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WAVEGUIDE FILTER HAVING BRANCH MEANS TO ABSORB
OR ATTENUATE FREQUENCIES ABOVE PASS-BAND

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Sheet 1 of 2

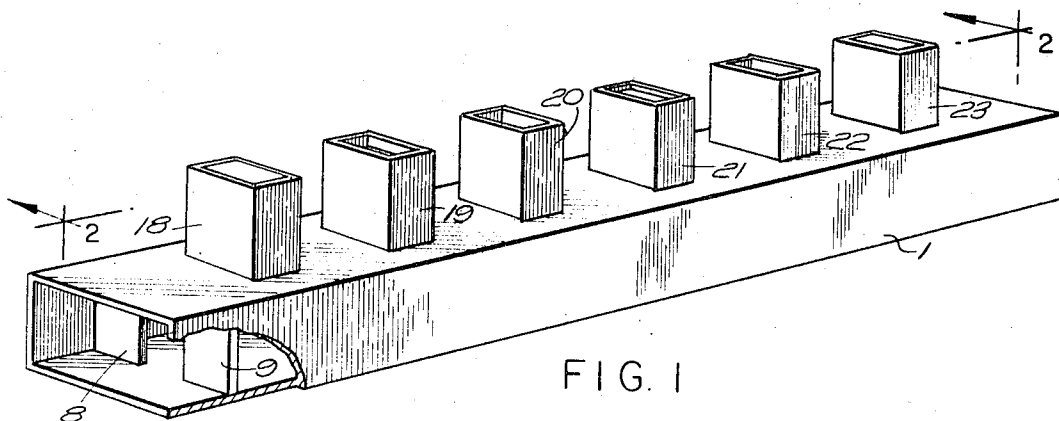


FIG. 1

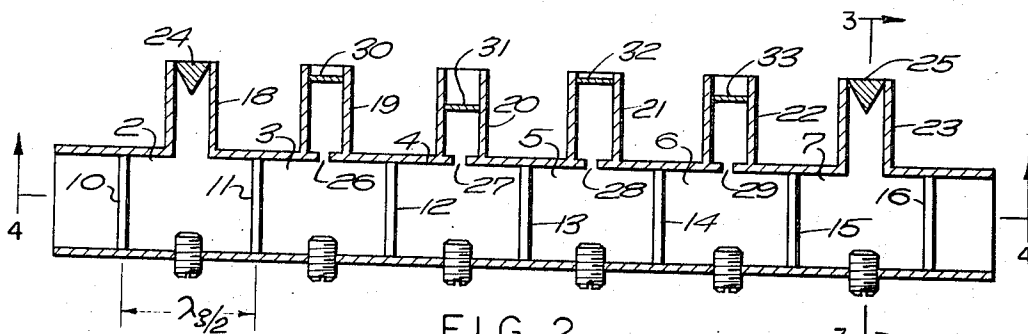


FIG. 2

