the third harmonic and are in groups of threes. The third harmonic slots provide strong coupling into the load for TE_{M0} modes where M is an odd integer.

Additionally the slots are also resonant at two, three or more times the harmonic frequencies for which they are designed so that the filtering arrangement attenuates over the whole range of harmonic frequencies.

The broad wall slots will not couple TE_{0M} modes into the parallel plate waveguide and will provide reduced coupling of TE_{MN} modes $M, N \neq 0$ and in order to provide strong attenuation of such modes each narrow wall 6 is provided with a number of spaced slits 14, parallel to the minor axis of the waveguide 1, each slit being of width approximately equal to the thickness of the material forming the waveguide 1 and spaced by approximately two slit widths. Each set of slits is covered by a layer of ferrite loaded silicon rubber 15 which acts as a microwave absorptive load, the rubber being arranged in contact with the outside of each narrow wall 6. As before for high power handling capability of previously mentioned ceramic mixes may be used. With slits of such size and spacing, waves travelling in TE_{M0} modes which induce electric currents in the waveguide walls 2 in a direction parallel with the slits 14 are unaffected by the presence of the slits while TE_{MN} modes $N \neq 0$ which induce electric currents across the slits 14 are coupled through the slits 14 into the load 15 and attenuated.

By providing the slots, parallel plate waveguides and loads on both broad walls and the slits and loads on

each narrow wall, a harmonic filtering arrangement can be produced which will attenuate all modes at all harmonic frequencies.

FIG. 5 shows graphs of insertion loss against frequency and V.S.W.R. against frequency for the harmonic filtering arrangement of FIG. 4. These curves are self explanatory. Similar steps as already described can be employed to provide a low value of V.S.W.R.

What we claim is:

1. A waveguide filter for attenuating frequencies above a predetermined frequency, said filter comprising a length of rectangular waveguide having two broad and two narrow walls dimensioned for propagation of a desired frequency band; a plurality of spaced slot positions in at least one broad wall, each slot position having a slot extending substantially perpendicularly to the length of the rectangular waveguide; a pair of spaced conductive members on the outside of said at least one broad wall and presenting opposing surfaces defining a gap and arranged substantially parallel to the narrow walls to form a parallel plate waveguide capable of propagating substantially said desired frequency band; and microwave absorptive material positioned parallel to said at least one broad wall on the same side of the waveguide as said spaced members and spaced from the slots to absorb energy transmitted from said rectangular waveguide through the slots during operation of the device; and wherein the slots are spaced apart by one half wavelength of TE_{10} mode in said parallel plate waveguide at said predetermined frequency whereby waves propagating at frequencies below said predetermined frequency are transmitted through said rectangular waveguide without substantial radiation to the absorptive material while a substantial proportion of waves propagating through the rectangular waveguide in any TE_{MN} mode, where $M \neq 0$, at frequencies greater than the predetermined frequency is radiated from the slots and is attenuated by absorption by said absorptive material.

2. A waveguide filter as claimed in claim 1 in which the microwave absorptive material covers the gap between said opposing surfaces.

3. A waveguide filter as claimed in claim 1 in which the spacing of the spaced conductive members is less than the dimension of the at least one broad wall of the waveguide.

4. A waveguide filter as claimed in claim 1 in which the length of each slot is substantially one half wavelength at the predetermined frequency.

5. A waveguide filter as claimed in claim 1 and including additional slot positions provided in the other broad wall of the rectangular waveguide, each slot position having a slot extending substantially perpendicularly to the length of the rectangular waveguide; two further spaced conductive members, substantially identical to said pair of spaced conductive members, positioned on the outside of said other broad wall; and further microwave absorptive material arranged substantially identically to said microwave absorptive material to absorb energy transmitted through the slots; and wherein said other slots are spaced apart by one half wavelength of TE_{10} mode in said parallel plate waveguide at said predetermined frequency and wherein the longitudinal positions of said slots in said at least one broad wall are mid-way between the longitudinal positions of said additional slots in said other broad wall.

6. A waveguide filter as claimed in claim 1 and wherein the filter is adapted to act as a harmonic filtering arrangement passing frequencies in a band about a fundamental frequency and extending up to a predetermined frequency without substantial attenuation and attenuating a given harmonic frequency of said fundamental frequency wherein spacing of the slots is a half-wavelength at said predetermined frequency and the length of the slots is substantially one half wavelength at said given harmonic frequency at which maximum attenuation is required.

7. A waveguide filter as claimed in claim 5 and wherein the filter is adapted to act as a harmonic filtering arrangement passing frequencies in a band about a fundamental frequency and extending up to a predetermined frequency without substantial attenuation and attenuating given harmonic frequencies of said fundamental frequency wherein spacing of the slots is a half-wavelength at said predetermined frequency and in which the lengths of the slots in said at least one broad wall are a half wavelength at one harmonic frequency and the length of said other slots in said other broad wall are a half wavelength at another harmonic frequency.

8. A waveguide filter as claimed in claim 6 in which there are provided additional slots so as to form at each slot position a plurality of individual longitudinally aligned slots across the whole width of the broad wall, there being as many slots as the width of the broad wall allows.

9. A waveguide filter as claimed in claim 1 in which the lengths of the slots are progressively reduced from the center slot position toward the slot position at one end of the filter.

10. A waveguide filter as claimed in claim 9 in which the lengths of the slots are also progressively reduced from the center slot position toward the slot positions at the other end of the filter.

