Dec. 9, 1947. A. G. FOX 2,432,093

WAVE TRANSMISSION NETWORK

Filed July 30, 1942 3 Sheets-Sheet 1

FIG. 1

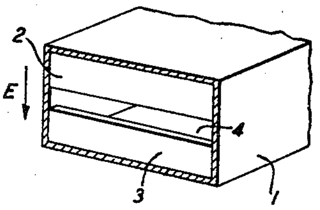

FIG. 2

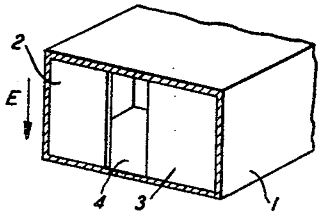

FIG. 3

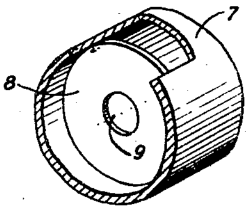

FIG. 4

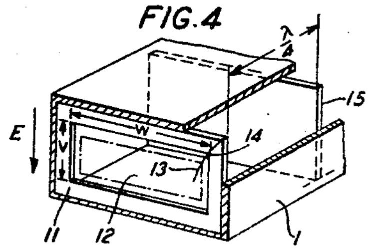

FIG. 5

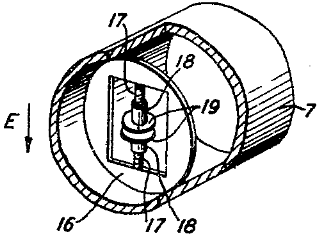

FIG. 6

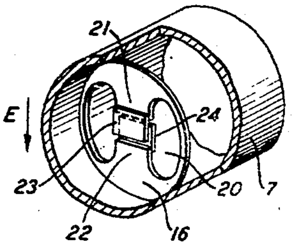

FIG. 7

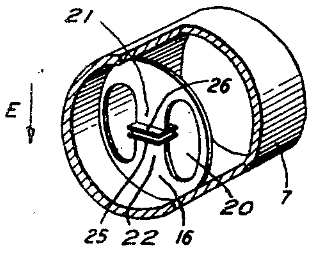

FIG. 8

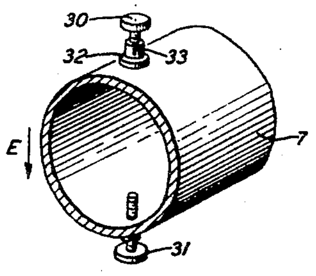

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FIG. 9

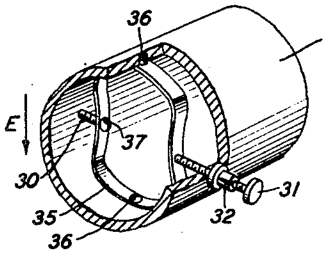

FIG. 10

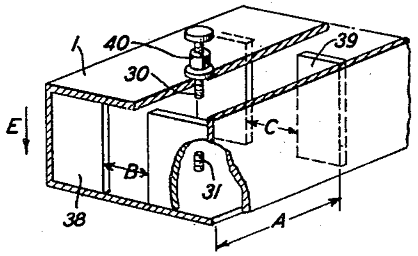

FIG. 11

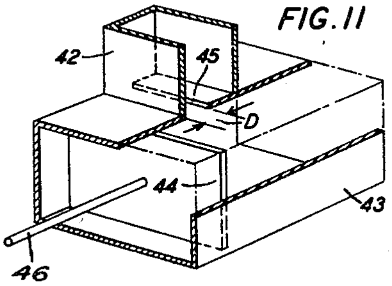

FIG. 12

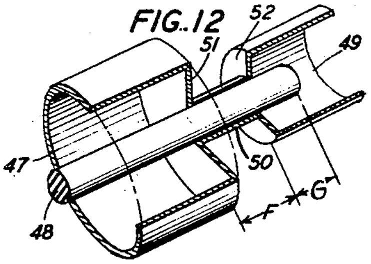

FIG. 15

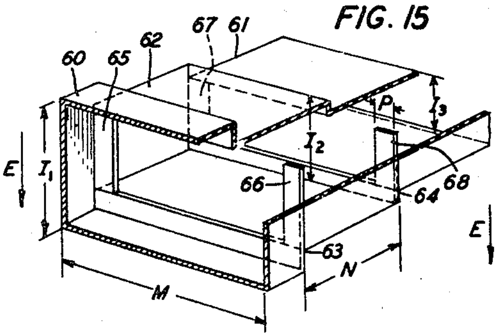

FIG. 16

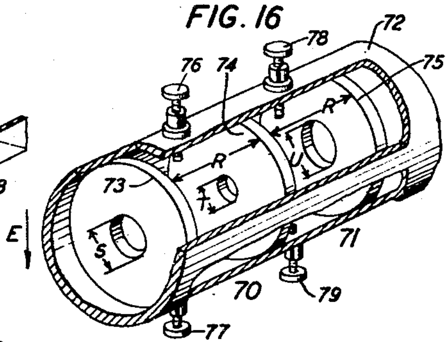

FIG. 17

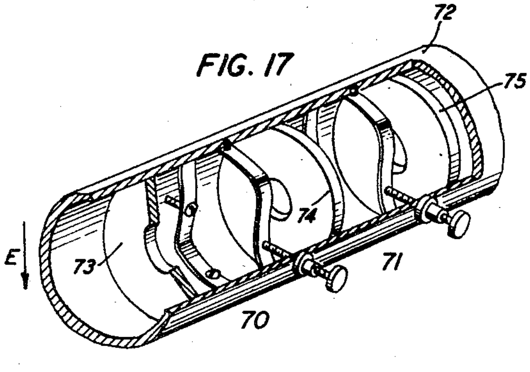

FIG. 18

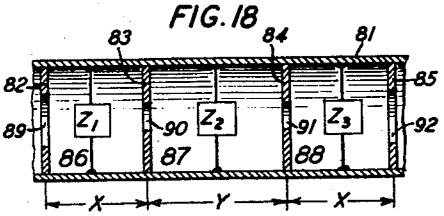

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FIG. 19

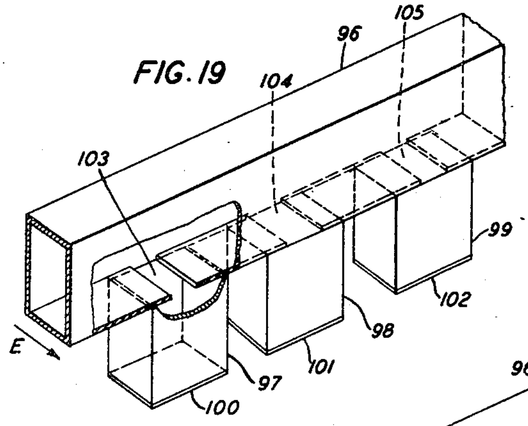


FIG. 20

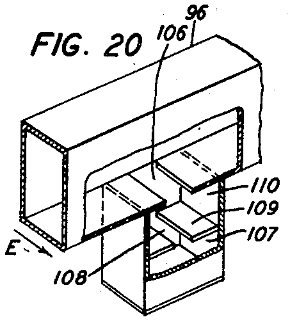


FIG. 21

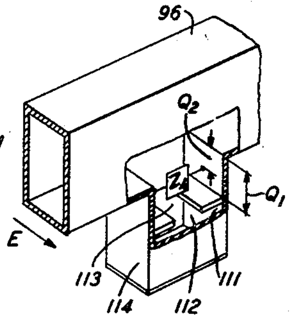


FIG. 13

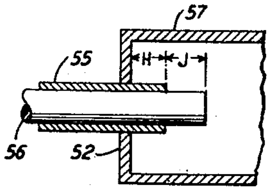


FIG. 22

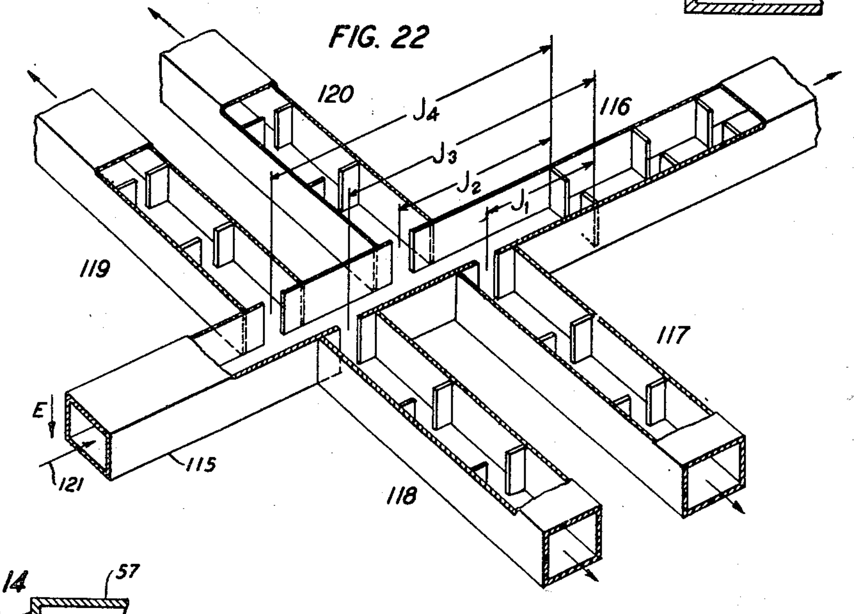
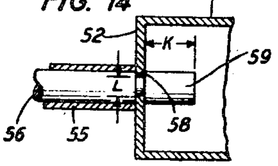


FIG. 14



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UNITED STATES PATENT OFFICE

2,432,093

WAVE TRANSMISSION NETWORK

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Application July 30, 1942, Serial No. 452,851

39 Claims. (Cl. 178—44)

This invention relates to wave transmission networks and more particularly to frequency selective networks for use in the transmission of guided electromagnetic waves.

An object of the invention is to transmit freely a band of guided electromagnetic waves while effectively blocking waves falling outside of the band.

Another object is to separate electromagnetic waves into individual channels on a frequency basis.