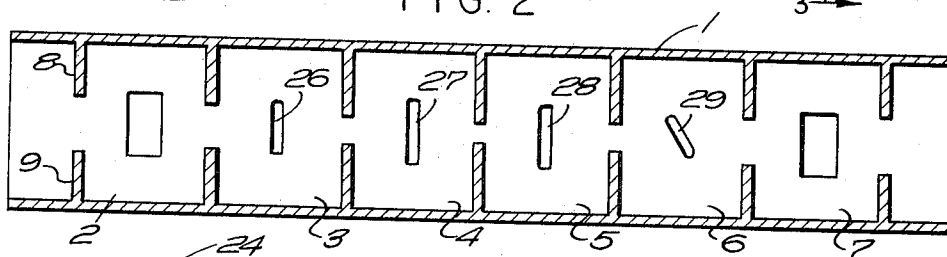


FIG. 4

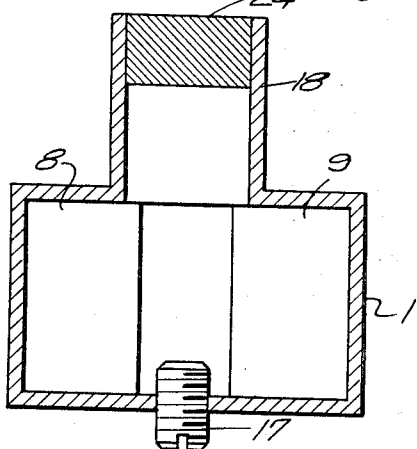


FIG. 3

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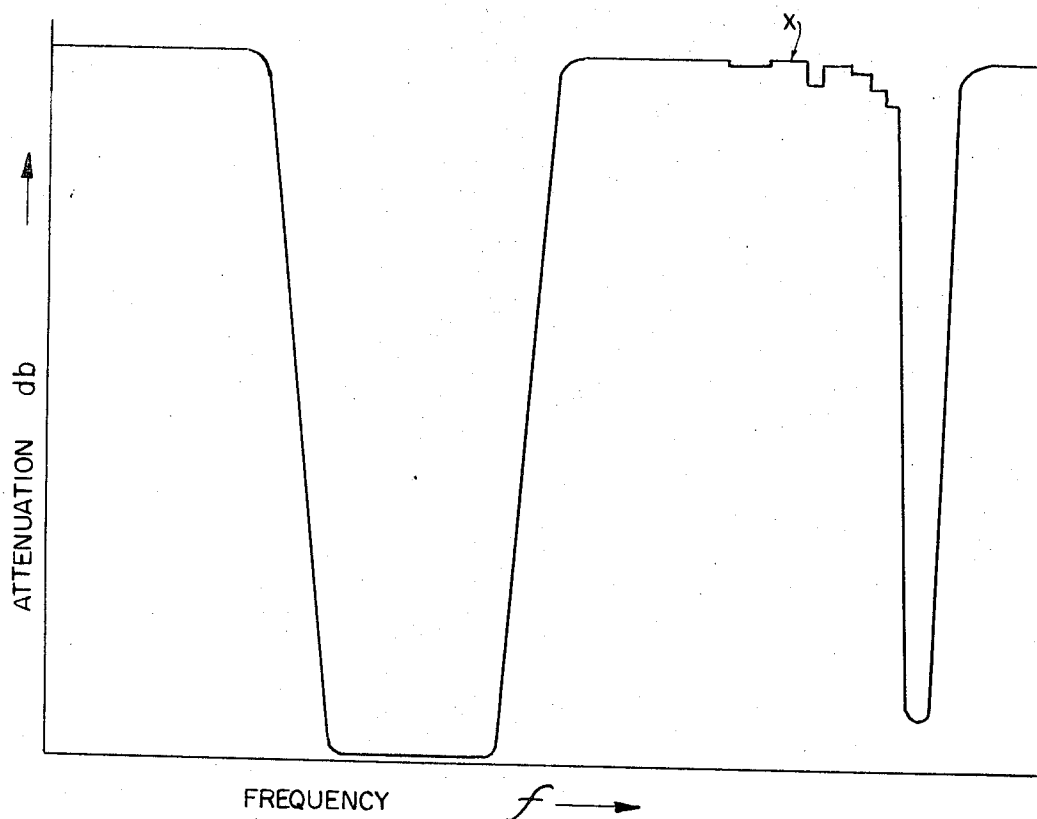
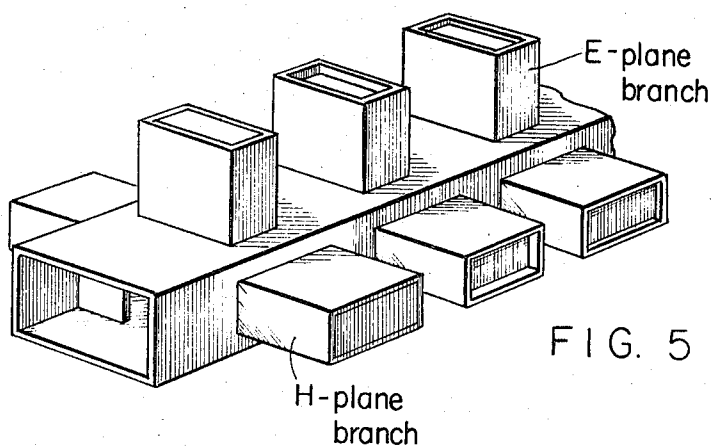
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Sheet 2 of 2



