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2,594,037 4/1952 Landon 333/73
2,849,683 8/1958 Miller 333/10
2,989,709 6/1961 Seidel 333/98

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[54] **MICROWAVE FILTER**
7 Claims, 9 Drawing Figs.

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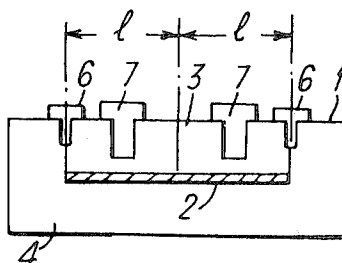
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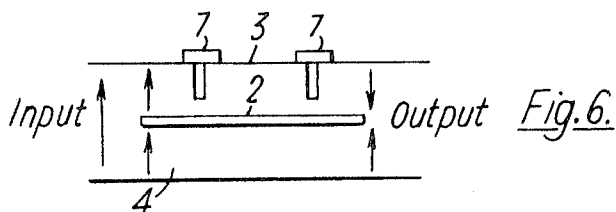
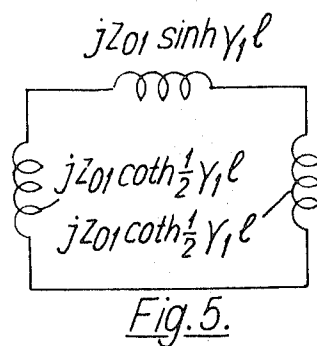
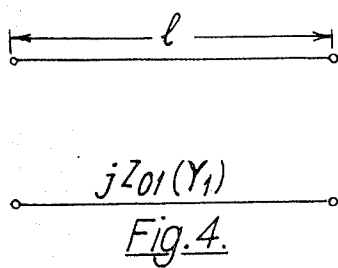
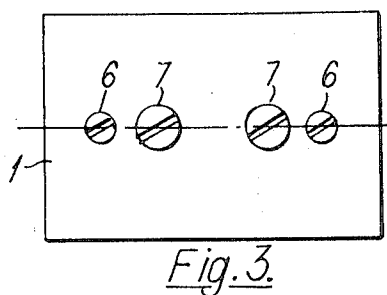
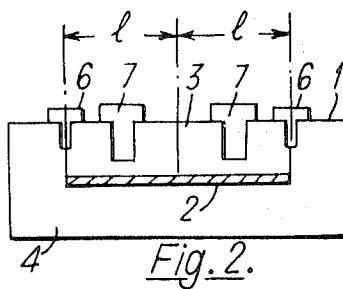
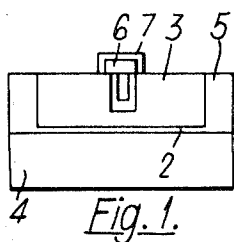
[56] **References Cited**

UNITED STATES PATENTS

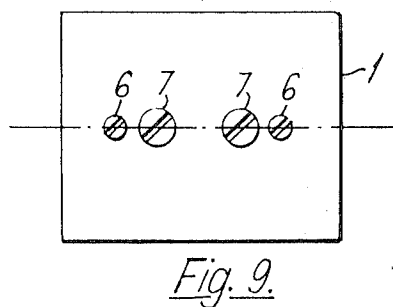
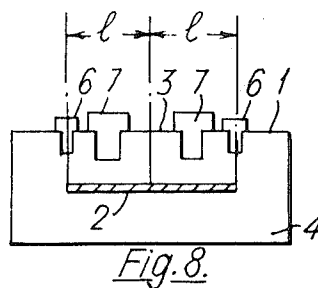
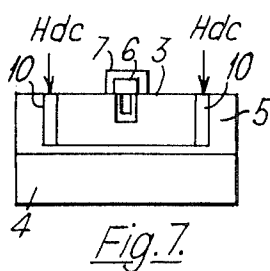
3,496,498 2/1970 Kawahashi et al. 333/73 W
2,866,949 12/1958 Tillotson 333/11

ABSTRACT: A microwave filter of the type wherein an H-plane bifurcation provides a first and second channel within a length of rectangular waveguide for the separate propagation of incident energy. In a preferred embodiment, the width of said first channel is reduced and two screws are inserted therein to convert said first channel into a 180° phase shift evanescent filter. Said evanescent filter is coupled to the rectangular waveguide by inserting in said waveguide a screw at each longitudinal end of said bifurcation. The combined outputs of said first and second channel cancel, thereby providing a rejection filter. In a modification of said preferred embodiment, a ferrite is positioned along the sidewalls of said evanescent filter and is subjected to a magnetic field. The strength of said magnetic field controls the phase shift of said evanescent filter and consequently the amount of cancellation achieved, and enables use as a switch.





