Jan. 19, 1960 S. B. COHN 2,922,123

DIRECTIONAL FILTERS FOR STRIP-LINE TRANSMISSIONS SYSTEMS

Filed Feb. 26, 1957 2 Sheets-Sheet 1

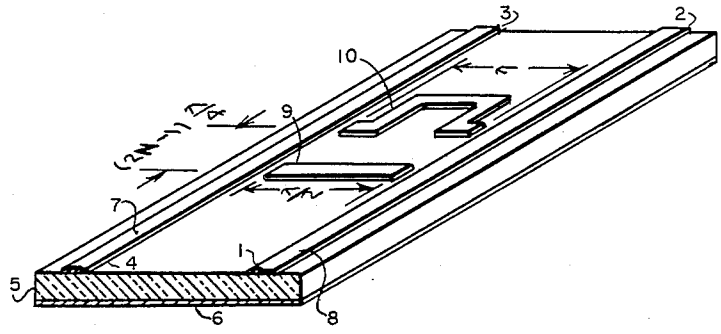


FIG. 2

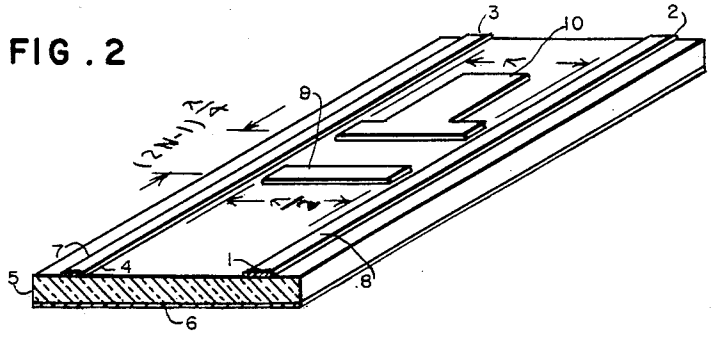


FIG. 3

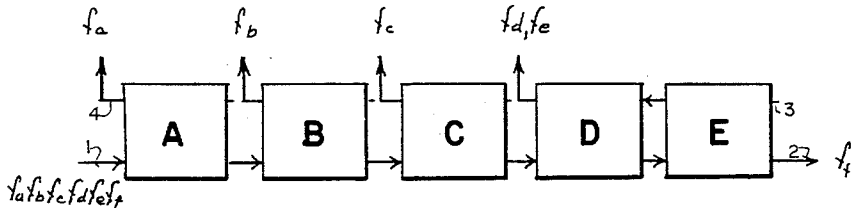


FIG. 8

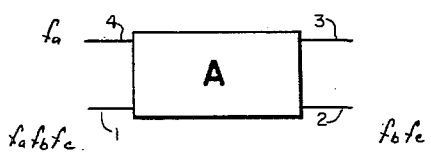


FIG. 1

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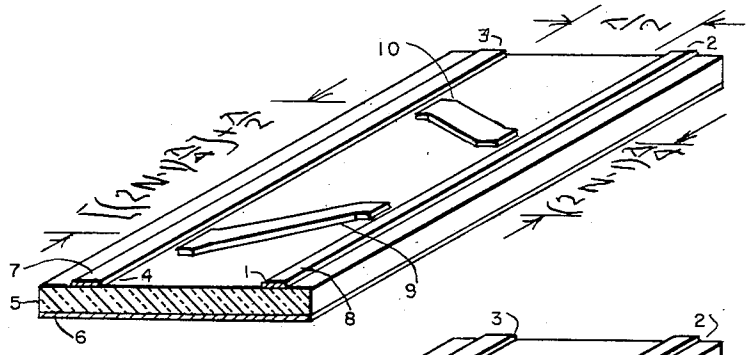


