

Feb. 22, 1966

V. G. PRICE
MICROWAVE FILTER

3,237,134

Filed March 26, 1963

2 Sheets-Sheet 1

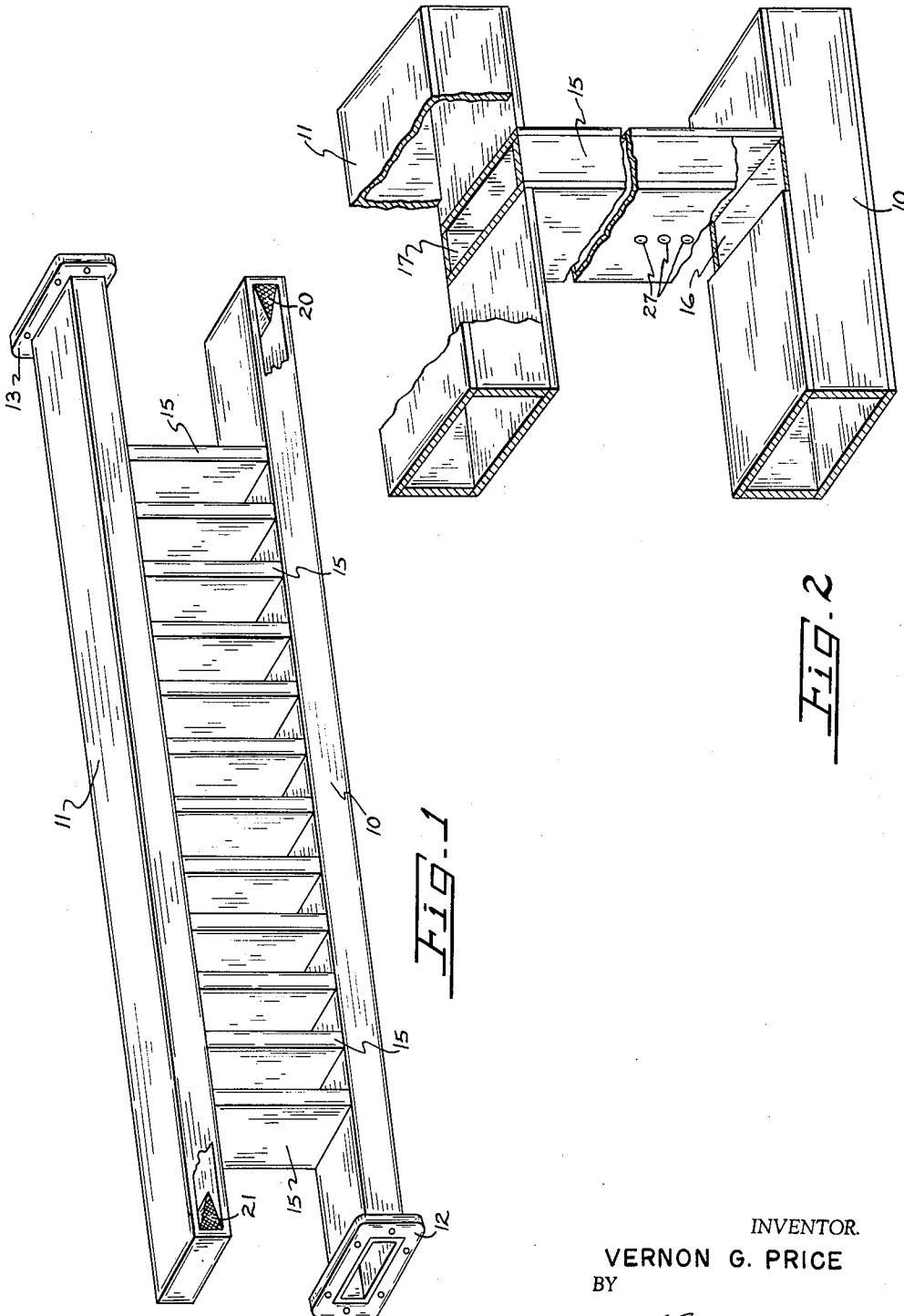


Fig. 2

Fig. 1

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2 Sheets-Sheet 2

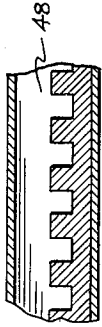


Fig. 4a

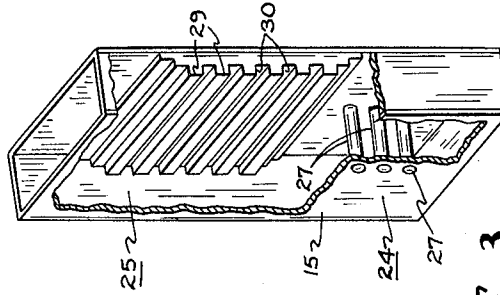


Fig. 3

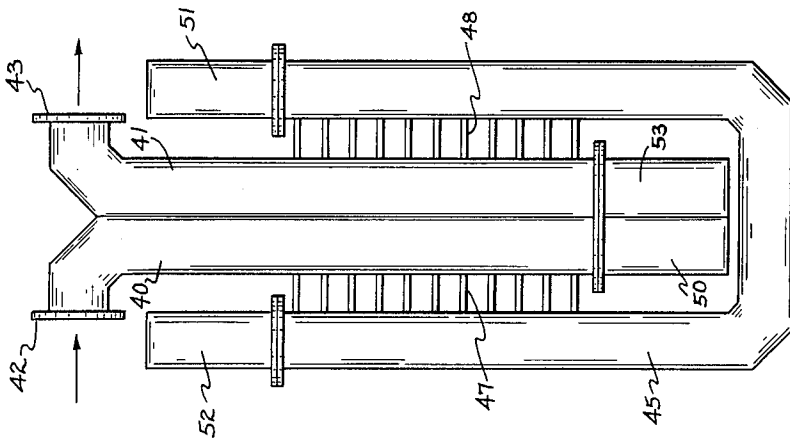


Fig. 4

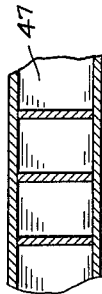


Fig. 4a

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MICROWAVE FILTER

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Filed Mar. 26, 1963, Ser. No. 267,996

6 Claims. (Cl. 333-73)

This invention relates to apparatus for separating high frequency electromagnetic waves according to their frequencies and more particularly to band-pass filter apparatus for microwaves.

The rapidly expanding employment of high frequency electromagnetic waves of the microwave portion of the spectrum, such waves being known as microwaves, has produced a corresponding problem of interference between users. Interference is minimized between groups of microwave communication systems in the same region by requiring that each system radiate signals from its antenna only within its respective allocated frequency band of microwaves, a frequency band which must be distinct from the other systems in the region. Therefore, the transmitter of microwaves in each system should radiate only the band of frequencies allocated to that transmitter. However, this requirement for avoiding interference is complicated by the microwave generators employed in the transmitters. Most microwave generators, such as magnetron and klystron oscillators, produce microwave signals not only at the frequencies for which they are tuned and intended to operate, but at many spurious frequencies. Such spurious signals are of two types: harmonic and non-harmonic. Harmonic spurious signals have frequencies which are integral multiples of and which are relatively