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Snell, Jr.

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[54] ORTHOGONAL RESONANT FILTER FOR PLANAR TRANSMISSION LINES

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[73] Assignee: **Bell Telephone Laboratories, Incorporated,** Murray Hill, N.J.

[22] Filed: **Apr. 4, 1973**

[21] Appl. No.: **347,839**

[52] **U.S. Cl.** .... **333/6,** 325/445, 330/4.9, 333/73 S, 333/76, 333/82 R, 333/84 M
[51] **Int. Cl.** **H01p 1/20,** H01p 5/12, H04b 1/26
[58] **Field of Search** .... 333/73 S, 84 M, 6, 76, 333/83 R, 82 R; 321/69 W, 69 NL; 325/445; 330/4.9

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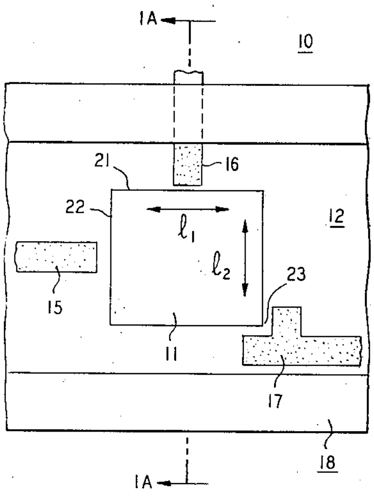
Primary Examiner—Paul L. Gensler
Attorney, Agent, or Firm—D. L. Hurewitz

[57] ABSTRACT

The conductor pattern on a dielectric substrate includes a rectangular element of finite thickness whose two surface dimensions are chosen so that each is one-half the wavelength of a desired frequency. Accordingly, the element will support two resonant orthogonal standing waves and external coupling to each wave may be provided independently. Common coupling to both waves may also be provided so that the dual resonant structure may be used as a three-port device for frequency combining and separating and is particularly well-suited for frequency conversion applications. A two-port arrangement permits generation of specific filter characteristics.