FIG. 4

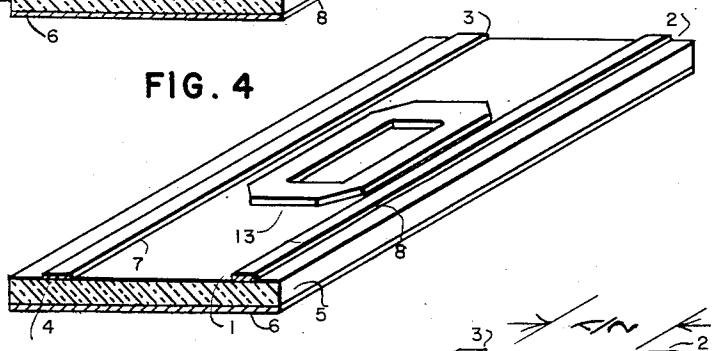


FIG. 6

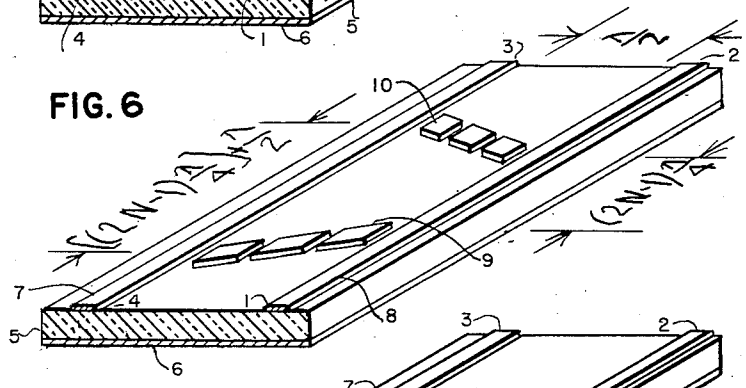


FIG. 5

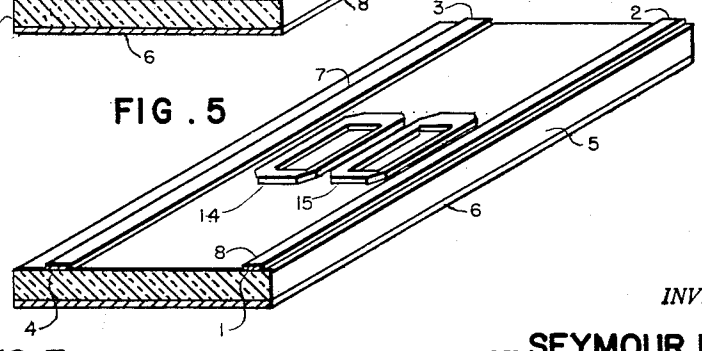


FIG. 7

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United States Patent Office 2,922,123
Patented Jan. 19, 1960

2,922,123

DIRECTIONAL FILTERS FOR STRIP-LINE TRANSMISSIONS SYSTEMS

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Application February 26, 1957, Serial No. 642,628

2 Claims. (Cl. 333—10)

The invention relates to directional filters, i.e., to filter components that have both the properties of selecting or extracting a signal having a certain band of frequencies from signals having other bands of frequencies and directing said signal into a predetermined circuit. It also relates to directional filter components designed for combining a signal of one band of frequencies with signals having other bands of frequencies and for directing the combined signals over a single circuit. More particularly, the invention relates to a directional filter component suitable for incorporation in a microwave strip-line transmission system to provide for multiplexing operations.

A strip-line transmission system is one designed for microwave transmission, and is composed of a conductor separated by a dielectric from a ground plane. The strip-line transmission lines are used primarily in short line arrangements. They may take several configurations, one of which is a wire, supported a uniform distance from a conducting surface by dielectric beads spaced along the wire at regular intervals. Another configuration, and the one used in this application to disclose the invention, is a strip of conducting material supported upon one side of a sheet of dielectric material, the opposite side of which is covered with a conducting material. Still another configuration of a strip-line transmission system provides a strip of conducting material immersed within a dielectric material supported upon a conducting surface. Other configurations of strip-line transmission systems are possible and for further information concerning their nature and characteristics reference is made to Proceeding of I.R.E. No. 40, December 1952, page 1644 ff.

A directional filter component of the type herein to be disclosed is characterized by having four arms, each composed of terminal pairs to which connections may be made for coupling input and output circuits. One arm is to have the response of a band-pass filter, another, the response of a band-rejection filter and a third a zero response. The fourth arm is used as the input arm. Regardless of which arm is used as the input arm the other arms have the aforementioned properties. When all of the arms are connected to their characteristic impedances there will be no reflection of energy within the filter component.