A further object is to connect without appreciable reflection two wave guides which differ in characteristic impedance.

Another object is to provide simple series resonant impedance branches and simple parallel resonant impedance branches for use in wave guides.

A further object of the invention is to provide variable capacitors and variable inductors for use in wave guides.

A uniform metallic sheath with or without a dielectric filler will serve as a guide for suitable electromagnetic waves. In cross section the sheath may be circular, rectangular, or of other shape. For all frequencies above a minimum, known as the cut-off frequency, the guide acts like a transmission line and has a specific propagation constant and characteristic impedance. For any particular frequency there are an infinite number of cross-sectional sizes and shapes of guide which will have the same characteristic impedance.

Shunt reactive elements are obtained by placing partial obstructions across the wave guide. In accordance with the present invention, shunt reactive elements for dominant transverse electric waves are obtained by using a transverse metal partition having a slit therein which extends substantially from one side to the other. If the slit is perpendicular to the direction of polarization of the electric field the element is primarily capacitive, and if parallel with the field the element is primarily inductive. If the slot is replaced by a centrally located square or circular opening, the reactance will still be dominantly inductive.

For a rectangular guide a rectangular opening in the partition may be proportioned to provide parallel resonance, that is, a high shunt impedance. The resonance may be sharpened by providing inwardly extending projections on opposite sides of the rectangular opening. A series resonance may be provided by making the slot sufficiently narrow. A wider opening may be used if the op-

posed edges of the slot are made thicker, or if the two halves of the partition are made to overlap.