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MICROWAVE FILTER

FIELD OF THE INVENTION

This invention relates to electrical waveguide arrangements.

SUMMARY OF THE INVENTION

An object of the invention is to provide a type of rejection filter which is simple, compact and tunable.

Another object of the invention is to provide an electrical waveguide arrangement which can function as an on-off switch, having application as a microwave transmitter-receiver switch.

According to the invention there is provided a waveguide filter comprising a length of waveguide, an H-plane bifurcation of a predetermined length for providing in said waveguide a first and second waveguide channel, means for increasing the cutoff frequency of said first waveguide channel above the operating frequency of the waveguide filter, means for terminating predetermined sections of said first channel in a reactance which at the operating frequency is the conjugate of the imaginary characteristic impedance of said first channel and means for coupling said first channel to said length of waveguide.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other objects of this invention will become apparent by reference to the following description in conjunction with the accompanying drawings in which:

FIGS. 1, 2 and 3 are end, side and plan views respectively of an electrical waveguide arrangement arranged to function as a rejection filter,

FIG. 4 is a transmission line equivalent of one section of the arrangement shown in FIGS. 1, 2 and 3,

FIG. 5 is a lumped circuit equivalent of the section, the

FIG. 6 shows the basis of operation of the arrangement of FIGS. 1, 2 and 3 as an isolation filter,

FIGS. 7, 8 and 9 are end, side and plan views respectively of an electrical waveguide arrangement arranged to function as an on-off switch.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. 1, 2 and 3, a length 1 of waveguide of rectangular cross section is internally divided by a longitudinal H-plane bifurcation 2 (a thin metal plate) into two reduced height waveguides 3 and 4. The height division is such that incident electromagnetic energy at one end of the length 1 divides equally between the two reduced height waveguides 3 and 4.

The width of the reduced height waveguide 4 (which is the same as the width of the full height of the undivided waveguide 1) is such that at the operating frequency of the arrangement, the reduced height waveguide 4 is propagating.

The width of the reduced height waveguide 3 is reduced, as by thickening the sidewalls 5, so that at the operating frequency the cutoff frequency of the reduced height waveguide 3 is above the operating frequency.

The reduced height waveguide 3 has two capacitive matching screws 6, one at each end, and two capacitive tuning screws 7. The purpose of these screws will be described later.

The screws 6 and 7 are located on the broad wall centerline of the waveguide, and each tuning screw 7 is located at the center of a section of length l of the reduced height waveguide 3, the reduced height waveguide therefore having a length of $2l$ and containing two such sections, each with its tuning screw 7.

Assuming electromagnetic energy at the required operating frequency to be present, in the dominant H-mode, at the left-hand end of the length 1, since the reduced height waveguide 3 is dimensioned to be beyond cutoff at this frequency, all modes in the length are evanescent.

Waveguide at frequencies below cutoff exhibits characteristics common to all nondissipative filter networks in their

stop-band region. The characteristic impedance which is real in the passband becomes imaginary in the stopband. The propagation constant which is imaginary in the passband becomes real in the stopband.

The transmission line analog of the section of length l of the reduced height waveguide 3 is shown in FIG. 4 as a line of length l having a positive imaginary characteristic impedance jZ_{01} and a real propagation constant Y_1 . To evanescent H waves therefore the length l 'looks' like a pure inductance. The lumped circuit equivalent of FIG. 4 is shown in FIG. 5 as a π equivalent circuit giving the inductance reactance values as functions of Z_{01} , Y_1 and l .

If the section of waveguide is terminated in a capacitance C such that the capacitive reactance X_C is the conjugate of the inductive reactance of the section, there will be full energy transfer through the section. The energy transfer is frequency sensitive and the section behaves as a band-pass filter.