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WAVEGUIDE FILTER HAVING BRANCH MEANS TO ABSORB OR ATTENUATE FREQUENCIES ABOVE PASS-BAND

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1 Claim

ABSTRACT OF THE DISCLOSURE

A band pass waveguide filter is constructed of directly coupled half wavelength resonant cavities. Branching from those cavities are waveguides which attenuate only the frequencies above the filter's pass band. The cut-off frequency of the branch waveguides is above the frequencies in the filter's pass band and the branches are terminated to absorb the wave energy propagating in the branches. The coupling between a branch waveguide and its resonant cavity can be frequency selective to suppress particularly troublesome stop band frequencies. Alternatively, the branch can be terminated in a short circuit which tunes the branch to resonate at the undesired frequencies.

This invention relates to frequency selective devices for use at those frequencies where hollow pipes are commonly employed to guide electromagnetic waves. More particularly, the invention pertains to a microwave band pass filter having improved stop band characteristics.

It is well known in the microwave filter art that many of the techniques developed in connection with the synthesis of lumped parameter linear passive networks may be adapted for synthesizing microwave filters formed by a cascade of large, generally lossless, reflecting elements regularly spaced in a uniform waveguide. General synthesis procedures for "quarter wave coupled" and "direct coupled" filters are set forth in "Microwave Transmission Circuits," volume 9, M.I.T. Radiation Laboratory Series, pp. 661—706.

Generally, prior "direct-coupled" filters have consisted of a number of reflecting elements spaced within a waveguide of uniform cross-section by one-half the wavelength in the guide of microwave energy vibrating at the center frequency of the filter. Because all the cavities formed in the uniform waveguide between reflecting elements are equal to or are multiples of $\lambda_g/2$ in length (λ_g , being the wavelength in the guide), all the cavities resonate at the same fundamental frequency and at those higher frequencies at which a single one of the cavities is resonant. In most uses of resonator filters, it is distinctly undesirable to have the filter pass all the higher frequencies at which the cavities are resonant. More commonly such filters are employed to pass only a continuous band of frequencies centered about the fundamental frequency. Conventional microwave band pass filters, commonly, are afflicted by "windows" at the higher frequencies. That is, microwave band pass filters of conventional design usually permit some frequencies lying above the pass band to go through the filter without any material diminution in strength. Thus, a "window" is marked by a range of undesired frequencies, outside of the pass band, which pass through the filter substantially unattenuated.

The present invention contemplates and has as its primary object the construction of a direct coupled waveguide filter having provisions for suppressing undesired

frequencies lying above the pass band so that windows are eliminated. A filter constructed in accordance with the invention can provide the pass-band characteristics of a conventional direct coupled filter while possessing stop band capabilities beyond those of the conventional filter.

The invention is particularly suited to a band pass filter requiring wide stop band capabilities. Because of the greater use made in recent years of the microwave region of the frequency spectrum, band-pass filters have become of increasing importance in suppressing the superfluous signals which frequency generators produce in addition to the wanted signals. In many situations, the pass-band filter is required to be capable of accommodating high power, have low insertion loss in the pass band, and be capable of appreciably attenuating all frequencies in a wide stop band.

In accordance with the invention, the waveguide filter is constructed of a plurality of directly coupled half wavelength resonant cavities with at least some of the cavities having branch waveguides. The branch waveguides are of internal dimensions such that the frequencies in the pass band of the filter are below the cut-off frequency of the branches and therefore do not propagate into the branches. Higher frequencies, however, do pass into the branch waveguides and are there attenuated. The coupling between a branch waveguide and the filter's resonant cavity may be made frequency selective so that the branch waveguide suppresses a range of higher frequencies in the stop band that is particularly troublesome. For example, where a window exists, the waveguide branches may be tuned to suppress the window frequencies. The waveguide branches may be terminated by wave energy absorbers of characteristic impedance. Alternatively, a waveguide branch may be terminated by a short circuit which tunes the branch to resonate at the undesired frequencies. To obtain a filter having excellent stop band characteristics, energy in the stop band must be absorbed despite the multitude of modes in which that energy can propagate. The invention has the capability of presenting a sufficient insertion loss for the troublesome modes to prevent a spurious pass band from developing out of mode conversion occurring in the filter or from modes launched at the filter's input.