A variable capacitor is provided by a pair of opposed diametral screws extending through the guide wall in the direction of the field. A variable inductor is provided by a strip of spring metal which is placed inside the guide and normally extends around the inner surface. Adjustment is made by means of a pair of opposed diametral screws perpendicular to the field which force the strip away from the wall as they are screwed in.

In accordance with the invention, the reactive elements just described are combined with sections of a wave guide to provide transmission networks such, for example, as wave filters and transformers. A simple filter is formed by inserting two apertured partitions in a guide at a properly chosen distance apart. A variable reactor placed at an intermediate point facilitates the adjustment of the characteristics of the filter. By proper adjustment of the apertures the filter may be made an impedance transforming network for connecting two guides of different characteristic impedance.

An impedance transforming bend is disclosed in which reflectionless transmission is obtained by the addition of a metallic flap which is used to provide the required aperture at the junction of the two guides. There is also shown a transformer for connecting an air-filled tubular guide to a guide having a dielectric core, in which the core extends into the end of the air-filled guide. A quarter-wave transformer is disclosed in which the capacitative reactance at the points of junction is neutralized by the addition of metallic flaps to constrict the apertures.

Filters with improved transmission characteristics are formed by connecting two or more chambers in tandem. The chambers may be tuned by means of variable reactors.

Band suppression filters with improved transmission characteristics are formed by providing two or more branch chambers spaced along the wave guide. Alternatively, a plurality of coupled chambers may be used in a single branch. For certain effects a variable reactor may be connected in the side branch at some point between the first apertured partition and the point of juncture between the branch and the main guide.

Also, in accordance with the invention, it is shown how a plurality of band-pass filters opening into a common wave guide may be arranged so that each filter will select a certain desired band of frequencies without adversely affecting transmission in the other channels.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, in which like reference characters refer to similar parts and in which:

Figs. 1, 2 and 3 are perspective views of wave guides having therein partitions with apertures which provide reactive elements;

Fig. 4 shows a partition with an aperture proportioned for parallel resonance;

Fig. 5 shows an impedance element that may be adjusted for either parallel or series resonance;

Figs. 6 and 7 show series-resonant elements;

Fig. 8 shows a variable capacitative reactor;

Fig. 9 shows a variable inductive reactor;

Fig. 10 is a perspective view, partly cut away, of a single-chamber wave guide filter with an adjustable reactor;

Fig. 11 shows an impedance transforming bend for a wave guide;

Figs. 12, 13 and 14 show transformers for connecting an air-filled wave guide to a guide having a solid dielectric core;

Fig. 15 shows a neutralized quarter-wave transformer;

Fig. 16 shows a two-chamber filter with variable capacitive reactors;

Fig. 17 shows a two-chamber filter with variable inductive reactors;

Fig. 18 shows a three-chamber filter;

Fig. 19 shows a band suppression filter comprising three branch chambers;

Fig. 20 shows a band suppression filter comprising two coupled chambers in a single branch;

Fig. 21 shows a side branch with a variable reactor; and

Fig. 22 shows five band-pass filters branching from a common wave guide.

Taking up the figures in more detail, Fig. 1 is a perspective view of a section of a metallic wave guide 1, in the form of a rectangular sheath, which has been cross-sectioned just ahead of a transverse, metallic partition comprising an upper portion 2 and a lower portion 3 with an aperture 4 therebetween extending from one side of the guide to the other. If the guide 1 is carrying dominant transverse electric waves with the electric field E polarized in a direction perpendicular to the length of the aperture 4, as indicated by the arrow, the partition will provide a shunt capacitive reactance. The magnitude of this reactance depends upon the width of the aperture 4 in the direction of the electric field E and decreases as the width is decreased.

Fig. 2 is similar to Fig. 1 except that the aperture 4 extends from the top to the bottom of the guide 1 and has its length parallel to the direction of the electric field E. A partition of this type provides a shunt inductive reactance the magnitude of which also decreases as the width of the aperture 4 decreases.

Fig. 3 is a perspective view, partly cut away, of a section of a circular wave guide 7 with a transverse partition 8 having a central circular aperture 9. This type of partition also provides a shunt inductive reactance which decreases as the diameter of the aperture 9 is decreased.

By properly proportioning the aperture, a partition in a wave guide may be made to provide both inductive and capacitive components in the right amounts to resonate at a particular frequency. This may be either a parallel resonance or a series resonance. For example, Fig. 4 shows a parallel-resonant element, that is, one providing a high shunt impedance, in a rectangular wave guide 1. The partition 11 has a symmetrically placed aperture 12 having a height V in a direction parallel to the electric field E and a width W perpendicular thereto. There are an infinite number of different apertures which will produce parallel resonance, but once either the height V or the width W has been chosen, then the other dimension is thereby determined. The line 13 gives the locus of the upper right-hand corner 14 of all possible rectangular apertures that will provide parallel resonance in the wave guide 1.

Associated with each height V of the aperture 12 in the parallel-resonant element shown in Fig. 4 there will be a resistance which is effectively shunted across the guide 1. The value of this resistance decreases as the dimension V decreases and its range may extend from a small fraction of the characteristic impedance of the guide 1 to infinity. It is possible, therefore, to design a particular resonant aperture which will have a shunt resistance equal to the characteristic impedance of the guide. Such an element placed in the guide and followed by a solid metallic partition such as 15 placed one quarter of a wave-length behind the element 11 will serve as a reflectionless termination for the guide 1. A termination of this type uses no conventional resistance elements. The power is dissipated by high circulating currents in the metal partition 11 which has high thermal conductivity and is in metallic contact with the walls of the guide 1 and therefore is capable of dissipating a large amount of power. The element 11, when used in a termination of the type described, is preferably made of a metal having comparatively low electrical conductivity such, for example, as iron, since it is thereby possible to make the aperture larger.