A directional filter component of this type is useful in multiplexing systems for performing multiplexing operation, i.e., for combining and separating signals having different bands of frequencies. It may be desirable in a microwave transmission system to transmit a large number of signals from a single antenna or over a single circuit. In this instance, directional filter components designed for passing different bands of frequencies, would be connected together to form a multiplexing system. The signals to be combined would be fed to the separate filter components wherein they are combined with other signals fed to these components and the combined signals would be fed from the multiplexing system to the antenna or common circuit. The same arrangement of filter components forming a multiplexing system is used at the receiving end of the system. There the combined signals

are received over the antenna or common circuit and fed to the multiplexing system. In the multiplexing system, the separate signals, having different bands of frequencies, are separated by the separate components and directed into their proper circuits from which they are taken to their ultimate point of use. Each filter component is designed for a definite band of frequencies and the number of components present in the multiplexing system must equal the number of bands of frequencies to be separated. There are other possible uses for such filter components than in communication systems as for example in multiple frequency radar systems, and systems wherein several electronic devices are to share the same circuit.

An object of the invention is to provide a directional filter component suitable for use in a strip-line transmission system for providing a multiplexing system for microwave transmission.

Another object of the invention is to provide improved directional filter components suitable for use in a strip-line transmission system.

Still another object of the invention is to provide improved directional filter components for strip-line transmission systems which are more compact and more economical to manufacture than previous filter components of the same character.

Other objects of the invention will become apparent upon consideration of the following description and the disclosure of the drawings in which;

Fig. 1 is a block diagram of a filter component illustrating the basic properties of a directional filter;

Fig. 2 is a perspective view of one embodiment of the invention in which a pair of dissimilar resonator strips are used to couple the transmission lines;

Fig. 3 is a perspective view of a modification of the embodiment of Fig. 2 in which the resonator strips have a different configuration;

Fig. 4 is a perspective view of another embodiment of the invention, wherein the resonator strips have similar configurations and are coupled to the transmission lines at spaced points, the spacing along one transmission line being different from the spacing along the other transmission line;

Fig. 5 is a perspective view of a modification of the embodiment shown in Fig. 4 wherein cascade connected resonator strips are provided;

Fig. 6 is a perspective view of another embodiment of the invention, in which the coupling means is a loop type resonator;

Fig. 7 is a perspective view of a modification of the embodiment of Fig. 6 and showing a plurality of loop resonators connected in cascade; and

Fig. 8 is a block diagram of a multiplexing system in which the filter components may be used.

The directional filter component of Fig. 1 may be one of many in a multiplexing system for a strip-line transmission system. It possesses four arms, 1, 2, 3 and 4, each of which is composed of terminal pairs to which connections may be made to other parts of a circuit, or to other components of a multiplexing system. In the illustration, arm 1 is used as the input arm, although any of the arms may be so used, either separately or simultaneously. An input, comprising a collection of signals f_a, f_b, and f_c, each of a different band of frequencies, may be connected to arm 1. The directional filter component selects the signal f_a from the collection and couples only this selected signal to arm 4. Since it is possible that the other signals will have frequency bands above and below that of the selected signal, the arm 4 is said to have, at least in effect, a response of a band pass filter. The arm 2, being actually the opposite end of the same transmission line as arm 1 is associated, passes the signals f_b and f_c to whatever circuit that may be connected to it. Since

it passes all signals except the one extracted it may be said to have, at least in effect, the response of a band-rejection filter. The arm 3, which is the other end of the transmission line with which the arm 4 is associated, is isolated from arm 1 by reason of the directional characteristics of the filter. It is said to have zero response as regards the input at the arm 1. The filter component may take the configuration of any one of the embodiments disclosed in this application.

There are certain features in all embodiments of the invention which are the same. These features will be treated first and later the distinguishing features will be disclosed.

Each embodiment relates to a strip-line transmission system. Such a transmission system comprises two lines more or less arranged in parallel relation in a unitary structure. It has a pair of conductive strips 7 and 8, as for example copper, supported upon and affixed to a sheet of dielectric material 5 in spaced parallel arrangement. The parallel arrangement is not an essential feature of the invention, as the strips may be oriented in other directions than parallel directions without destroying the important properties that are wanted. The strips may be affixed to the dielectric material in any known manner as for example by cement. Further, the said transmission system has a sheet of conductive material 6 covering the other side of the sheet of dielectric 5. This sheet of conductive material may be a coating deposited in any known manner. The two strips 7 and 8 on the one side of the dielectric 5 with the conductive coating 6 on the other side provide the two transmission lines of the system. One line has the arms 1 and 2 and the other line has the arms 3 and 4. The ends of the strips form one terminal of the terminal pairs and the conductive coating forms the other terminal of the terminal pair. The arms may be connected to other parts of a circuit or to other circuits by any suitable means well known in the art. For best results the dielectric sheet 5 should be of uniform thickness and homogeneity.