widely separated from the fundamental operating frequencies. For example, a microwave generator tuned to provide microwave signals in the fundamental frequency range of 3.2 to 3.4 kilomegacycles (kmc.), also generates second harmonic signals in the frequency range 6.4 to 6.8 kmc. and third harmonic signals in the frequency range 9.6 to 10.2 kmc. Non-harmonic spurious signals have frequencies relatively close to the basic frequency. In the above example, strong non-harmonic signals are generated in the frequency range of 3.4 to 6.4 kmc.

One of the earliest approaches to eliminating spurious frequency signals from the output of a microwave generator was to employ band-pass filters in the main transmission channel. Microwaves are usually transmitted between generator and antenna over hollow waveguiding sections, such as coaxial transmission lines or hollow rectangular waveguides. These waveguiding sections only have a limited power handling capacity. If its maximum power handling capacity is exceeded, electrical breakdown occurs in the waveguiding section and impedes the transmission of microwaves therethrough. The insertion of protuberances and obstacles, which comprise the prior art band-pass filters, into the waveguiding section substantially reduces its maximum power handling capacity. Therefore, the early filtering systems, which employed band-pass filters in the main waveguiding sections, were handicapped by significantly reduced power handling capacities.

An additional disadvantage of using band-pass filters in this prior art manner, is the failure of the filters to impede the passage of certain spurious waves having frequencies remote from the allocated or design frequency band. With the advent of high powered microwave generators, spurious signals produced at frequencies remote from the design frequency have substantial amounts of energy and can cause significant interference with other nearby communication systems.