Fig. 5 shows a circular guide 7 having therein an impedance element which may be adjusted for either parallel resonance or series resonance. The partition 16 has a rectangular aperture into which project a pair of threaded studs 17 having their axes along a diameter of the guide 7 and parallel to the electric field E. The two internally threaded sleeves 18, each with a circular metal plate 19 fastened to one end, may be screwed onto the studs 17. The separation between the plates 19 may thus be adjusted as desired. For series resonance only a small separation is required. For parallel resonance the spacing will be greater, and in this case the plates 19 may not be required. An advantage of using an aperture with one or more inwardly extending projections, as shown in Fig. 5, is that sharper resonances may be obtained.

Fig. 6 shows an element more particularly adapted for series resonance, providing a low shunt impedance. The partition 16 has a symmetrical aperture 20 having its length perpendicular to the electric field E and its width constricted toward the center by means of the inwardly extending projections 21 and 22, to which are attached, on opposite sides of the partition 16, two overlapping metallic flaps 23 and 24. These flaps 23 and 24 may be bent toward or away from each other to adjust the spacing therebetween and thereby the resonant frequency of the element.

Fig. 7 shows a modification of the series-resonant element of Fig. 6 in which the flaps 23 and 24 are replaced by two opposing metallic plates 25 and 26 which are perpendicular to the partition

16 and attached to the ends of the projections 21 and 22.

Since a metallic obstruction in a wave guide usually produces a point of low potential and high current, it is preferable that the partition be secured to the walls of the guide by soldering, welding or in some other appropriate manner such that a good electrical contact is obtained. It should also be noted that thinner partitions than those shown in the drawings will, under some circumstances, produce more satisfactory results. The partitions have been shown thicker in the drawings only in the interest of clarity.

Fig. 8 shows how a variable shunt capacitive reactance may be provided in a wave guide 7, which in this case is circular in cross section. The two machine screws 30 and 31 enter the guide through holes on opposite sides and are disposed with their axes along a diameter and parallel to the electric field E. Each screw threads into a nut, such as 32, which is soldered to the guide in line with the hole. In order to provide a good electrical contact between the screw and the guide wall the nut 32 is partially split longitudinally in one or more places, as shown at 33, and the resulting segments sprung inward to insure a tight fit. The capacitance may be increased by screwing the screws toward each other, or decreased by retracting them.

Fig. 9 is a perspective view, partly cut away, of a variable inductive reactor in a section of circular wave guide 7. The screws 30 and 31 are similar to those shown in Fig. 8 but in this case their axes are perpendicular to the electric field E. Inside of the guide 7 is a metallic strip 35, made, for example, of spring brass or silver, which is firmly attached to the guide 7 at two opposite points by the screws 36. At two other opposite points the strip 35 has holes through which a smaller screw, such as 37, passes and threads into a tapped hole in the end of the larger screw 30. When the screws 30 and 31 are retracted the strip 35 lies against the wall of the guide 7. However, as the screws 30 and 31 are screwed toward each other the strip 35 is forced away from the guide wall at two places. There is thus provided a shunt inductance which decreases in value as the screws 30 and 31 are screwed in.

There will now be described some wave guide filters and transformers which use, as component parts, the reactive impedance elements described above. Fig. 10 is a perspective view, partly cut away, of a single-chamber, adjustable band-pass filter in a rectangular guide 1. The filter comprises two shunt reactors 38 and 39 spaced apart a distance A determined by the width of the transmission band desired and the wave-length λ within the guide 1 at the mid-band frequency. For narrow bands, A will be approximately equal to $n\lambda/2$, where n is any integer. As the band width is increased, however, the spacing A may depart considerably from this value and, in fact, it will approach a value of $m\lambda/4$, where m is an odd integer. To provide the greatest discrimination between the transmitted and the suppressed frequencies A is made approximately equal to $\lambda/2$.

As illustrated, the reactors 38 and 39 are of the inductive type shown in Fig. 2, in which the slot in the partition is parallel to the electric field E. In this case, for the greatest discrimination, the distance A between the reactors must be made somewhat shorter than $\lambda/2$. Alternatively, the reactors 38 and 39 may be of the capacitive type, as shown in Fig. 1, in which case, for the greatest discrimination, A must be slightly greater than $\lambda/2$.

In order to provide means for adjusting the effective length of the chamber a variable reactor 40 is inserted in the guide 1 at a point, preferably midway, between the reactors 38 and 39. As shown, the reactor 40 is a variable capacitor of the type shown in Fig. 8. As the screws 30 and 31 are screwed in, the effective length of the chamber is increased; if they are screwed out, the effective length is decreased. Alternatively, the reactor 40 may be a variable inductor of the type shown in Fig. 9, in which case screwing the screws in will decrease, and screwing them out will increase, the effective length of the chamber.

The width of the band transmitted by the filter depends upon the distance B between the two parts of the partition 38 and the distance C between the two parts of the partition 39. The smaller these distances are made, the sharper will be the resonance and the narrower will be the band. If the filter is to be used to connect two sections of guide having the same characteristic impedances, the spacings B and C are ordinarily made approximately equal. In practice it is found desirable to start by making the openings B and C somewhat undersized. A rough check of the frequency response will show that the resonance is sharper than is desired. The openings are then enlarged in steps until the desired characteristic is attained. As the spacing is increased the tuning screws 30 and 31 are retracted slightly. When a very narrow band is required, it will be found that an impedance match looking into the filter from one direction will be obtained when the nearer aperture is made somewhat larger than the farther aperture. For example, if the wave is entering from the left in Fig. 10, B is made slightly larger than C in order to provide a characteristic impedance load for the sending end.

The guide 1 and the partitions 38 and 39 of Fig. 10, as well as the corresponding parts shown in the other figures, may be made of brass or other alloy or metal of good electrical conductivity. The transmission efficiency of the filters and transformers may be improved by silver-plating the inner surfaces of the chambers.