The separate embodiments differ from each other in the character of the means and the mode of coupling the two transmission lines to obtain the same properties in each.

In Fig. 2 the coupling between the two transmission lines is provided by a pair of resonator strips 9 and 10, placed in approximate parallel relation to each other and oriented in a direction transversely to the strips 7 and 8. The resonator strips 9 and 10 differ in length and in configuration. The strip 9 has a length, related to the mid-band frequency of the band of frequencies to be passed, and equal to one-half wave length. The strip 10 has a length related to the same band of frequencies equal to a wave length. It is folded upon itself in the direction parallel to the strips 7 and 8 so that its greater length may be accommodated between the strips 7 and 8 with the same spacing as required to accommodate the strip 9. The ends of the strips 9 and 10 are positioned adjacent to the strips 7 and 8 so as to be capacitively coupled thereto, at points spaced apart along the strips 7 and 8, each a distance of one-quarter wave length, at the mid-band-pass frequency. In this and other embodiments, the mid-frequency of the band to be passed determines the dimensions of the wave length. Filters designed for different band passes will have resonators of different dimensions and couplings having different spacings.

The modification illustrated in Fig. 3 is the same as that described and shown in Fig. 2, except as to the configuration of the strip 10. In this embodiment, the resonator strip 10 is formed in the shape of a T with the shaft of the T extending in the direction parallel to the strips 7 and 8. This particular configuration of the strip 10 functions in the same way as the strip 10 in Fig. 2. It provides for an effective length equal to a wave length at the mid-band-pass frequency.

The mode of operation of the embodiments of Figs. 2 and 3 is given in rigorous mathematical analysis in my article published in Proceedings I.R.E., vol. 44 pp. 1018–1024 dated August 1956.

The embodiments of Figs. 2 and 3 may be described less rigorously to operate in the following manner. If it is assumed that the input fed to arm 1 is composed of several signals of different frequency bands and the filter component is designed to pass one of these frequency bands, the input will be fed along the line made up of the strip 8 and the coating 6 towards the arm 2. The signal, which we shall call the selected signal, having the band of frequencies for which the filter is designed, excites the resonators, formed by the strips 9 and 10 in combination with the coating 6. Since the strips 9 and 10 couple with the strip 8 at points spaced apart one-quarter wavelength at mid-band-pass frequency, the excitation of the resonator of which the strip 10 is a part will lag that of which the strip 9 is a part, in time phase equal to one-quarter wave length, or 90 degrees. The resonator strip 10 being twice the length of that of resonator strip 9 the excitation coupled to the line of which the strip 7 is a part from the resonator 10, undergoes a further lag of a half wave length, or 180 degrees. As a result, the energy coupled from the resonators 9 and 10 to the line of which the strip 7 is a part, will be three-quarter wave length or 270 degrees in time phase apart, and at points spaced one-quarter wave length apart along the strip 7.

The energy coupled to these two spaced points on strip 7 will propagate a wave in the two directions along the strip 7. The wave propagated from the point of coupling of the strip 10 and the strip 7, in the direction of the arm 4, will arrive at the point of coupling between the strip 9 and the strip 7 with a further change in time phase of one-quarter wave length or with a total change in time phase of 360 degrees, to be in phase with the wave propagated from the point of coupling between the strip 9 and the strip 7 in the direction of the arm 4. The two waves will re-enforce each other and since this wave is composed of the frequencies coupled by the resonators, the arm 4 will transmit only those frequencies for which the filter is designed.

If we now consider the wave propagated from the point of coupling between the strip 9 and the strip 7 in the direction of the arm 3, this wave will undergo a time lag of one-quarter wave length or 90 degrees in traversing the distance between the point of coupling of strip 9 with the strip 7 and the point of coupling of the strip 10 and the strip 7. Since this wave undergoes a change of phase of one-quarter wave length whereas the wave from the point of coupling between the strip 10 and the strip 7 in the direction of the arm 3 undergoes a change of phase of three-quarters wave length, all lagging, the wave from the point of coupling between the strip 9 and the strip 7 arrives at the point of coupling between the strip 10 and the strip 7 in phase opposition to that wave propagated from the point of coupling of the strip 10 and the strip 7 in the direction toward the arm 3, and they will cancel each other. The output from the arm 3 will be zero if the amplitudes of the two waves in opposition are of equal amplitudes.