The invention, both as to its construction and its manner of operation, can be better understood from a study of the following exposition when considered in conjunction with the accompanying drawings in which:

FIG. 1 is a perspective view of a microwave filter embodying the invention;

FIG. 2 is a vertical section, taken along the parting plane 2—2 in the preceding figure;

FIG. 3 is a sectional view taken along the parting plane 3—3 in the first figure;

FIG. 4 is a sectional view, taken along the line 4—4 of FIG. 3, showing the apertures coupling the main waveguide to its branches;

FIG. 5 shows an embodiment of the invention employing H-plane branches in addition to the E-plane branches; and

FIG. 6 is a plot showing the attenuation of a direct coupled filter as a function of signal frequency.

Referring now to FIGS. 1 through 4 of the drawing, a preferred embodiment of the invention is illustrated having a main hollow rectangular waveguide 1 in which reactive elements are arranged to form resonant cavities 2, 3, 4, 5, 6, and 7 within the main guide. Each reactive element is, for example, an inductive iris formed, as depicted in FIG. 3, by a pair of metallic plates 8 and 9. The reactive elements, 10, 11, 12, 13, 14, 15 and 16, are spaced along the waveguide so that each reactive element is one-half wavelength ($\lambda_g/2$) distant from the immedi-

ately preceding reactive element, λ_g being the wavelength in the guide at the center frequency of the filter. To permit tuning the individual cavities, each cavity is provided with a tuning screw, such as the screw 17 shown in FIG. 3 protruding from the lower broad wall of the guide. The tuning screws permit compensating adjustments to be made for variations in the internal dimensions of the reactive elements. Where the waveguide is of highly precise dimensions and the reactive elements are accurately positioned, the tuning screws may be eliminated.

An E-plane waveguide branches from each resonant cavity. The branch waveguides 18, 19, 20, 21, 22, and 23 are reduced in width compared to the width of the main guide 1. The internal dimensions of the branch waveguides are such that the cut-off frequency of the branch waveguide is above the highest frequency in the pass band of the filter. Wave energy whose frequency is within the filter's pass band, cannot propagate along the branch waveguides and is, therefore, confined to propagation along the main guide. Wave energy whose frequency lies above the pass band of the filter and above the cut-off frequency of the branch guides can, when appropriately coupled, propagate into the branch guides. By terminating a branch waveguide in its characteristic impedance, energy propagating along that branch can be completely absorbed so that none of the energy is reflected back into the main guide. In FIG. 2, for example, branch waveguides 18 and 23 are respectively terminated in their characteristic impedance by resistive pads 24 and 25.

As an alternative to the absorption of undesired wave energy by a resistive terminal in the branch waveguide, the branch guide may be coupled to the main guide by a frequency selective aperture and the branch guide may be tuned by terminating it in a short circuit. At the resonant frequency of the tuned branch guide, appreciable absorption of power from the main guide occurs. The resonance of the branch circuit can be made extremely sharp to suppress those frequencies outside of the pass band that are particularly troublesome. By tuning a number of the branch guides, the troublesome frequencies, that is, those frequencies outside the pass band to which the main guide is substantially transparent, are successively attenuated by absorption in the tuned branch guides. In FIG. 2, by way of example, branch waveguides 19, 20, 21 and 22 are coupled to the main waveguide by slots 26, 27, 28, and 29 and are terminated by short circuiting plugs 30, 31, 32, 33, respectively. If desired, the short circuiting plugs can be made adjustable to permit the branches to be tuned to suppress various frequencies.

The geometries of coupling slots 26, 27, 28, and 29 are important, as are their orientation and location upon the main waveguide. It is the geometry, orientation and location of the slot that determine the coupling of its branch to the multitude of modes in which the stop band frequencies propagate. For an efficient filter, it is desirable to have each slot provide coupling to a multitude of modes with as large a coupling factor as is consistent with a low reflection coefficient. It is highly desirable to have as many modes as possible included within the high coupling factor range. In general, a narrow rectangular slot having rounded ends has been found to provide good mode coupling when the slot is disposed transversely in the broadwall of the main guide and is symmetrically oriented with respect to the resonant cavity to which it couples, as represented by coupling slots 26, 27 and 28 in FIG. 4. The narrow slot couples primarily to a magnetic field that is parallel to the long dimension of the slot. The dimensions of a transverse coupling slot can be determined from the relationship.

$$l = \frac{\lambda_0}{2} + 0.278w$$

where:

l is the resonant length of the narrow rounded slot, λ_0 is the free space wavelength, w is the slot width.