The filter of Fig. 10 may be made impedance transforming, so that it can be used to connect two wave guides having different characteristic impedances, by making the opening into the higher impedance guide larger than the opening into the lower impedance guide. For example, in Fig. 10, if the right-hand termination has the higher impedance, the spacing C is made larger than B. By properly adjusting the spacing B, the partition 39 may be entirely removed. This condition gives the widest possible transmission band for any particular set of guide and chamber impedances. The length A of the transformer section will, in general, depend upon the characteristic impedance of the guide 1 and the impedances of the reactors 38 and 39. However, the transmission band may be still further widened by making the characteristic impedance of the transformer section the geometric mean of the terminating impedances. In this case the partitions 38 and 39 may be reduced to flaps such as 65, 66, 67 and 68 shown in Fig. 15 and described more fully below. These flaps perform the function of neutralizing the terminal reactances.

Fig. 11 is a perspective view, partly cut away, showing how two guides 42 and 43 of unequal characteristic impedance may be connected together in a right angle without reflection. The guide 43, which has the lower characteristic impedance, extends beyond the junction and is closed by a slidable reflecting plate 44 which may be moved by means of the push rod 46. The plate 44 is located at a distance from the mid-point of the junction which, for bends in the electric plane, is equal approximately to $\lambda/2$ and, for bends in the magnetic plane, is equal approximately to $\lambda/4$. The proper location of the plate 44 is the one which gives optimum transmission and may be found by trial. There will, however, generally be reflections of energy due to a mismatch of impedances at the junction of the two guides. These reflections may be substantially eliminated by adding a metallic flap 45 by means of which the opening D of the junction aperture may be adjusted.

Fig. 12 is a perspective view, partly cut away, of a system for transforming the impedance of a wave guide having a cylindrical sheath 47 and a solid concentric core 48 of dielectric material to match the impedance of an air-filled guide having a cylindrical sheath 49. The core 48 extends beyond the end of the sheath 47 for a distance F and extends into the sheath 49 a further distance G. The intermediate cylindrical metallic sheath 50 fits around the portion F of the core 48 and is conductively connected to the sheaths 47 and 49 by means of the metallic end plates 51 and 52, respectively.

In order to match one wave guide to another one, or to any other wave medium, it is, in general, necessary to have two independent tuning controls. In the system shown in Fig. 12 these controls are the lengths F and G of the dielectric core 48. The proper adjustment may be determined as follows. One of the guides is terminated in its characteristic impedance and wave energy is supplied to the transformer in such a way that it passes through a standing wave detector located in the other guide. Then the distances F and G are adjusted, alternately, to minimize the standing wave. The desired adjustment is attained when the detector indicates an absence of any standing wave.

A special case of the system of Fig. 12 is the one in which the sheath 47 and the end plate 51 are omitted. This will generally require a readjustment of the distances F and G in order to get a proper impedance match. The protruding portion of the core 48 may now be used as a dielectric antenna for launching or collecting electromagnetic wave energy.

Fig. 13 is a cross-sectional side view of a transformer for connecting a guide having a cylindrical sheath 55 filled with a solid dielectric core 56 to a guide having a cylindrical sheath 57 filled with a material of lower dielectric constant such, for example, as air. The sheath 55 and core 56 pass through the end plate 52 and extend into the sheath 57 for a distance H. The core 56 alone extends beyond the sheath 55 for a further distance J. The transformer is tuned to transmit the desired mid-band frequency by alternately adjusting the distances H and J, as explained above, until no standing wave is detected.

Fig. 14 is a cross-sectional side view showing an alternative form of the transformer of Fig. 13. The portion H of the sheath 55 internal to the sheath 57 has been omitted and the core 56 has an annular groove 58 with an internal diameter L into which fits the end plate 52 to form a shunt impedance element. The core 56 extends into the sheath 57 for a distance K and, to facilitate assembly, this internal portion 59 may be a separate part which is attached in some suitable manner to the remainder of the core 56 after the portion having the groove 58 has been inserted into the circular hole in the end plate 52. The two variables in this transformer are the distance K and the diameter L. These are adjusted, as already explained, for no standing wave.

Although Figs. 12, 13 and 14 show wave guide structures of circular cross section, it is to be understood that, with suitable modification, the transformers may be applied to rectangular or other forms of wave guides.

Fig. 15 is a perspective view, partly cut away, of what may be termed a neutralized quarter-wave transformer for connecting two wave guides 60 and 61 which differ in size and in characteristic impedance. The guides 60 and 61 have rectangular cross sections of the same width M but differ in the cross-sectional dimensions I_1 and I_3 which are parallel to the direction of the electric field E. The guides 60 and 61 are connected by an intermediate section of guide 62 which has a length N approximately equal to a quarter wave-length, or an odd multiple thereof, at the mid-band frequency to be transmitted. The characteristic impedance of the section 62 is made approximately the geometric mean of those of the guides 60 and 61 by making its height I_2 equal to $\sqrt{I_1 I_3}$. Since the cross section of the system is changed in the direction of the electric field E at each of the junction points 63 and 64, the junctions appear like shunt capacitive reactances, of the type shown in Fig. 1. In order to neutralize these capacitive reactances the junction 63 is constricted in the magnetic direction by the addition of the flaps 65 and 66 and the junction 64 is likewise constricted by the flaps 67 and 68. These flaps are made of proper width P to introduce a shunt inductive reactance which, at the mid-band frequency to be transmitted, is equal in magnitude but opposite in sign to the associated capacitive reactance. In this way each junction 63 and 64 is converted into a parallel resonant shunt reactance of the type shown in Fig. 4.

Fig. 16 is a perspective view, partly cut away, of a band-pass wave guide filter comprising two resonant chambers 70 and 71 connected in tandem. The cylindrical metallic sheath 72 has three partitions 73, 74 and 75 with a spacing R equal approximately to a half wave-length, or an integral multiple thereof, at the mid-band frequency to be transmitted. The partitions 73, 74 and 75 have centrally located circular apertures designated by their diameters S, T and U respectively. In order to permit an adjustment of the effective length R of the chamber, a pair of oppositely disposed tuning screws 76 and 77 is provided for the chamber 70 and a second similar pair 78 and 79 for the chamber 71.