As heretofore noted, the signals, having bands of frequencies other than that for which the filter is designed, fed to the arm 1, pass on to the arm 2. The output from this arm differs from the input at the arm 1 by the absence of the band of frequencies extracted and coupled to the arm 4. This output is comparable to that output of a band-rejection filter and the arm 2 may thus be said to have the response of a band-rejection filter. The structure of the filter is such that it makes no difference which arm is used as the input arm, for there will always

be arms having outputs of the same character as described above.

The embodiment of Fig. 4 differs from the previously described embodiments in the manner of the coupling of the desired band of frequencies between the two transmission lines. In this embodiment, the resonator strips 9 and 10 are alike in configuration and length. Each strip 9 and 10 has a length of one-half wave length at the mid-band-pass frequency. The strips 9 and 10 are arranged between the strips 7 and 9 and extend in a direction generally transverse to the strips 7 and 8. The ends of the strips 9 and 10 are capacitively coupled to the strips 7 and 8 at points spaced differently along the two strips 7 and 8. The points of coupling of the resonator strips 9 and 10 with the strip 8 are spaced apart one-quarter of a wavelength, whereas the points of coupling of the resonator strips 9 and 10 with the strip 7 are spaced apart three-quarters of a wave length. This is, in effect, the same as in the previously described embodiments, because, if in these embodiments the distances from the point of coupling between the strip 9 with the strip 8 and the point of coupling between the strip 9 and the strip 7 are compared with the distance between these same points by way of the strip 10, it will be found to be the same and to be a wave length.

The modification shown in Fig. 5 is similar to that of Fig. 4 except that there are a plurality of resonator strips connected in cascade to form each coupling 9 and 10. The resonator strips are each one-half wave length long and are coupled capacitively to each other. The end strips of the cascade are capacitively coupled to the strips 7 and 8 in the same manner as the single strips 9 and 10 in the embodiment of Fig. 4. The cascade arrangements 9 and 10 are coupled to the strip 8 at points spaced apart one-quarter wave length, whereas they are coupled to the strip 7 at points spaced apart three-quarters wavelength.

The mode of operation of the embodiments of Figs. 4 and 5 is identical with that of the embodiments of Figs. 2 and 3. The cascade arrangement of the strips in the embodiment of Fig. 5 provides for a sharper bandpass response and enables a greater selectivity to be obtained.

The third embodiment of the invention illustrated in Fig. 6 and the modification thereof illustrated in Fig. 7 differ to a greater extent from the previously described embodiments in the means and mode of coupling, than the previously described two embodiments so differ from each other. Nevertheless, the properties present in the previous embodiments are also present in these embodiments.

In the embodiment of Fig. 6, a loop shaped strip 13 having an effective length equal to one wave length at the mid-band-pass frequency is arranged between the strips 7 and 8 for providing the desired selective coupling. The loop 13 is shaped such as to have portions thereof parallel to portions of the strips 7 and 8 so as to couple therewith. The parallel strip coupling arrangement as provided by the parallel portion provides for directional property of the coupling. A traveling wave along one strip-line will produce a traveling wave in the opposite direction in the other strip-line. At the frequency for which the loop is designed a traveling wave builds up to a large amplitude in a manner similar to that in a resonant cavity.

The modification of Fig. 7 is the same except that two loops, each a wave length long, are provided, where one is provided in Fig. 6. The two loops 14 and 15 are shaped to have their adjacent sides parallel and the sides adjacent strips 7 and 8 parallel thereto. The parallel portions provide for the coupling between the strips and the loops and between the loops. The multiple loop arrangement provides for a sharper band-pass than is possible with a single loop and gives a gain in selectivity.