By ascertaining the direction of the magnetic field vector for each mode which propagates in the stop band the coupling slots can be oriented to assume coupling to those modes. Slot 29 is represented in FIG. 5 as oriented to couple to modes whose magnetic field vectors are generally as indicated by the adjacent arrow.

The energy coupled out of the main guide by one slot may be insufficient to provide the desired degree of attenuation. It may be necessary, therefore, to employ a number of identical slots, each slot coupling energy into its own branch where that energy is absorbed. Where a sufficient number of branches are available, an extremely wide stop band can be obtained in which all frequencies are materially attenuated.

The number of cascaded half wavelength resonant cavities in the main waveguide can be increased to provide additional E-plane branches. However, increasing the number of such cavities also tends to increase the transparency of the filter to frequencies outside of the pass band. In lieu of locating the tuning screws in the manner depicted in FIG. 2, the means for tuning the main guide resonant cavities can be located in the narrow guide wall. By relocating the tuning apparatus, the lower broad wall of the main guide is free to accommodate additional E-plane branch guides. The number of E-plane branches can, in this fashion, be doubled without requiring more half wavelength resonant cavities in the main guide.

Where it is desired to retain the tuning screws in the bottom broad wall of the main guide and more branch guides are required, rather than add additional half wavelength resonant cavities to the main guide, H-plane branches can be coupled to the existing resonant cavities of the main guide as indicated in FIG. 5. The H-plane branches can be terminated in the same manner as the E-plane branches, viz, by a resistive pad or by a short circuiting plug. The H-plane branches, as in the case of the E-plane branches, are of such internal dimensions that their cut-off frequency is above the highest frequency in the filter's pass band.

Where the cut-off frequency of the branches is sufficiently above the pass band, it has been ascertained that the branches have no appreciable effect upon the transmission through the filter of frequencies in the pass band. However, as the cut-off frequency of the branches approaches the upper end of the pass band, some attenuation of the pass band frequencies is manifested. It is, therefore, desirable to have the cut-off frequency of the branches located between the upper end of the pass band and the nearest "window." That is, referring to FIG. 6 which shows the attenuation versus the frequency of signals applied to the filter, the cut-off frequency, is preferably, located somewhere in the vicinity of frequency X, which is somewhat closer to the first "window" than it is to the upper end of the pass band.

In practice, it has been found that satisfactory results are obtained when both resistive and short circuit terminations are employed for the branch waveguides in a single filter. Usually the resistive terminations are used in the first and last branches, with the short circuits being used in the intermediate branches. On occasion, however, it has been determined that better results are obtained with some other sequence of resistive and short circuit termination.

In view of the different ways in which the invention can be embodied, it is not intended that the scope of the invention be restricted to the precise structure illustrated in the drawings or described in this exposition. Rather, it is intended that the scope of the invention be delimited by the claim appended hereto and to include such structures as do not in essence fairly depart from the invention there defined.

What is claimed is:

1. A microwave band pass filter comprising:

(1) a hollow, conductively bounded, main waveguide having in it a plurality of irises partitioning the

waveguide into a plurality of directly coupled half wavelength resonant cavities which determines the pass band of the filter;

- (2) a plurality of branch waveguides, each branch waveguide having its cut-off frequency above the highest frequency in the filter's pass band, each branch waveguide forming an E-plane junction or an H-plane junction with a resonant cavity of the main waveguide; 5
- (3) means coupling wave energy in the main waveguide resonant cavities to the branch waveguides, at least some of the coupling means being frequency selective some of the coupling means being frequency selective so as to couple energy in regions of the stop band; and 10
- (4) means terminating the branch waveguides to cause energy coupled into the branch waveguides to be absorbed, the means in at least some of the branch waveguides being resistive termination of characteristic impedance, and other branch waveguides being terminated in short circuits causing those branch 20

waveguides to be resonant at frequencies in the stop band.

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