16 Claims, 9 Drawing Figures



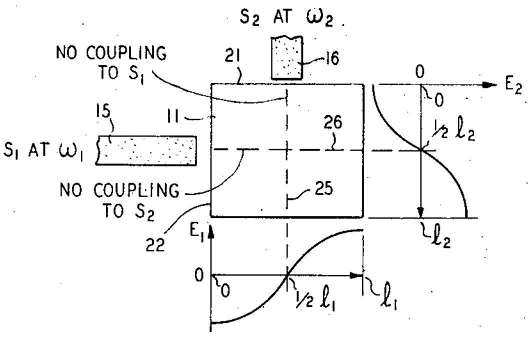


FIG. 1

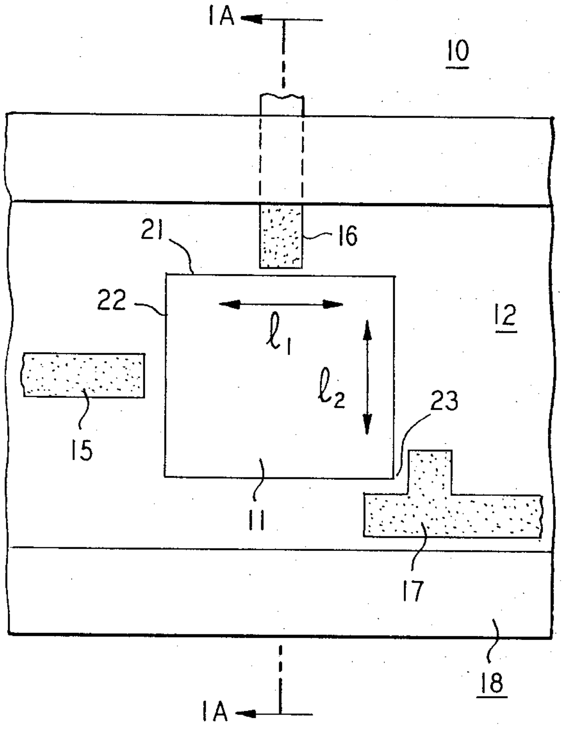


FIG. 1A

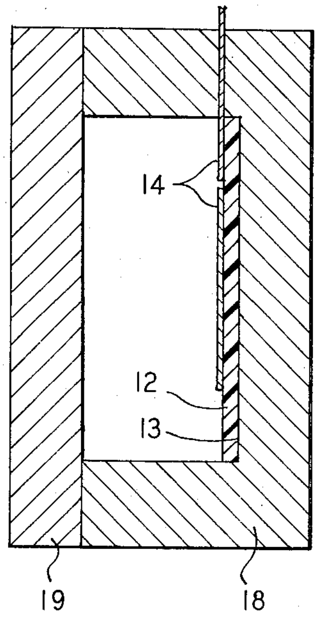


FIG. 2

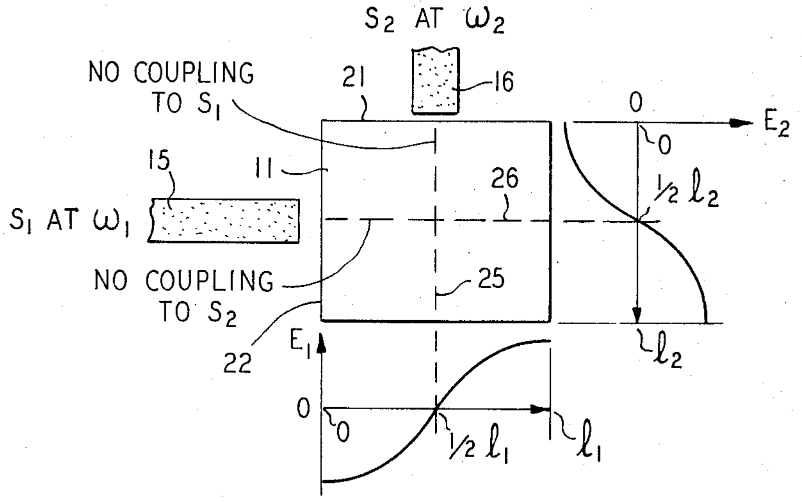


FIG. 3

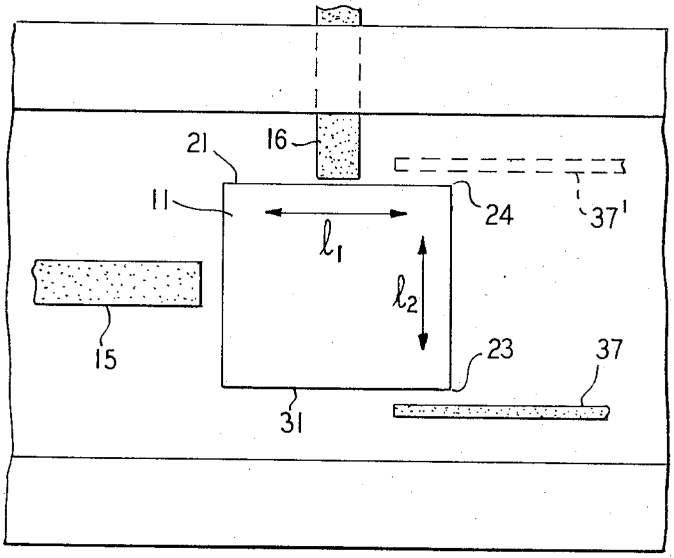


FIG. 4

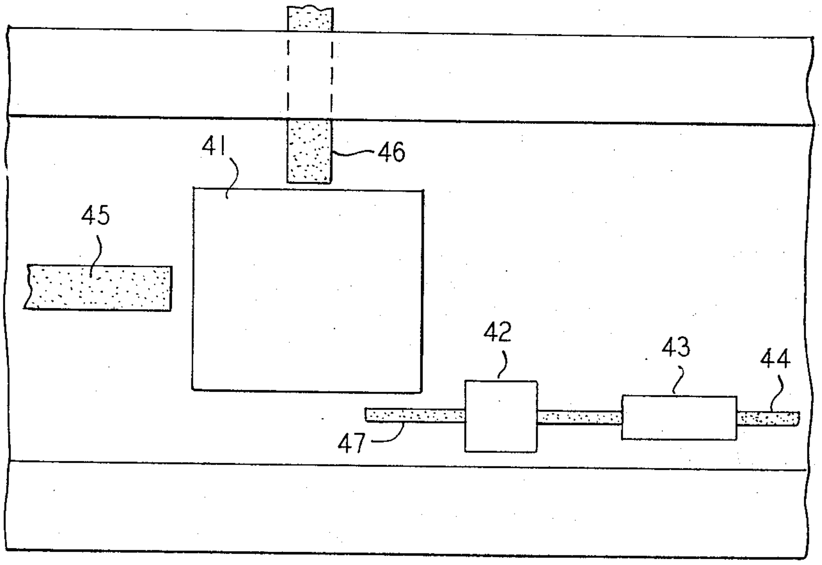


FIG. 5

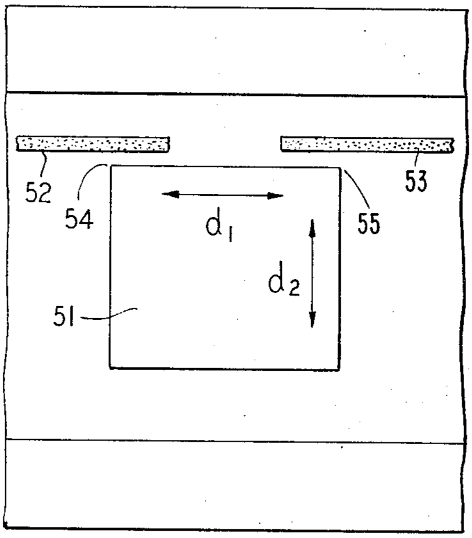


FIG. 5A

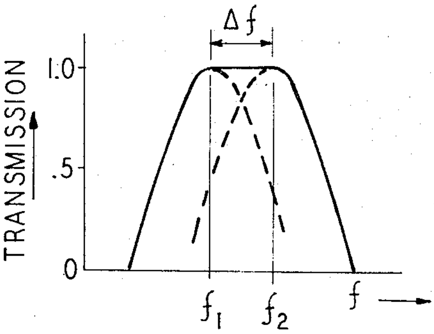