The filter of Fig. 16 will, in general, have two peaks of transmission, the frequency separation between which will be decreased as the aperture T in the intermediate partition 74 is decreased in size. For a sufficiently small aperture T the two peaks of transmission will fuse into a single peak. As the aperture T is decreased in size it will be necessary to increase the effective length R of each chamber by screwing in the tuning screws 76, 77, 78 and 79 in order to maintain the same mid-band frequency. On the other hand, to broaden the transmission band, the aperture T is enlarged and the screws 76, 77, 78 and 79 are retracted.

After the desired separation between transmission peaks has been obtained by an adjustment of the aperture T, as described above, the valley between the peaks may be filled in, and thus a more uniform transmission characteristic within the band provided, by increasing the size of the apertures S and U in the end partitions **73** and **75**, respectively. As the apertures S and U are increased in size, the chambers are retuned by retracting the tuning screws **76**, **77**, **78** and **79**, in order to maintain the same mid-band frequency. Of course, the opposite adjustment may also be made. That is, the apertures S and U may be decreased in size and the tuning screws screwed in.

As long as the width of the transmission band exceeds, say, one per cent of the mid-band frequency, the end apertures S and U are kept about the same size. For narrower bands, however, it will usually be found that a characteristic impedance termination for the sending end may be obtained by making the aperture farthest away from the source of the wave energy smaller than the aperture nearest the source. For example, in the filter shown in Fig. 16 if the waves enter from the left, the aperture U is made smaller than the aperture S. At the same time the effective length R of the first chamber **70** is preferably made shorter than that of the second chamber **71**. This adjustment is accomplished either by retracting the screws **76** and **77** or by screwing in the screws **78** and **79**.

It should be noted that the mid-band frequency of the transmission band may be moved in one direction or the other by adjusting the four tuning screws. With the apertures S, T and U fixed in size, the mid-band may be moved to a lower frequency by screwing in the screws **76**, **77**, **78** and **79**, and it may be moved to a higher frequency by retracting all four of the screws. To increase the height of one transmission peak and decrease the height of the other transmission peak, the screws associated with one chamber, for example, **76** and **77**, may be screwed in while the screws **78** and **79**, associated with the other chamber, are retracted.

Fig. 17 shows a two-chamber filter similar to the one shown in Fig. 16 except the variable reactors are of the inductive type shown in Fig. 9. The apertures in the partitions **73**, **74** and **75** may be made larger or smaller, as explained in connection with Fig. 16, for the same purposes. In this case, however, to adjust the effective lengths of the chambers **70** and **71** the tuning screws are screwed in when in the filter of Fig. 16 they would be retracted, and they are retracted when in Fig. 16 they would be screwed in. The filter of Fig. 17 may be designed and adjusted to give substantially the same type of transmission characteristic as that obtainable with the filter of Fig. 16.

By using three or more coupled chambers connected in tandem a filter with three transmission peaks, a more uniform transmission characteristic, and sharper cut-offs may be obtained. Fig. 18 is a cross-sectional view, partly diagrammatic, showing, as an example, a three-chamber filter comprising a cylindrical metallic sheath **81** with two end partitions **82** and **85** and two spaced intermediate partitions **83** and **84** which divide the guide into two end chambers **86** and **88** and an intermediate chamber **87**. The two end partitions **82** and **85** have centrally located circular apertures **89** and **92**, respectively, which are ordinarily of approximately the same size and larger than the ordinarily equal-sized apertures **90** and **91** in the intermediate partitions **83** and **84**, respectively. Also, the end chambers **86** and **88** will usually have equal lengths X while the intermediate chambers, such as **87**, will have a somewhat longer length Y. As shown, the three chambers **86**, **87** and **88** have the shunt impedances Z_1, Z_2 and Z_3, shown diagrammatically, connected at the respective mid-points. These impedances Z_1, Z_2 and Z_3 may, for example, be of the type shown in Fig. 8 or Fig. 9 and are preferably made variable so that the effective length of the associated chamber may be properly adjusted in the manner already explained.

The following adjustment procedure is suggested for the three-chamber filter of Fig. 18. The end chambers **86** and **88** are given a length X of approximately a half wave-length, or an integral multiple thereof, at the mid-band frequency to be transmitted and are individually tuned by means of the variable reactances Z_1 and Z_3 so that the primary transmission peak will occur at the desired mid-band freqeuncy. The end chambers **86** and **88** are then assembled on either side of the central chamber **87** which, for a three-peak filter, is given a length Y of approximately a half wave-length, or an integral multiple thereof, at the mid-band frequency. The effective length of the central chamber **87** is then tuned by means of the variable reactance Z_2 until the two secondary transmission peaks are spaced at equal distances on either side of the primary peak. Next, the apertures **90** and **91** in the intermediate partitions **83** and **84** are adjusted in unison to give the desired band width. Finally, the apertures **89** and **92** in the end partitions **82** and **85** are adjusted in unison to produce a flat band.

The filter of Fig. 18 may be given a two-peak characteristic by making the length Y of the central chamber approximately equal to an odd integral multiple of a quarter wave-length at the mid-band frequency. This relegates one secondary peak nearly to zero or infinite frequency and brings the other secondary peak nearly into coincidence with the primary peak. By a proper adjustment of Z_2 these two last-mentioned peaks may be separated by the required amount to give the desired band width. All four of the apertures **89**, **90**, **91** and **92** are then adjusted to obtain a uniform transmission characteristic within the band.

Fig. 19 is a perspective view, partly cut away, of a band-suppression filter comprising a rectangular wave guide **96** and three tuned side-branch chambers **97**, **98** and **99**. The chambers are closed at their outer ends by the end plates **100**, **101** and **102**, respectively, and open into the guide **96** through the apertures **103**, **104** and **105**. The centers of the apertures **103**, **104** and **105** are spaced from each other approximately a quarter of a wave-length, or an odd integral multiple thereof, at the mid-frequency of the band to be suppressed. As in the other figures the electric field E of the dominant transverse electric waves is polarized in the direction indicated by the arrow. Each of the branch chambers **97**, **98** and **99** is tuned to resonate at the mid-band frequency by properly choosing its length, and the resonance is made as sharp as desired by a proper choice of the width of the associated aperture **103**, **104** or **105**. The three-branch filter shown may be designed to have high attenuation at the mid-band frequency and, on each side thereof, a frequency of substantially perfect transmission, giving very sharp cut-offs.