The passband frequency limits (f_1 and f_2) are given by:

$$f_1 = \tanh \frac{1}{2} Y_1 l / Z_{01} 2\pi C \quad (1)$$

$$f_2 = \coth \frac{1}{2} Y_1 l / Z_{01} 2\pi C \quad (2)$$

The center frequency, f_0 , occurs at the geometric mean $f_0 = \sqrt{f_1 f_2}$

$$\text{Therefore} \quad f_0 = 1/2\pi Z_{01} C \quad (3)$$

The bandwidth is a function of Y_1 and (in the ideal lossless case) as $Y_1 l \rightarrow \infty$, then $\tanh Y_1 l \rightarrow \coth Y_1 l$, and the bandwidth ($f_2 - f_1$) reduces towards zero.

The reduced height waveguide 3 therefore behaves as a two section band-pass filter, in which the required value for each section capacitance to provide conjugate matching with the inductance of the respective section is provided by suitably adjusting the capacitive tuning screws 7.

The two matching screws 6 are adjusted to tune out the shunt susceptances arising from the transition from full height and width waveguide to the reduced height reduced width waveguide.

Each section of the reduced height waveguide 3 causes a phase retardation of $\pi/2$ at resonance, so that the two sections together cause a phase shift of 180° .

The length of the H-plane bifurcation 2 is made equal to the guide wavelength (λ_g) or an integral multiple thereof at the operating frequency. As indicated in FIG. 6, assuming the input wave to have unit amplitude at the input end of the arrangement, with the characteristic impedances of the two networks formed respectively by the energy transmitting reduced height waveguide 3 with its screws 6 and 7 suitably adjusted and by the energy transmitting reduced height waveguide 4 proportioned so that the energy divides equally between 3 and 4, since the reduced height waveguide 4 is propagating, the phase of its wave at the output, i.e., at λ_g from the input, is the same as the phase of the wave at the input.

The reduced height waveguide 3 causes a 180° phase shift between input and output. The output wave therefore has zero amplitude, all the energy being reflected.

The arrangement thus functions as a rejection filter for a given operating frequency, with the H-plane bifurcation 2 having a length equal to λ_g or an integral multiple thereof and the two section evanescent mode band-pass filter formed by the reduced height waveguide 3 tuned to a center frequency which is the operating frequency. It will be appreciated that it is also possible to have an evanescent mode band-pass filter having four sections with an H-plane bifurcation length of $1\frac{1}{2} \lambda_g$, as this combination will also result in the required 180° phase shift for zero amplitude output wave.

When so tuned, there is full energy transfer through the evanescent mode band-pass filter. With progressive detuning, the amount of energy passed through is progressively reduced until the reduced height waveguide 3 behaves solely as a length of evanescent guide, with very high attenuation.

With effectively no energy transfer through the evanescent waveguide 3 and full energy propagation through the propagating waveguide 4, the arrangement is in the 'on' condition of a switch. With the evanescent mode filter tuned to the

operating frequency, the arrangement is in the 'off' condition of a switch.

If it can be arranged for the tuned (off) condition to be readily altered to the detuned (on) condition, the arrangement can function as an on-off switch.

FIGS. 7, 8 and 9 show such an arrangement which can be changed from 'on' to 'off' very rapidly.

The arrangement is similar to that already described, and like reference numerals have been used for like integers of the two arrangements. The reduced height waveguide 3 in the arrangement now being described additionally includes two strips 10 of ferrimagnetic material, such as ferrite or garnet, one strip on each sidewall, the length of the strips 10 being equal to that of the H-plane bifurcation 2, i.e., λ_g . The ferrimagnetic strips 10 are subjected to a transverse DC magnetic field H_{dc} .

It has been established that for a transversely magnetized ferrite in rectangular waveguide (H_{01} mode) the cutoff frequency may be controlled by the DC magnetic field. The cutoff frequency can be made higher or lower than the empty waveguide value. This is a consequence of the fact that the effective permeability μ_e of the ferrite can be varied from positive to negative values by the DC magnetic field. Thus for $\mu_e > 0$ the RF field is concentrated in the ferrite and the effective width of the waveguide is increased, whereas for $\mu_e < 0$ the RF energy is excluded from the ferrite and the effective width is reduced.