FIG. 6

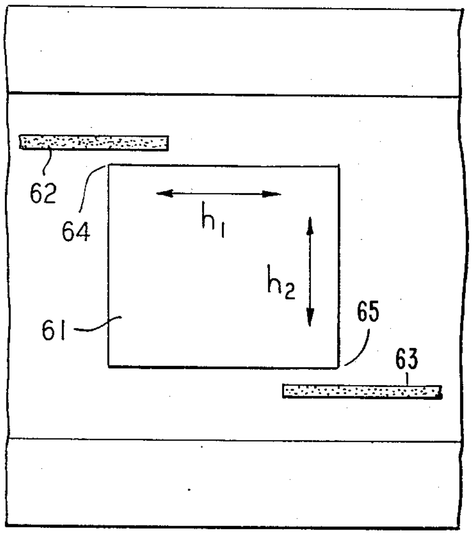
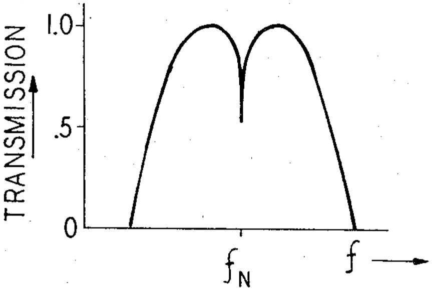


FIG. 6A



ORTHOGONAL RESONANT FILTER FOR PLANAR TRANSMISSION LINES

BACKGROUND OF THE INVENTION

This invention relates to planar transmission line structures, such as microstrip or stripline, and more particularly, to filter circuits utilizing transmission elements dimensioned to support resonance at selected frequencies.