It will be understood, of course, that either more or less than three side-branch chambers may be used. Furthermore, the chambers may branch from any of the four sides of the wave guide **96**, although it will usually be preferable to place them along the sides which are parallel to the electric field E, as shown. The chambers may be tuned to different resonant frequencies to increase the width of the suppression band. For example, two chambers, tuned to slightly different frequencies, may be used to provide two peaks of attenuation with sustained attenuation between. If a still wider band is desired, any one or all of the branches **100**, **101** and **102** may be replaced by side branches of the type shown in Fig. 21, described below.

Fig. 20 shows another form of band-suppression filter comprising a side-branch chamber **110**, opening into the guide **96** through the aperture **106**, and a second chamber **107**, coupled to the chamber **110** through the aperture **108** in the partition **109**. Each of the chambers **107** and **110** is tuned to resonate at the mid-band frequency. The filter will have two attenuation peaks the spacing between which depends upon the size of the aperture **108**.

Fig. 21 shows a wave guide filter using a modified form of side branch **114** which may be designed either to transmit or to suppress a narrow band of frequencies. The branch **114** comprises an end chamber **111** opening through an aperture **112** into a side-branch section **113** of length Q_1 which connects the chamber **111** with the main wave guide **96**. Shunted across the section **113** at a distance Q_2 from the side of the main guide **96** is a reactive impedance branch Z_4 which may, for example, be of the type shown in Fig. 8 or Fig. 9. As already mentioned in connection with Fig. 19, two or more branches **114** may be used to provide a wider band.

The adjustment of the filter of Fig. 21 is as follows. First, the end chamber **111** is tuned to resonate at the desired mid-band frequency. Then, for a band-pass characteristic, the length Q_1 of the section **113** is adjusted until waves of the mid-band frequency travelling through the main guide **96** are freely transmitted. The distance Q_2 is determined by finding experimentally a point of standing wave voltage minimum within the section **113**. The frequency of the waves is now changed to a frequency considerably to one side of the mid-band and the magnitude of the reactance Z_4 adjusted to produce a peak of attenuation. If a symmetrical characteristic is desired, the value of Z_4 is found first for a frequency at a certain distance to one side of the mid-band and then for a second frequency the same distance to the other side of the mid-band. The reactance Z_4 is then set at the average of the two values thus determined. For a band-suppression characteristic the adjustment is the same as just described except that the length Q_1 is adjusted for reflection of power at the mid-band frequency, and Z_4 is adjusted for a transmission peak at a frequency to one side or the other of the mid-band.

Fig. 22 is a perspective view, partly cut away, of a branching filter arrangement for separating wave energy into individual channels on a frequency basis. The arrangement comprises a main rectangular wave guide **115** and five filters **116**, **117**, **118**, **119** and **120** each of which is connected to the guide **115** through the front aperture. As shown, the filters are of the two-chamber type shown in Figs. 16 and 17 but are of rectangular cross section instead of circular. In the interest of simplicity the variable reactances associated with the chambers are not shown. It will be understood, of course, that each filter may comprise only a single chamber, or more than two chambers. The filters **116** to **120** are of the band-pass type, with different bid-band frequencies f_1, f_2, f_3, f_4 and f_5, respectively. The corresponding wave-lengths at the mid-band frequency are λ_1, λ_2, λ_3, λ_4 and λ_5, respectively. Each filter is designed so that, at its mid-frequency, it matches the guide **115** in characteristic impedance.

One of the filters, **116**, is shown connected to the end of the guide **115**. Alternatively, the end of the guide **115** may be closed by a metal plate. In order to terminate properly the main guide **115** over the frequency range for all of the channels, each filter, with the exception of **116**, should be connected to the main guide at a point of voltage maximum for the standing wave of the mid-band frequency of that particular filter. For example, the distances J_1, J_2, J_3 and J_4 may be made equal to $\frac{1}{4}\lambda_2$, $\frac{1}{4}\lambda_5$, $\frac{3}{4}\lambda_3$ and $\frac{3}{4}\lambda_4$, respectively. Now, assuming that the energy entering the guide **115**, as indicated by the arrow **121**, includes frequencies falling within all of the bands, it will be separated by the filters **116** to **120** into five individual channels, as indicated by the outgoing arrows. If the mid-band frequencies f_1 to f_5 have sufficient separation, no filter will be appreciably affected by the presence of the other filters.

Part of the subject-matter disclosed herein is being claimed in my copending United States patent applications having the following serial numbers and filing dates: 610,956 and 610,957, filed August 17, 1945; 612,680 and 612,681, filed August 25, 1945, and 614,935 to 614,937, inclusive, filed September 7, 1945.

What is claimed is:

1. A filter for transmitting a band of guided electromagnetic waves comprising a metallic sheath, two spaced shunt reactors within said sheath, and a third shunt reactor within said sheath at a point intermediate to said two reactors, said third reactor comprising a pair of opposed screws extending through said sheath.

2. A filter in accordance with claim 1 in which each of said first-mentioned two reactors comprises a transverse partition with an aperture therein, said apertures being dissimilar.

3. A filter in accordance with claim 1 in which one of said reactors consists of means for restricting the cross-sectional area of said sheath only in a direction perpendicular to the direction of the electric field of the waves to be transmitted.

4. A filter in accordance with claim 1 in which one of said reactors comprises a transverse partition with an unsymmetrical aperture therein, the longest dimension of said aperture being substantially parallel to the direction of the electric field of the waves to be transmitted.