11. A waveguide filter as claimed in claim 1 in which the rectangular waveguide is provided with a plurality of spaced elongate slits in at least one narrow wall, said spaced elongate slits extending substantially parallel to the minor axis of the waveguide; and microwave absorptive material positioned closely adjacent that side, remote from said gap, of said at least one narrow wall of the waveguide and arranged to cover each slit, the spacing and dimensioning of the slits being such that a predetermined frequency band propagating in any TE_{MO} mode, where M is any integer, is passed along the waveguide without substantial attenuation and all other modes are attenuated by absorption by said material.

12. A waveguide filter as claimed in claim 11 in which the width of each slit is less than twice the thickness of the material forming the waveguide.

13. A waveguide filter as claimed in claim 11 in which each slit extends the full width of the narrow wall.

14. A waveguide filter as claimed in claim 11 in which the slits are equally spaced by two slit widths.

15. A waveguide filter as claimed in claim 11 in which the other narrow wall is provided with a plurality of spaced, elongate slits substantially parallel to the minor axis of the waveguide; and microwave absorptive material.

16. A waveguide filter as claimed in claim 1 in which the microwave absorptive material comprises a single layer of ferrite loaded silicon rubber.

17. A waveguide filter as claimed in claim 1 in which the microwave absorptive material is formed from a base of ceramic material loaded with a material capable of absorbing energy in the operating frequency range of the filter.

18. A waveguide filter as claimed in claim 17 in which the loading material is carbonyl iron powder.

19. A waveguide filter as claimed in claim 17 in which the loading material is ferrite.

20. A waveguide filter for attenuating frequencies above a predetermined frequency, said filter comprising in combination:

a rectangular waveguide formed by a first and second broad wall, each having a given length and width, and a first and second narrow wall, the widths of said broad and narrow walls being dimensioned for propagation of a desired frequency band, and said first broad wall being provided with a plurality of slot positions disposed along its length, each slot position having at least one oblong slot with its longer dimension extending in a direction substantially parallel to the width of said first broad wall; a pair of spaced conductive members projecting outwardly from said first broad wall, each of said pair of conductive members being parallel to said first and second narrow walls and spaced apart by a distance at least closely approximating said given width of said first broad wall to form a parallel plate waveguide which is not cut off for said desired frequency band;

microwave absorbing means extending between said conductive members and in spaced, parallel relation to said first broad wall for absorbing energy transmitted from said rectangular waveguide through said oblong slots; and

each of said oblong slots being spaced from that oblong slot nearest to it by one half wavelength of TE_{10} mode in said parallel plate waveguide at said predetermined frequency whereby waves propagating at frequencies below said predetermined frequency are transmitted through said rectangular waveguide without substantial radiation to said microwave absorbing means while a substantial portion of waves propagating through said rectangular waveguide in any TE_{M0} mode, where M is an integer, at frequencies greater than said predetermined frequency is radiated from said oblong slots and is attenuated by absorption by said microwave absorbing means.

21. A waveguide filter as recited in claim 20 wherein said longer dimension of at least some of said oblong slots is substantially one half the wavelength of a frequency just above said predetermined frequency.

22. A waveguide filter as recited in claim 20 wherein said desired frequency band is a band about a fundamental frequency and extending up to said predetermined frequency and the longer dimension of at least some of said oblong slots is substantially one half wavelength at a given harmonic of the fundamental frequency.

23. A waveguide filter as recited in claim 22 wherein said second broad wall is provided with a plurality of additional slot positions disposed along its length, each

of said additional slot positions having at least one oblong slot with its longer dimension extending in a direction substantially parallel to the width of said second broad wall; and including an additional pair of spaced conductive members projecting outwardly from said second broad wall, each of said additional pair of conductive members being parallel to said first and second narrow walls and spaced apart by a distance closely approximating the width of said second broad wall to form an additional parallel plate waveguide which is not cut off for said desired frequency band; and including an additional microwave absorbing means positioned in a plane parallel to said second broad wall and spaced therefrom for absorbing energy transmitted from said rectangular waveguide through said slots at said additional slot positions; and wherein each of said slots at said additional slot positions is spaced from that slot nearest to it by one half wavelength of TE_{10} mode at said predetermined frequency whereby waves propagating at frequencies below said predetermined frequency are transmitted through said rectangular waveguide without substantial radiation to said additional microwave absorbing means while a substantial portion of waves propagating through said rectangular waveguide in any TE_{M0} mode, where M is an integer, at frequencies greater than said predetermined frequency is radiated from said additional oblong slots and is attenuated by absorption by said additional microwave absorbing means.

24. A waveguide filter as recited in claim 22 wherein said given harmonic is the n th harmonic and additional oblong slots are provided at each slot position to present a plurality n of longitudinally aligned oblong slots at each slot position.

25. A waveguide filter as recited in claim 23 wherein the longer dimension of at least some of said oblong slots at said additional slot positions is substantially one half wavelength at a given harmonic m of said fundamental frequency, where m is an integer.

26. A waveguide filter as defined in claim 25 wherein a plurality m of slots are provided at each additional slot position.

27. A low pass waveguide filter comprising a main waveguide of the broad wall type dimensioned in cross section to pass a particular band of frequencies about a fundamental frequency propagated in the TE_{10} mode, and an absorber waveguide associated with said main waveguide and dimensioned in cross section to pass said fundamental frequency, said main and absorber waveguides having a common broad wall and said broad wall having a series of oblong slots therein which have their longer dimensions extending transversely of said broad wall and which are spaced uniformly along the length of said broad wall, the lengthwise spacing between slots being one half wavelength of the TE_{10} mode in said absorber waveguide at a first frequency within said band of frequencies and the length of at least some of said slots being one half wavelength at a second frequency which is close to but greater than said first frequency, whereby said low pass waveguide has a rejection band which commences within said band of frequencies.

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