Hollow waveguides have been used as transmission media for many years. However, with current interest in higher frequency signals, such as millimeter waves and above, planar transmission lines are more attractive than waveguide structures, since the smaller dimensions of planar transmission lines make fabrication easier, and reasonably sized devices provide appropriate impedance levels, such as 50 ohms, while similar impedances are difficult to obtain in waveguide structures.

Cavity resonators are commonly employed as filters with waveguide structures and the resonance phenomenon is also used to provide filtering in both microstrip and stripline types of planar transmission lines. Rectangular portions of the conductive pattern may be designed to have their major dimensions equal to one-half the wavelength of a desired frequency so that the rectangles will function as filters for that frequency. Both end-coupling and side-coupling are used to transfer energy into and out of these filter elements, but conventional design techniques prescribe the widths of the elements. By following the accepted procedures, such as are set forth in Chapter 10 of *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, by G. L. Matthaei, L. Young and E. M. T. Jones (1964), the width is always very narrow relative to the length in order to insure that an element's conductance satisfies the design equations. This narrow dimension does not support resonance in a transverse mode at or near the frequency of operation.

It is an object of the present invention to provide a planar transmission line structure capable of supporting multiple resonances. In particular, it is an object to provide such a structure capable of supporting two orthogonal resonances.

SUMMARY OF THE INVENTION

In accordance with the present invention the conductor pattern of a planar transmission line, such as a microstrip or stripline, includes a rectangular conductive element physically isolated from, but electrically coupled to, the rest of the pattern by conductive leads. A first standing wave can be excited to resonate between two opposite edges of the element by coupling a signal having a wavelength equal to twice the distance between these opposing edges. Simultaneously, another standing wave can be excited to resonate normal to the first wave by coupling a signal having a wavelength equal to twice the distance between the two edges orthogonal to the first. Coupling to the resonator is reciprocal so that energy may be coupled into or out of the resonator by either capacitive or inductive coupling between the resonator element and the conductive leads.

The resonating element has a finite thickness and is deposited upon a dielectric substrate by conventional techniques identical to those used to create the rest of

the conductor pattern. The dimensions of the resonator are chosen so that two signals of selected frequencies each resonate in orthogonal modes with total isolation within the resonator. A coupling conductor located at an edge but off its midpoint couples to both modes while a coupling conductor located at an edge and symmetrically positioned with respect to the edge's midpoint, couples only to the resonance transverse to that edge.

Thus, a three-port device can be used as both a dual signal filter and combiner by locating a pair of conductors so that each exclusively excites one resonant mode and a common conductor coupling energy from both. This configuration, which can be used reciprocally as a separator, finds application in frequency converters.

Supporting dual resonant signals in accordance with the principles of the invention also permits specific filter resposes to be generated. For example, a two-port device can be arranged to couple to a nearly square rectangular resonator element so that a single input excites the two orthogonal resonances at nearly identical frequencies and a single output lead couples energy from both resonating modes out of the resonator. With specific coupling combinations the relative phasing between the energy associated with the two modes can be adjusted to generate either notch or doubly-tuned characteristics.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top view of a section of a microstrip type of planar transmission line illustrating a resonator circuit in accordance with the present invention;

FIG. **1**A is a section view taken along line **1**A of FIG. **1**, showing the shielding structure used in conjunction with a planar transmission line;

FIG. **2** is a representation illustrating the instantaneous standing wave patterns of the orthogonal resonances in the resonator of FIG. **1**;

FIG. **3** illustrates a modified version of the structure of FIG. **1**;

FIG. **4** illustrates a frequency converter circuit utilizing the resonator of FIG. **1**;

FIG. **5** illustrates a specific filter arrangement in accordance with the principles of the invention;

FIG. **5**A is a graphical presentation of the filter characteristic associated with the structure of FIG. **5**;

FIG. **6** illustrates another specific filter arrangement in accordance with the principles of the invention; and

FIG. **6**A is a graphical presentation of the filter characteristic associated with the structure of FIG. **6**.