Another disadvantage of the prior art filtering apparatus described above arises from the tendency of micro-

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waves to travel in multiple modes along the waveguiding sections. A mode of transmission is the configuration of the electric and magnetic fields comprising a wave during propagation of the wave along a waveguiding section. In waveguides, an obstacle in the path of wave transmission induces new modes, additional to those the wave originally possessed when it encountered the obstacle. Since the conventional band-pass filters described above do not function properly for all wave modes, certain of the propagation modes of the spurious signal frequencies pass through the filters without being sufficiently attenuated.

Therefore, it is the principal object of this invention to provide improved microwave filter apparatus to obviate the difficulties of prior art filters.

Another object of this invention is to provide improved band-pass filter apparatus.

Another object of this invention is to provide improved band-pass filter apparatus for insertion in a waveguide transmission system without reducing the power handling capability thereof.

Another object of this invention is to provide improved band-pass filter apparatus for substantially attenuating all signals having frequencies greater than the highest frequency in the design frequency band.

Another object of this invention is to provide improved band-pass filter apparatus for substantially attenuating all waves having frequencies greater than the highest frequency of the design frequency band, regardless of the mode of propagation of the waves.

The foregoing objects are achieved, according to one embodiment of the invention by providing, in a microwave communication system of the type above-described, a pair of main waveguiding sections, one for receiving the microwave signals provided by the microwave generator and the other for transmitting for utilization the appropriately filtered output signals. A plurality of waveguiding branches couple the two waveguiding sections together so that the microwave energy is transmitted from one waveguiding section to the other through the plurality of branches as a number of separate signal portions. A plurality of band-pass filter members and a plurality of low-pass filter members are disposed in the waveguiding branches. The band-pass filter members transmit without substantial attenuation only electromagnetic waves having frequencies inside the band of frequencies allocated to the communication system. The low-pass filter members substantially attenuate all electromagnetic waves having frequencies greater than the highest frequency of the allocated band. At least one of the band-pass filter members and one of the low-pass filter members is disposed in each branch, so that each portion of microwave energy traveling from one waveguiding section to the other must pass through both of these filter members. In this manner the low-pass filter members substantially attenuate the signals having harmonic frequencies and which may not be substantially attenuated by the band-pass filter members. Furthermore, each waveguiding branch may be designed with a smaller cross-section than the main waveguiding sections since but a small portion of the total power travels therethrough. By so limiting the cross-section of the branches the number of possible modes of transmission of the waves is limited and the waves do not encounter the filter members in modes for which the members are not designed. Furthermore, since no filter member is inserted in the main waveguiding sections, the total power handling capacity of the communication system is not reduced by the band-pass filter apparatus of the instant invention.

The invention will be described in reference to the accompanying drawings wherein:

FIGURE 1 is a perspective view, partly in cross-section, of the filter apparatus of this invention;

FIGURE 2 is a perspective view, partly in cross-section, of a portion of the filter apparatus of FIG. 1;

FIGURE 3 is a perspective view, partly in cross-section, of a portion of the apparatus shown in FIG. 2;

FIGURE 4 is an elevational view of an additional embodiment of this invention;

FIGURE 4a is a longitudinal cross-section view of a waveguide segment of FIG. 4 showing the contained band-pass filter member; and

FIGURE 4b is a longitudinal cross-section view of a waveguide segment of FIG. 4 showing the contained low-pass filter member.

The filter apparatus of FIG. 1 transmits without substantial attenuation only electromagnetic waves having frequencies inside a frequency range, or band, defined by a lower first frequency and an upper second frequency, and substantially attenuates electromagnetic waves having frequencies outside such range. A first main waveguiding section, such as hollow rectangular waveguide section 10, receives for filtering the microwave signals provided by a microwave generator, not shown. A second main waveguiding section, such as hollow rectangular waveguide section 11, transmits for utilization the filtered output signals of the filter apparatus. A coupler, such as flange 12, is affixed to one end of waveguide section 10 for coupling the filter apparatus to the microwave generator, or to a waveguiding system which transmits microwave signals from the microwave generator to the filter apparatus. A coupler, such as flange 13, is affixed to one end of waveguide section 11 for coupling the filter apparatus to utilization apparatus, such as an antenna, or to a waveguiding system which transmits microwave signals from the filter apparatus to the utilization apparatus.