In operation, the embodiments of Figs. 6 and 7 produce the same results as are obtained from the previously described embodiments, but they are conceived to operate in a slightly different manner. The arm 1, used for purposes of this disclosure as an input arm, receives a pluurality of signals, the signals being in different frequency bands and thus have different wavelengths. The waves representing the different signals traveling down the strip 8 toward the arm 2 has one component of the proper wave length suitable for exciting the loop 13 and causes a traveling wave to be excited in the loop, which builds up to a large amplitude. The excited traveling wave in the loop 13 travels in a direction opposite to that the wave travels in the strip 8. The traveling wave in the loop 13 when it reaches the portion of the loop paralleling the strip 7 will be traveling in a direction which is the same as that in the strip 8 and it will excite a traveling wave in the strip 7 in a direction towards the arm 4. The arm 3 will be isolated by reason of the directional properties of the coupling. The arm 2 will transmit the signals, having other than the proper wave lengths to other circuits to which the arm 2 may be connected.

The modification of Fig. 7 operates the same as that in Fig. 6 except the plurality of loops require that the coupling be repeated. In the repetition of coupling between resonant loops a sharper selectivity is procured.

The filter components of the various embodiments may be used to form a multiplexing system as is illustrated in Fig. 8. The separate components of the multiplexing system are indicated by the letters A, B, C, D and E and are alike except that they are designed to have different band-pass characteristics. The arms 1 of the components B, C, D and E are connected to the arms 2 of the components A, B, C and D respectively. In addition the arm 4 of the component E is connected to the arm 3 of the component D. Connections may be made to the arms 4 of the components A, B, C and D from which may be taken the separate signals or to which separate signals may be fed. A connection may also be made to the arm 1 of the component A to which may be fed the input containing the signals f_a, f_b, f_c, f_d, f_e, and f_f. The signals f_a, f_b, f_c respectively may be taken from the arms 4 of the components A, B and C. The signals f_d and f_e may be taken from the arm 4 of the component D because the connection between the components D and E permits the output of the component E to be combined with the output of the component D. The signal f_f, being the residue of input signals, would pass out of the arm 2 of the component E.

The same arrangement may be used for combining the several bands of frequencies for propagation along a single circuit without structural alteration, merely by reversing the direction of feed to the device, as for example feeding the system through the arms 4 and taking off the combined output at the arm 1 of the component A.

The principles disclosed in this application may be easily extended to obtain other circuits operating in a similar fashion to produce the same results.

My invention, as I regard it to be, is set forth in the following claims.

What is claimed is:

1. A strip-line directional filter component for a microwave multiplexing system comprising a sheet of dielectric material; a conductive coating affixed to a first side of said sheet of dielectric material; a pair of conductive strips affixed in spaced relation to a second side of said sheet of dielectric material, the pair of conductive strips and the conductive coating forming boundaries for an electromagnetic field therebetween and constituting two transmission lines along which microwave energy may be propagated; a first transverse conductive strip affixed to said second side of said sheet of dielectric material extending between said pair of conductive strips, said first transverse conductive strip and said conductive coating forming a first resonator and said first transverse conductive strip having a length to tune said first resonator to a

predetermined frequency; a second transverse conductive strip affixed to said second side of said sheet of dielectric material extending between said pair of conductive strips, said second transverse conductive strip and said conductive coating forming a second resonator, the said second transverse conductive strip having a length equal to twice the length of the first transverse conductive strip whereby said second resonator will be tuned to the same frequency as the first resonator is tuned; and means coupling said first and second transverse conductive strips to each of said pair of conductive strips at points spaced apart along each of said pair of conductive strips a distance equal to one-quarter wave length at the frequency of said resonators.

2. A strip-line directional filter component for a multiplexing system comprising a sheet of dielectric material having a first and second surface in parallel relation to each other, a pair of conductive strips in spaced parallel relation affixed to the first surface of said sheet of dielectric material, a sheet of conductive material affixed to the second surface of said sheet of dielectric material, each of said strips forming with the conductive sheet a separate transmission line, a first coupling means comprising a conductive strip affixed to said first surface of said dielectric material extending between said transmission lines with their ends in close adjacency to said transmission lines, a second coupling means comprising a conductive strip affixed to said first surface of said dielectric material extending between said transmission lines with its ends in close adjacency thereto and at points spaced along said transmission lines a distance equal to one quarter wavelength of a predetermined frequency, said coupling strips forming with said sheet of conductive material a pair of resonators tuned to the predetermined frequency and one of said resonators being twice as long as the other resonator, whereby the energy waves from said resonator combine to provide uni-direction propagation in the transmission line to which said energy is transferred.

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