Many of the structures are common to two or more figures and where these structures are the same, they are designated by identical numerals.

DETAILED DESCRIPTION

FIGS. **1** and **1**A illustrate a section of planar transmission line **10**, whose conductor pattern includes resonator element **11** capable of supporting two orthogonal resonant modes. These figures depict a microstrip type of planar transmission line having dielectric substrate **12** mounted upon ground plane **13** and conductor pattern **14** deposited upon the substrate parallel to ground plane **13**. The conductor pattern, which has a finite thickness, at least as great as the electrical penetration at the transmission frequency (on the order of a few microns for GHz frequencies), is normally deposited by conventional evaporation techniques. In the section of transmission line **10** shown, this conductor pattern **14** consists of resonator **11** and conductor leads **15, 16** and **17** for coupling to the resonator.

The microstrip line is enclosed by a conductive shield conveniently formed by two separable portions. The first portion forms a channel **18,** whose internal surface constitutes ground plane **13** and whose side walls define the width of the channel. The other portion, which forms a cover **19,** mates with channel **18** by conventional means to complete the enclosure and form a rectangular cross section. The shield is not absolutely necessary for operation of the invention, but microstrip lines having substrates of low dielectric constant are conventionally enclosed by such a shield to prevent loss due to radiation of energy from resonating elements. Accordingly, channel **18** and cover **19** are included in the interest of completeness. Of course, the planar transmission line may also be of the stripline variety where two ground planes are provided and the conductor pattern is suspended between the ground planes. The stripline embodiment may also be shielded in which case the two surfaces of the shielding structure parallel to the conductor pattern would constitute the ground planes.

Conductor lead **15** couples one signal to resonator **11** by the capacitive effect between the narrow end of lead **15** and edge **22** of resonator **11.** Similarly, a second signal is capacitively coupled to resonator **11** by lead **16** which couples to edge **21.** Lead **16** is shown passing through the side wall of channel **18** where it may couple to the second signal propagating, for example, in a waveguide (not shown) adjacent the shielded transmission line **10.**

Resonator **11** is rectangular in shape and adjacent edges **21** and **22** are therefore perpendicular. The electrical length l_1 of edge **21** is chosen to be one-half a wavelength of the frequency of the first signal coupled from lead **15** and the electrical length l_2 of edge **22** is chosen to be one-half the wavelength of the frequency of the second signal coupled from lead **16.** The physical lengths of edges **21** and **22** are minutely shorter than the electrical lengths l_1 and l_2 since the effects of fringing and loading extend the electrical length slightly beyond the boundaries of resonator **11.**

The dimensions of resonator **11** permit the two signals to simultaneously resonate in transverse modes without interacting with each other. Furthermore, the intrinsic Q of each resonance is many times higher than in a conventional narrow width, single resonant filter for the same frequency since the dimension transverse to the direction of resonance is much wider than in the conventional filter.

The operation of the orthogonal mode resonator may be further explained with reference to FIG. **2** where it is assumed that signal S_1 at frequency ω_1 is applied via conductor lead **15** and signal S_2 at frequency ω_2 is applied via conductor lead **16.** S_1 couples to edge **22** and establishes a sinusoidal voltage which varies with the distance along edge **21** as shown instantaneously as E_1 at the bottom of FIG. **2.** Since the overall electrical length l_1 is one-half λ_1, where λ_1 is the wavelength corresponding to ω_1, a standing wave is established and a null results at the electrical midpoint of length l_1. If the other signal, S_2, is coupled transversely to the length l_1 at this midpoint, it will resonate in a transverse mode without coupling to S_1. Thus, if conductor lead **16** is positioned symmetrically with respect to centerline **25,** which is the perpendicular bisector of dimension l_1, it will see a null of the E_1 voltage. If the end of lead **16** extends to both sides of line **25,** it is noted that coupling to S_1 will occur to the right of line **25,** but simultaneously an equal and opposite coupling will occur on the left of line **25** and the net result will be no coupling to the resonating S_1 signal if lead **16** is centered on line **25.**

Similarly, signal S_2 will generate the standing wave pattern shown instantaneously as E_2 at the right of FIG. **2** and a null will result at the midpoint of length l_2 along its perpendicular bisector, centerline **26.** Accordingly, if lead **15** is centered along this line, resonating E_1 energy will not couple to the resonating E_2 energy.