A plurality of waveguiding branches, or channels, such as hollow rectangular waveguide segments 15, couple together waveguide sections 10 and 11, so that microwave energy may be transmitted from section 10 to section 11. Each of segments 15 communicates with the interior of section 10 through an aperture 16, FIG. 2, in one broad wall of section 10, and with the interior of section 11 through an aperture 17, in one broad wall of section 11. The height, or narrow dimension, of waveguide segment 15 is substantially less than the corresponding dimension of waveguide sections 10 and 11. Each of segments 15, therefore, transfers a portion of the microwave energy propagating along section 10 to section 11.

Preferably adjacent ones of segments 15 are spaced apart along the length of waveguide sections 10 and 11 by distances equal to one-quarter of the wavelength at which microwave energy propagates along waveguide sections 10 and 11. In the embodiment of FIG. 1 the distance between centers of adjacent ones of segments 15 is equal to one-quarter waveguide wavelength of microwaves traveling along sections 10 and 11 which have frequencies equal to the middle frequency of the range of frequencies to be transmitted by the filter apparatus. Although the spacing between segments 15 is preferred as one-quarter waveguide wavelength, this spacing may be a greater odd number of quarter waveguide wavelengths in those instances wherein assembly of the filter apparatus is facilitated by a greater separation of segments 15. However, the larger spacings are employed at the expense of reduced pass band bandwidth, since the amount of coupling provided by each branch is influenced by the deviation in spacing between branches from an odd number of quarter waveguide wavelengths.

The length of each waveguide segment 15 is preferably an odd multiple of quarters of the wavelength at which microwaves propagate along the length of the segments, this odd multiple of quarter wavelengths being determined at the middle frequency of the range of frequencies to be transmitted by the filter apparatus. The choice of the quarter wavelength multiplying factor will depend upon

the maximum bandwidth to be transmitted. In general, the multiplying factor is kept small consistent with the desired attenuation in the stop band.

The structure thus far set forth describes a device known as a branch guide directional coupler, wherein each of segments 15 comprises a branch of the directional coupler. A directional coupler may be defined as two waveguides coupled together in a manner such that a single traveling wave in either waveguide will induce a single traveling wave in the other waveguide, the direction of the latter wave being determined by the direction of the former. Thus, microwaves entering waveguide section 10 at the left-hand end thereof and traveling to the right therealong are transferred to waveguide section 11 through the various waveguide segments 15 and travel to the right in waveguide section 11, leaving section 11 at the right-hand end thereof. However, it is only waves in the design frequency range that the branch guide directional coupler transmits unattenuated from input to output terminal. Waves having frequencies outside the design range are not coupled entirely to waveguide 11 and, consequently, a portion thereof continue to travel to the right in waveguide section 10. Such uncoupled waves are absorbed in a matched termination 20 disposed in the right-hand end of section 10. The portions of the waves having frequencies outside the design range which are transferred to waveguide section 11 do not all travel to the right therein, but, instead, some of these waves travel in the reverse direction and are absorbed in matched termination 21 disposed in the left-hand end of section 11.

Thus, the basic structure of FIG. 1 which defines a branch guide directional coupler performs a simple filtering function. However, the attenuation provided outside the design frequency range is not sufficiently great for the branch guide directional coupler, alone, to be satisfactory as a filter. Instead, additional means must be provided for strongly attenuating signals having frequencies lying immediately outside the design range and frequencies far removed from the design range.

Because of the reduced height of segments 15, all modes of wave transmission cannot pass through the segments. Therefore waves in these prohibited modes, which may be introduced in section 10, will continue to the right therein to be absorbed in termination 20.

In the instant invention, the design of the basic structure of FIG. 1 is in accordance with the principles for designing a branch guide directional coupler to transmit the entire input wave of design frequency. Such a structure is known as a 0-db directional coupler, which signifies that there is no loss, due to attenuation, directional characteristics, or other means, for the design frequency wave in passing through the apparatus. The techniques for the design of branch guide directional couplers, and accordingly the basic structure shown in FIG. 1, are described in an article by L. Young "Branch Guide Directional Couplers," Proceedings of the National Electronics Conference 1956, pages 723-732, and in an article by J. Reed, "The Multiple Branch Waveguide Coupler," IRE Transactions on Microwave Theory and Techniques, October 1958, pages 398-403.