Thus for a given magnetic field (which may be zero) in the ferrimagnetic strips, the effective width of the reduced height waveguide 3 is determined. The imaginary characteristic impedance of the evanescent waveguide 3 is a function of this effective width, and with the two sections of the evanescent waveguide tuned by the screws 7 to provide conjugate matching with the inductance of the respective section at the evanescent mode band-pass filter center frequency corresponding to the operating frequency, there is full energy transfer through both of the reduced height waveguides 3 and 4 (4 being propagating) with the output wave having zero amplitude because of the 180° phase shift caused by the band-pass filter. This corresponds to the 'off' condition.

Variations in the magnetic field H_{dc} causes an alteration in the effective width of the evanescent waveguide 3. This causes the imaginary characteristic impedance to be altered, so that the setting of the tuning screws 7 no longer provides the conjugate matching condition required for full energy transfer through the evanescent waveguide. By varying the magnetic field H_{dc} sufficiently to detune the filter sufficiently for zero energy to be transferred through the evanescent waveguide 3, there is an output as a result of the propagated wave through the propagating waveguide 4. This corresponds to the 'on' condition.

The magnetic field is made variable when applied by permanent magnet pole pieces by arranging for the pole pieces to be movable, and when applied by electromagnetic pole pieces by varying the current.

The required variation in the magnetic field can be made extremely rapidly for the arrangement to function as an on-off switch for use for example as a microwave transmitter-receiver switch.

By way of example, a ferrimagnetic loaded arrangement as described with reference to FIGS. 7, 8 and 9, constructed in waveguide having a width of 0.9 inches and an undivided height of 0.4 inches, with the evanescent mode reduced height

waveguide having a width of 0.622 inches, magnetic field 890 gauss, at an operating frequency of 8.83 GHz, had an insertion loss on transmission of 0.3 db. and a bandwidth > 43 db. over a 30 MHz. frequency band (8.81–8.84 GHz.).

It has been stated in the above description that each section of the evanescent mode band-pass filter formed by the reduced height waveguide introduces a phase retardation of $\pi/2$ (90°). While this is true when each section is precisely tuned to the operating frequency, slight detuning will still permit significant energy transfer, but as with any tuned circuit, the phase change can vary quite largely with such slight detuning. Thus in practice, it is possible to achieve a desired phase change for example the described 180° change for the rejection filter function, by the two section evanescent mode filter, with each section causing a phase change which is not $\pi/2$, but whose two phase changes add up to the required 180° .

We claim:

1. A waveguide filter comprising:
 - a length of waveguide;
 - an H-plane bifurcation having a length equal to a multiple of the guide wavelength for providing in said waveguide a first and second waveguide channel;
 - means for increasing the cutoff frequency of said first waveguide channel above the operating frequency of the waveguide filter;
 - means for terminating predetermined sections of said first channel in a reactance which at the operating frequency is the conjugate of the imaginary characteristic impedance of said first channel; and
 - means for coupling said first channel to said length of waveguide.
2. A waveguide filter, according to claim 1, wherein said means for coupling said first channel to said length of waveguide includes a first and second screw positioned along the longitudinal axis of said waveguide and extending into said first channel, one at each end of said H-plane bifurcation.
3. A waveguide filter, according to claim 1, wherein said predetermined length includes an even number of predetermined sections and wherein said means for terminating predetermined sections includes an even number of screws, one for each section, positioned along the longitudinal axis of said waveguide and extending into said first channel at the midpoint of said predetermined sections.
4. A waveguide filter, according to claim 1, wherein said means for increasing the cutoff frequency of said first waveguide channel includes ferrimagnetic material having a length equal to the length of said bifurcation mounted adjacent to the sidewalls of said waveguide channel and means for applying a magnetic field to said ferrimagnetic material.
5. A waveguide filter, according to claim 1, wherein said ferrimagnetic material is a ferrite.
6. A waveguide filter, according to claim 4, wherein said means for coupling said first channel to said length of waveguide includes a first and second screw positioned along the longitudinal axis of said waveguide and extending into said first channel, one at each end of said H-plane bifurcation.
7. A waveguide filter, according to claim 4, wherein said predetermined length includes an even number of predetermined sections and wherein said means for terminating predetermined sections includes an even number of screws, one for each section, positioned along the longitudinal axis of said waveguide and extending into said first channel at the midpoint of said predetermined sections.