It is noted that the degree of coupling to the resonator is dependent upon the spacing between the ends of the conductors and the edges of the resonator. The loaded Q of the resonance can, of course, be adjusted by adjusting this coupling. As can be seen in FIGS. **1** and **2,** tighter coupling is provided between lead **16** and the resonator than between lead **15** and the resonator, but this difference in coupling is shown merely as an illustration.

Though this description assumes that leads **15** and **16** are input ports and provide coupling of external signals into the resonator, the phenomenon is a reciprocal one and these leads could as well be output ports coupling resonating energy from resonator **11** to external circuitry. For convenience, however, conductive lead **17** in FIG. **1** will be referred to as the output port. This lead is centered on neither line **25** nor line **26** and will accordingly couple to both orthogonal resonating modes. Lead **17** is located at corner **23** so that it couples substantially equally to both standing waves, but if it were located along one edge between the centerline and a corner, it would also couple to both waves, to a greater or lesser degree, depending upon its location. Any lead located off the centerline will therefore commonly couple to the two orthogonal modes.

The conductor leads are shown in FIG. **1** as being capacitively coupled but they may also be inductively coupled. As shown in FIG. **3,** a modified version of FIG. **1,** common lead **37,** which couples to both orthogonal resonances, can be inductively coupled by placing its side, or longer edge, parallel to an edge, such as **31,** of resonator **11.** The side-coupling of lead **37** also provides a capacitive effect so that the total coupling is a result of the combination of inductive and capacitive coupling.

FIG. **3** also shows an additional lead **37'** which may be used as a second output port. This auxiliary lead is positioned at corner **24** and therefore couples in common to both orthogonal modes. The absolute values of energy coupled into leads **37** and **37'** are identical. However, a **180** degree phase difference exists between corners **23** and **24** for the energy resonating as a result of excitation at lead **16.** This can be seen by the instantaneous plot of the standing wave shown at the right side of FIG. **2.** No phase difference exists between corners **23** and **24** for energy resonating as a result of excitation from lead **15.** Due to the phase reversal of only one resonance the outputs at leads **37** and **37'** may be usefully combined in applications such as balanced downconverters.

FIG. 4 illustrates rectangular resonator element **41** in a frequency conversion circuit. Lead **47** forms a series connection with mixer element **42**, filter **43** and port **44**. If leads **45** and **46** provide the pump and RF signal inputs, respectively, resonator **41** will provide filtering of each signal while the output on lead **47** will contain a combination of both signals. This combination is then heterodyned in mixer **42** which may be Schottky Barrier Diode if the circuit is used for downconversion. The product of the mixer is applied to a conventional lowpass filter, such as lumped element filter **43**, which passes the IF output frequency to port **44**. Due to the frequency selectivity of resonator **41** with regard to the RF signal, only one sideband is applied to mixer **42** so that the circuit has the characteristics of a single-sideband downconverter.

Of course, the resonator operates reciprocally and single-sideband upconversion may be provided by utilizing as the mixer instead of a Schottky diode another appropriate mixing device. For instance, a nonlinear resistive diode or a nonlinear capacitor, such as a varactor diode, may be used. In this case, the pump signal from lead **45** would be coupled from resonator **41** to lead **47**. It would then be heterodyned (or parametrically amplified if a varactor diode were used) in **42** with an IF input signal from port **44** to produce a double-sideband product at lead **47**. Only one sideband couples from lead **47** to resonator **41** where it is removed via lead **46**.