The additional means provided, other than the simple filtering action of the branch guide directional coupler structure, for strongly attenuating signals having frequencies lying immediately outside the design range and frequencies far removed from the design range are the band-pass filter members 24 and the low-pass filter members 25 (FIG. 3). In the embodiment of FIGS. 1-3, each of waveguide segments 15 comprises a band-pass filter member 24 and a low-pass filter member 25 disposed in cascade between waveguide sections 10 and 11. In this manner each portion of the microwave energy transferred from section 10 to section 11 passes through both types of filter members. Bandpass filter member 24 transmits without substantial attenuation only electromagnetic

waves having frequencies inside the design range and strongly attenuates waves having frequencies immediately outside the design range. Low-pass filter member 25 substantially attenuates all electromagnetic waves having frequencies greater than the highest frequency of the design range and strongly attenuates spurious signals harmonically related to frequencies in the design range. Accordingly, all significant signals leaving the right-hand output end of waveguide section 11 lie only in the design range of frequencies. Thus, the novel filter of the instant invention eliminates, or reduces to an insignificant level, all signals having frequencies outside the design frequency range, regardless of their mode of transmission.

In the embodiment of FIGS. 1-3 band-pass filter member 24 comprises a plurality of spaced-apart conductive posts 27. Each of posts 27 extends between the upper and lower broad walls of segment 15 and presents an inductive reactance to the waves traveling along segment 15. The mode of design of a band-pass filter comprising a plurality of inductive elements spaced along the length of a waveguide is known in the art and is described, for example, in G. C. Southworth "Principles and Applications of Waveguide Transmission," Van Nostrand Co., Inc., New York, 1950, pages 285-303. The design of conductive posts to provide proper values of inductive reactance for employment in a filter is described in the Southworth publication at pages 255-261. Other types of reactive elements, such as irises, may be employed for providing a band-pass filter; see, for example, pages 244-250 of the Southworth publication.

Low-pass filter member 25, in the embodiment shown, is known as a varying-impedance type, wherein a series of waveguide elements of alternating characteristic impedance are connected together. Thus, filter member 25 comprises a plurality of transverse conductive ridges 29 separated by conductive troughs. The top of each ridge 29 and the upper broad wall of waveguide segment 15 define a waveguide element having a first value of characteristic impedance. The lower surface 30 of each trough and the upper broad wall of waveguide segment 15 define a waveguide element having a second value of characteristic impedance. A cascaded array of waveguide elements having alternating values of characteristic impedance may be employed as a low-pass filter member. The mode of design of a low-pass filter of this type is known in the art and is described, for example, in "Very High-Frequency Techniques," vol II, Radio Research Laboratory Staff, McGraw-Hill Book Co., Inc., New York, 1947, pages 685-721 and 731-736.

Accordingly, in the instant invention, the filter members 24 and 25 are disposed in the various branches of the directional coupler structure employed. Since only a small fraction of the total microwave power to be filtered is passed through each such branch, and since no filter member is inserted in the main waveguiding sections 10 and 11, the total power handling capacity of the communication system is not reduced by the band-pass filter apparatus of the instant invention.

In the filter apparatus embodiment of FIG. 4, only one type of filter member is disposed in each directional coupler branch in order that shorter waveguide segments which comprise the branches may be employed with a consequent increase in pass band bandwidth. A first main waveguiding section, such as hollow rectangular waveguide section 40, receives for filtering the microwave signals provided by a microwave generator, not shown. A second main waveguiding section, such as hollow rectangular waveguide section 41, transmits for utilization the filtered output signals of the filter apparatus. A coupler, such as a flange 42, is affixed to one end of waveguide section 40 for coupling the filter apparatus to the microwave generator, or to a waveguiding system which transmits microwave signals from the microwave generator to the filter apparatus. A coupler, such as flange 43, is affixed to one end of waveguiding

section 41 for coupling the filter apparatus to utilization apparatus, such as an antenna or to a waveguiding system which transmits microwave signals from the filter apparatus to the utilization apparatus.

A U-shaped intermediate waveguiding section, such as hollow rectangular waveguide section 45, functions to transfer the partially filtered microwave signals from one portion of the filter apparatus to another.

A plurality of hollow rectangular waveguide segments 47 couple together waveguide section 40 and one leg of waveguide section 45, so that microwave energy may be transmitted from section 40 to section 45. Each of segments 47 communicates with the interior of sections 40 and 45 through apertures in the respective broad walls of the two waveguide sections. A plurality of hollow rectangular waveguide segments 48 couple together waveguide section 41 and the other leg of waveguide section 45, so that microwave energy may be transmitted from section 45 to section 41. Each of segments 48 communicates with the interior of sections 45 and 41 through apertures in the respective broad walls of the two waveguide sections. The height, or narrow dimension of waveguide segments 47 and 48 is substantially less than the corresponding dimension of waveguide sections 40, 41, and 45. Thus, each of segments 47 transfers a portion of the microwave energy propagating along section 40 to section 45 and each of segments 48 transfers a portion of the microwave energy propagating along section 45 to section 41.

Preferably, adjacent ones of segments 47 are spaced apart along the length of waveguide sections 40 and 45 by distances equal to one-quarter of the wavelength at which microwave energy propagates along waveguide sections 40 and 45. Segments 48 are similarly spaced apart along the length of waveguide sections 41 and 45. Although the spacing between adjacent ones of segments 47 and between adjacent ones of segments 48 is preferred as one-quarter waveguide wavelength at the middle frequency of the range of frequencies to be transmitted by the filter apparatus, this spacing may be a greater odd number of quarter waveguide wavelengths in those instances wherein assembly of the filter apparatus is facilitated by a greater separation of these segments. Employing the greater spacing is again accompanied by a reduction in pass band bandwidth.

The length of each of waveguide segments 47 and 48 is preferably an odd multiple of quarters of the wavelength at which microwaves propagate along the length of the segments, this odd multiple quarter wavelengths being determined at the middle frequency of the range of frequencies to be transmitted by the filter apparatus. Again, if assembly is facilitated, the length of segments 47 and 48 may be a greater odd multiple of quarter waveguide wavelengths; however, in the embodiment of FIG. 4 the waveguide segments employed need not be as long as those in the embodiment of FIGS. 1, 2, and 3 since only one filter member is disposed in each of segments 47 and 48, whereas a pair of filter members are disposed in each of segments 15.

As described in connection with FIG. 1, each of segments 47 and 48 comprises a branch of one of two branch guide directional couplers. Thus, microwaves entering section 40 at the upper end thereof and traveling downward therealong are transferred to the left-hand leg of waveguide section 45 through the various waveguide segments 47 and travel downward along section 45. Microwaves traveling upward in the right-hand leg of section 45 are transferred to waveguide section 41 through the various waveguide segments 48 and travel upward in section 41, leaving section 41 at the upper end thereof. Waves having frequencies outside the design range of the branch guide directional couplers described are not coupled entirely into the respective sets of waveguide segments and, consequently, a portion of

such waves continue to travel along the original waveguides in which they entered the directional couplers. Such uncoupled waves are absorbed in a matched termination member 50 disposed at the lower end of section 40 and in the matched termination member 51 disposed at the upper end of the right-hand leg of section 45. Again, the portions of the waves having frequencies outside the design range, which are transferred through the two sets of waveguide segments of the respective directional couplers, do not all travel in the forward direction after transfer. Instead, some of these waves travel in the reverse direction. These reverse traveling waves are absorbed in matched termination member 52 disposed at the upper end of the left-hand leg of section 45 and in matched termination member 53 disposed at the lower end of section 41.

Because of the reduced height of segments 47 and 48, all modes of wave transmission can not pass through the segments. Therefore, waves in these prohibited modes, which may be introduced in section 40, will continue downward therein to be absorbed in termination member 50. Similarly, waves in these prohibited modes, which may be introduced in section 45 will continue upward in the right-hand leg thereof to be absorbed in termination member 51.

Additional means is provided in the embodiment of FIG. 4, other than the simple filtering action of the respective branch guide directional coupler structures, for strongly attenuating signals having frequencies lying immediately outside the design range and frequencies far removed from the design range. Such additional means are band-pass filter members and low-pass filter members of the type described in connection with the embodiment of FIGS. 1-3. Thus, a band-pass filter member, such as band pass filter member 24, is disposed in each of waveguide segments 47, FIG. 4A. A low-pass filter member, such as low-pass filter member 25, is disposed in each of waveguide segments 48, FIG. 4B. In this manner the input waves transferred through segments 47 and entering the left-hand leg of section 45 have frequencies inside the design range of frequencies substantially unaffected, but have frequencies immediately outside the design range strongly attenuated. These partially filtered waves in section 45 then pass through waveguide segments 48, wherein the low-pass filter members strongly attenuate spurious signals harmonically related to frequencies in the design range. Accordingly, all significant signals leaving the upper end of waveguide section 41 lie only in the design range of frequencies. The novel filter of the embodiment of FIG. 4 eliminates, or reduces to an insignificant level, all signals having frequencies outside the design range, regardless of their mode of transmission.

While the principles of the invention have now been made clear in an illustrative embodiment, there will be immediately obvious to those skilled in the art many modifications in structure, arrangement, proportions, the elements, materials, and components used in the practice of the invention, and otherwise, which are particularly adapted for specific environments and operating requirements, without departing from those principles. The appended claims are therefore intended to cover and embrace any such modifications, within the limits only of the true spirit and scope of the invention.

What is claimed is:

1. A filter for transmitting, without substantial attenuation, electromagnetic waves having frequencies inside a frequency range defined by a lower first frequency and an upper second frequency, and for substantially attenuating electromagnetic waves having frequencies outside said range, comprising:

- first and second waveguiding sections;
- a plurality of waveguiding segments coupling said waveguiding sections together;

a plurality of band-pass filter members, each comprising a plurality of spaced reactive elements, for transmitting without substantial attenuation electromagnetic waves having frequencies inside said range; and,

a plurality of low-pass filter members, each comprising a series of elements of alternating characteristic impedance, for substantially attenuating all electromagnetic waves having frequencies greater than said second frequency;

said filter members being disposed in said segments such that each portion of said electromagnetic waves traveling from said first section to said second section through such segments passes through at least one of said band-pass filter members and at least one of such low-pass filter members.

2. The filter of claim 1 further including means for coupling electromagnetic waves into one end of said first section and means for removing electromagnetic waves from one end of said second section.

3. The filter of claim 2, wherein the cross-sectional area of each of said waveguiding segments is less than the cross-sectional area of said waveguiding sections.

4. A filter for transmitting, without substantial attenuation, electromagnetic waves having frequencies inside a frequency range defined by a lower first frequency and an upper second frequency, and for substantially attenuating electromagnetic waves having frequencies outside said range, comprising:

first and second waveguiding sections;

a plurality of waveguiding channels coupling said sections together;

a plurality of band-pass filter member, each comprising a plurality of spaced reactive elements, for transmitting without substantial attenuation only electromagnetic waves having frequencies inside said range; and,

a plurality of band-pass filter members, each comprising a series of elements of alternating characteristic impedance, for substantially attenuating all electromagnetic waves having frequencies greater than said second frequency;

at least one of said band-pass filter members and one of said low-pass filter members being disposed in each of said channels.

5. Band-pass filter apparatus for transmitting without substantial attenuation electromagnetic waves having frequencies inside a frequency range defined by a lower first frequency and an upper second frequency, comprising:

first and second rectangular waveguide sections;

a plurality of rectangular waveguide segments coupling said sections together, the transverse height of each of said segments being less than the transverse height of said sections;

a plurality of band-pass filter members, each comprising a plurality of spaced reactive elements, for transmitting without substantial attenuation only electromagnetic waves having frequencies inside said range; and,

a plurality of low-pass filter members, each comprising a series of elements of alternating characteristic impedance for substantially attenuating all electromagnetic waves having frequencies greater than said second frequency;

at least one of said band-pass filter members and one of low-pass filter members being disposed in each of said segments.

6. Band-pass filter apparatus for transmitting without substantial attenuation electromagnetic waves having frequencies inside a frequency range defined by a lower first frequency and an upper second frequency, comprising:

- first and second rectangular waveguide sections;
- a plurality of first rectangular waveguide segments coupling said first and second sections together,

third and fourth rectangular waveguide sections;
 a plurality of second rectangular waveguide segments
 coupling third and fourth waveguide sections to-
 gether;
 the cross-sectional height of each of said segments being 5
 less than the cross-sectional height of said sections;
 means for coupling one end of said second waveguide
 section to one end of said third waveguide section;
 a plurality of band-pass filter members, each compris- 10
 ing a plurality of spaced reactive elements for trans-
 mitting without substantial attenuation only electro-
 magnetic waves having frequencies inside said range,
 one of said band-pass filter members being disposed
 in each of said first waveguide segments; and,
 a plurality of low-pass filter members, each comprising 15
 a series of elements of alternating characteristic im-
 pedance, for substantially attenuating all electro-

magnetic waves having frequencies greater than said
 second frequency, one of said low-pass filter mem-
 bers being disposed and each of said second wave-
 guide segments.

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