5. A filter in accordance with claim 1 in which one of said reactors comprises a transverse partition having an aperture which extends from one side of said sheath to the other in a direction parallel to the direction of the electric field of the waves to be transmitted.

6. A filter in accordance with claim 1 in which the axes of said screws are in line and are substantially parallel to the direction of the electric field of the waves to be transmitted.

7. A filter in accordance with claim 1 in which the axes of said screws are in line and are sub-

stantially perpendicular to the direction of the electric field of the waves to be transmitted.

8. A filter in accordance with claim 1 in which said third reactor includes a metallic strip extending around said sheath on the inside, the inner ends of said screws making physical contact with said strip and the axes of said screws being substantially perpendicular to the direction of the electric field of the waves to be transmitted.

9. A filter for transmitting a band of guided electromagnetic waves comprising a metallic sheath, two transverse apertured partitions spaced apart within said sheath to form a chamber, and means for adjusting the effective electrical length of said chamber comprising a pair of oppositely disposed screws extending through the walls of said sheath into said chamber.

10. A filter in accordance with claim 9 in which the axes of said screws are in line and are substantially parallel to the direction of the electric field of the waves to be transmitted.

11. A filter in accordance with claim 9 in which said adjusting means include a metallic strip extending around said sheath on the inside, the inner ends of said screws making physical contact with said strip and the axes of said screws being substantially perpendicular to the direction of the electric field of the waves to be transmitted.

12. A filter for transmitting a band of guided electromagnetic waves comprising a metallic sheath and two transverse partitions therein spaced apart a distance approximately equal to an integral multiple of a half wave-length for the mid-band frequency of said band, each of said partitions having an aperture therein and the areas of said apertures being unequal.

13. In combination, a filter in accordance with claim 12 and a wave guide connected to one end thereof, the larger of said apertures being the nearer to said guide, whereby said filter is adapted to provide a characteristic impedance termination for said guide.

14. A filter in accordance with claim 12 adapted to operate between unequal load impedances, the larger of said apertures being in the partition nearer to the larger load impedance.

15. A filter in accordance with claim 12 which includes a variable reactor located within said sheath at a point intermediate to said partitions.

16. A filter for transmitting a band of guided electromagnetic waves comprising a metallic sheath and three transverse partitions therein forming two chambers resonant near the mid-band frequency, each of said partitions having an aperture therein and two of said apertures differing in size.

17. A filter in accordance with claim 16 in which the apertures in the two end partitions differ in size.

18. A filter in accordance with claim 16 in which the intermediate partition has the smallest aperture.

19. A filter in accordance with claim 16 in which the size of the aperture in the intermediate partition is so small that the filter has substantially a single peak of transmission.

20. In combination, a filter in accordance with claim 16 and a wave guide connected to one end thereof, the aperture in the partition nearest to said one end being larger than the aperture in the partition farthest from said one end, whereby said filter is adapted to provide a characteristic impedance termination for said wave guide.

21. A filter in accordance with claim 16 in which the size of the aperture in the intermediate partition is adjusted to provide the filter with two transmission peaks having the desired frequency separation and the sizes of the other apertures are adjusted to fill in the valley between said peaks and thereby provide a substantially uniform transmission characteristic within said band.

22. A filter in accordance with claim 16 which includes a variable shunt reactor within said sheath at a point intermediate to two of said partitions.

23. A filter in accordance with claim 16 which includes means for adjusting the resonant frequency of one of said chambers.

24. A filter in accordance with claim 16 which includes means for adjusting the resonant frequency of each of said chambers.

25. A variable inductive reactor for use in a wave guide comprising a sheath, a metallic strip extending around said sheath on the inside and normally lying in contact therewith, means for attaching said strip to said sheath at two opposite points, and adjustable means at two other opposite points for forcing said strip away from said sheath.

26. A reactor in accordance with claim 25 in which said two points of attachment lie in a line substantially parallel to the direction of polarization of the electric field of the waves transmitted in said guide.

27. A reactor in accordance with claim 25 in which said adjustable means comprise a pair of screws.

28. A reactor in accordance with claim 25 in which said adjustable means comprise a pair of screws and locking means associated with said screws.

29. A filter in accordance with claim 16 which includes a pair of opposed screws extending through said sheath into one of said chambers.

30. A filter in accordance with claim 16 which includes a pair of opposed screws extending through said sheath into one of said chambers, the axes of said screws being substantially parallel to the direction of the electric field of the waves to be transmitted.

31. A filter in accordance with claim 16 which includes a pair of opposed screws extending through said sheath into one of said chambers, the axes of said screws being substantially perpendicular to the direction of the electric field of the waves to be transmitted.

32. A filter in accordance with claim 16 in which one of said chambers has therein a metallic strip extending around said sheath on the inside and means for adjusting the separation between said strip and said sheath at two points which lie on a line substantially perpendicular to the direction of the electric field of the waves to be transmitted.

33. A filter in accordance with claim 16 in which said chambers are tuned to different frequencies.

34. A filter in accordance with claim 16 in which the apertures in the two end partitions differ in size and said chambers have different effective electrical lengths.

35. A variable inductive reactor for use in a wave guide comprising a sheath, a metallic strip extending around said sheath on the inside and means for adjusting the separation between said strip and said sheath at two opposite points which lie on a line substantially perpendicular to the direction of the electric field of the waves to be transmitted.

36. A variable reactor in accordance with claim 35 in which said means comprise a pair of screws extending through said sheath.

37. A filter for transmitting a band of guided electromagnetic waves comprising a chamber, openings at opposite ends of said chamber and means for adjusting the effective electrical length of said chamber comprising a pair of opposed screws extending through the walls of said chamber.

38. A filter in accordance with claim 37 in which the axes of said screws are substantially parallel to the direction of the electric field of the waves to be transmitted.

39. A filter in accordance with claim 37 in which one of said openings is unsymmetrical and its longest dimension is substantially parallel to the direction of the electric field of the waves to be transmitted.

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