Another application of the orthogonal resonator is shown in FIG. **5**. This is a two-port device with each port connected to a lead **52** or **53**. These leads are placed respectively at opposite corners **54** and **55** of resonator **51**, and thus located each is provided with essentially equal coupling to both orthogonal modes in resonator **51**. The electrical dimensions d_1 and d_2 are selected so that both resonant frequencies add constructively in parallel to produce a doubly-tuned bandpass characteristic illustrated in FIG. **5**A. This is accomplished by making d_1 and d_2 nearly identical, differing only enough so that their respective resonant frequencies f_1 and f_2 are separated by Δf, which is one-half the frequency of the overall desired doubly-tuned filter. It is noted that the coupling between the leads and the resonator can be adjusted to realize loaded Q's for both orthogonal resonances which are twice the loaded Q of the overall filter response as required to produce the desired doubly-tuned characteristic.

FIG. 6 illustrates another two-port orthogonally resonant filter designed to produce a notch filter characteristic. Resonantor element **61** is, like resonator element **51**, a nearly square rectangle. The input is coupled via lead **62** to corner **64** and the output is coupled at adjacent corner **65** to lead **63**. The notch filter operates similarly to the doubly-tuned filter of FIG. **5**, except that the location of lead **63** at corner **65** causes the energy of one resonating wave to be coupled 180 degrees out-of-phase from that coupled to output lead **53** in the doubly-tuned filter. This results in destructive interference, rather than constructive interference, with the resulting filter characteristic shown in FIG. **6**A. The notch frequency f_N may be located as desired within the band by appropriate selection of the dimensions h_1 and h_2 of resonator **61**, and by adjustment of the coupling at leads **62** and **63**.

In all cases it is to be understood that the above-described arrangements are merely illustrative of a small number of the many possible applications of the principles of the invention. Numerous and varied other arrangements in accordance with these principles may readily be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In a planar transmission circuit having a ground plane, a substrate, and a conductive pattern on the substrate parallel to the ground plane, a resonant filter operative in a selected frequency band, said filter being included in said conductive pattern and comprising:

a rectangular element of conductive material having a first pair of opposite edges being dimensioned equal to one-half the wavelength of a first selected frequency and the other pair of opposite edges adjacent the first edge being dimensioned equal to one-half the wavelength of a second selected frequency, both said first and second frequencies being within said frequency band,

said element being capable of supporting two orthogonal resonant standing waves, the first wave producing a first resonant mode between the two edges of the other pair of edges, the second wave producing a second resonant mode orthogonal to the first and between the two edges of the first pair of edges,

at least three ports,

means for exclusively coupling energy between the first port and the first resonant mode,

means for exclusively coupling energy between the second port and the second resonant mode, and

means for simultaneously coupling energy between the third port and the orthogonal first and second resonant modes.

2. A resonant filter as claimed in claim **1** wherein each means for coupling energy between a port and a resonant mode includes a conductor lead, an edge of the lead being positioned parallel to an edge of the element and spaced apart therefrom so that capacitive coupling exists between the lead and the element.

3. A resonant filter as claimed in claim **2** wherein the spacing between the edge of the lead and the edge of the element is selected to establish the Q of the resonance coupled via said lead.

4. A resonant filter as claimed in claim **2** wherein at least one of the leads has its side positioned parallel to and spaced apart from the edge of the element so that inductive coupling exists between the lead and the element.

5. A resonant filter as claimed in claim **1** wherein said means for exclusively coupling energy between the first port and the first mode includes a first conductor lead being positioned symmetrically with respect to the centerline perpendicularly bisecting the electrical length of one edge of the other pair of edges.

6. A resonant filter as claimed in claim **5** wherein said means for exclusively coupling energy between the second port and the second resonant mode includes a second conductor lead being positioned symmetrically with respect to the centerline perpendicularly bisecting the electrical length of one edge of the first pair of edges.

7. A resonant filter as claimed in claim **1** wherein said means for simultaneously coupling energy between the third port and the orthogonal first and second resonant modes includes a common conductor lead being positioned at a first corner of the element to couple substantially equally to both orthogonal resonating modes.

8. A resonant filter as claimed in claim **7** wherein said means for simultaneously coupling energy between the third port and the orthogonal first and second resonating modes further includes an auxiliary conductor lead being positioned at a second corner of the element adjacent the first corner to couple substantially equally to both orthogonal modes, the energy of one of said modes being shifted in phase by 180 degrees from the energy of that mode coupled at the first corner.

9. In a planar transmission circuit having a ground plane, a substrate, and a conductive pattern on the substrate parallel to the ground plane, a frequency converter circuit included in said conductive pattern and comprising:

a rectangular element of conductive material being dimensioned to support two orthogonal resonant modes at two selected frequencies,

at least three ports,

means for exclusively coupling a pump signal at the first port to resonate in a first mode within the element,

means for exclusively coupling energy between the second port and a second resonant mode orthogonal to the first mode within the element,

means for simultaneously coupling energy between a common point and both orthogonal modes, and

mixing means connected to the common point and to the third port for interacting the pump signal and another signal applied thereto to produce a third signal.

10. A frequency converter circuit as claimed in claim **9** wherein an RF signal is applied via the second port to the element and both the pump signal and the input RF signal are coupled from the element at the common point, and wherein said mixing means is a Schottky Barrier Diode which heterodynes the pump signal and the input RF signal to produce an IF output at the third port.

11. A frequency converter circuit as claimed in claim **9** wherein an input IF signal is applied to the mixing means via the third port, and the pump signal is coupled from the element at the common point, and wherein said mixing means is a varactor diode which parametrically amplifies the input IF signal to produce an RF output signal at the common point.

12. In a planar transmission circuit having a ground plane, a substrate, and a conductive pattern on the substrate parallel to the ground plane, a resonant filter included in said conductive pattern, and comprising:

a rectangular element of conductive material being dimensioned to support two orthogonal resonant modes at a first and second frequency, respectively,

means for coupling energy from external the element to excite the two orthogonal resonant modes, and

common means for simultaneously coupling energy from both the excited orthogonal modes to external the element.

13. A resonant filter as claimed in claim **12,** wherein said filter has a first and second port, and wherein said means for coupling energy from external the element is a single input conductor lead located at one corner of the element and wherein said common means for simultaneously coupling energy from both the excited orthogonal modes is an output conductor lead located at another corner of the element.

14. A resonant filter as claimed in claim **13** wherein the element is nearly square, the locations of the input and output leads being selected so that energy of each of said resonant modes couples to the output conductor lead with constructive addition to produce a doubly-tuned frequency response with the center frequency of the response located between the first and second frequencies.

15. A resonant filter as claimed in claim **13** wherein the element is nearly square, the location of said leads being selected so that the energy of each of the resonant modes couples to the output conductor lead with destructive interference to produce a notch frequency response.

16. In a planar transmission circuit having a ground plane, a substrate, and a conductive pattern on the substrate parallel to the ground plane, a resonant filter operative in a selected frequency band, said filter being included in said conductive pattern and comprising:

a rectangular element of conductive material having a first pair of opposite edges being dimensioned equal to one-half the wavelength of a first selected frequency, and means for coupling energy into the element to excite a resonant standing wave at the first frequency,

characterized in that the other pair of opposite edges of the element adjacent the first edges are dimensioned equal to one-half the wavelength of a second selected frequency, both said first and second frequencies being in said selected frequency band,

said element is capable of supporting two orthogonal resonant standing waves at the first and second frequencies,

said means for coupling energy includes at least one conductor lead and is capable of exciting the two orthogonal resonating waves, and

said filter further includes means for simultaneously coupling energy from both the excited resonant orthogonal waves to external the element.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,796,970 Dated March 12, 1974

Inventor(s) William W. Snell, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In column 5, line 33, "opposite" should read --adjacent--.

In column 5, line 54, "adjacent" should read --opposite--.

In claim 1, at column 6, line 16, "edge" should read --edges--.

Signed and sealed this 16th day of July 1974.

(SEAL)
Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents