United States Patent [19]

Low et al.

[11] **3,737,815**

[45] **June 5, 1973**

[54] **HIGH-Q BANDPASS RESONATORS UTILIZING BANDSTOP RESONATOR PAIRS**

[76] Inventors: **George M. Low**, Acting Administrator of the National Aeronautics and Space Administration with respect to an invention of; **Herman C. Okean**, Huntington, N.Y.

[22] Filed: **Nov. 27, 1970**

[21] Appl. No.: **93,329**

[52] **U.S. Cl.** ....**333/73 R,** 333/73 S, 333/82 A, 333/84 M

[51] **Int. Cl.** **H01p 3/04,** H01p 3/08, H03h 7/08

[58] **Field of Search** ....333/73, 84 M, 82, 333/95, 97

[56] **References Cited**

UNITED STATES PATENTS

3,417,351	12/1968	DiPiazza	333/73
3,345,589	10/1967	DiPiazza	333/73
2,968,012	1/1961	Alstader	333/73
2,964,718	12/1960	Packard	333/73
3,343,069	9/1967	Tsuda	333/73
3,444,485	3/1969	Okean	333/73

FOREIGN PATENTS OR APPLICATIONS

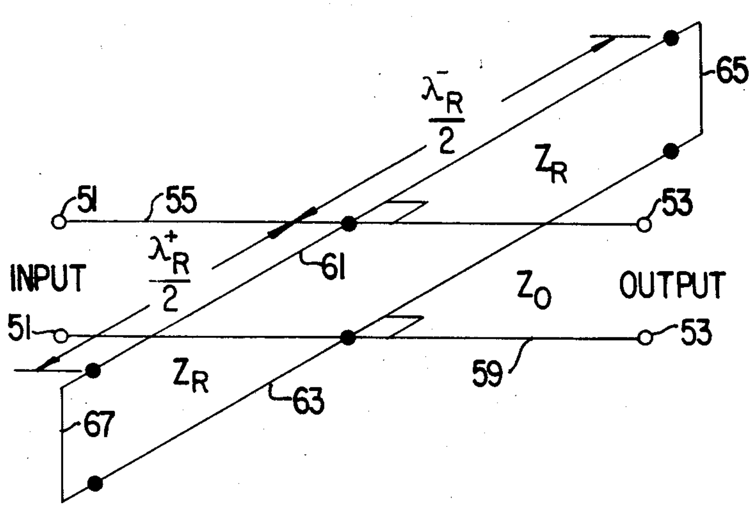
941,284	11/1963	Great Britain	333/73 C

Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—Marvin Nussbaum
Attorney—G. M. Fisher, R. F. Kempf and John R. Manning

[57] **ABSTRACT**

This disclosure describes high-Q bandpass resonators utilizing composite bandstop resonator pairs. The bandstop resonator pairs are formed of composite series or parallel connected realizable transmission line elements. The elements are exclusively either quarter-wavelength lines or half-wavelength lines.

2 Claims, 11 Drawing Figures



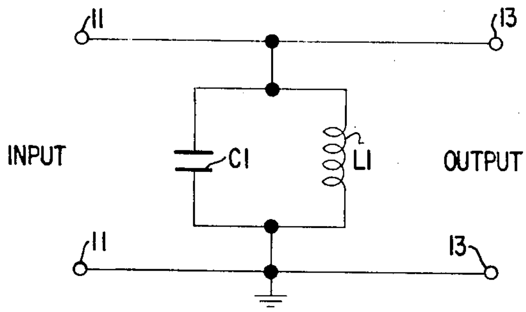


FIG.1

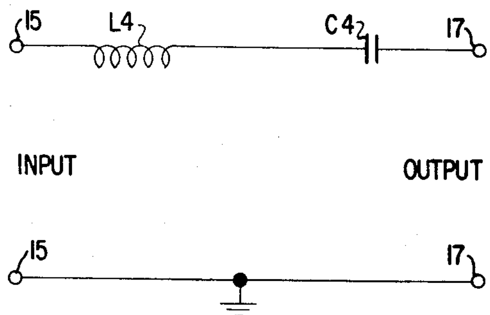


FIG.3

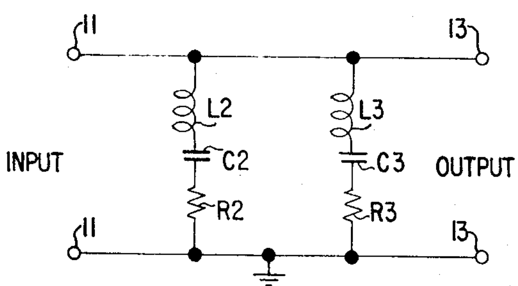


FIG.2

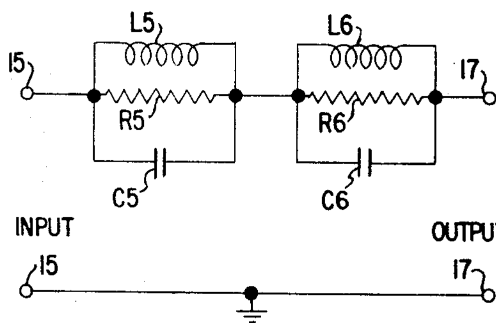


FIG.4

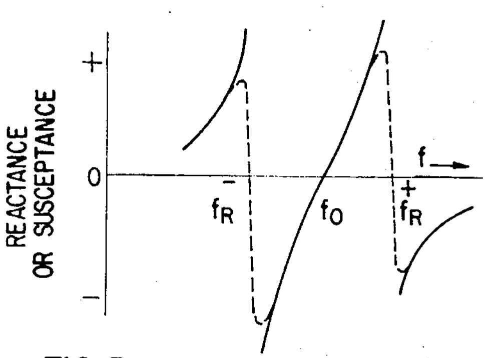


FIG.5

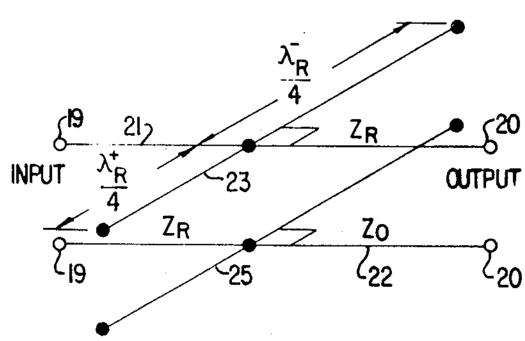


FIG.6

INVENTOR
HERMAN C. OKEAN

BY

ATTORNEYS

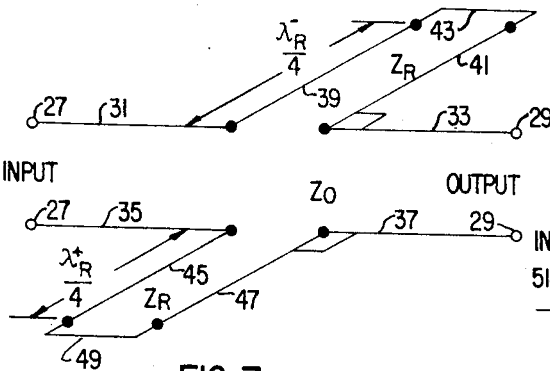


FIG. 7

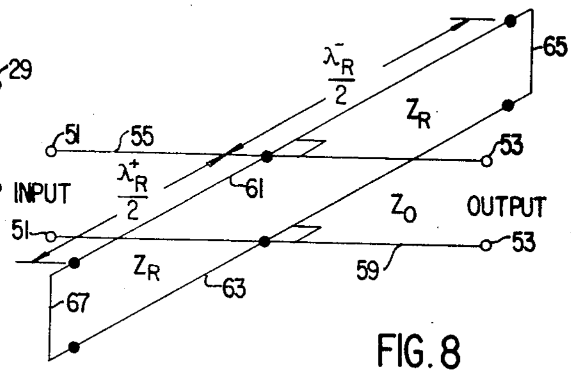


FIG. 8

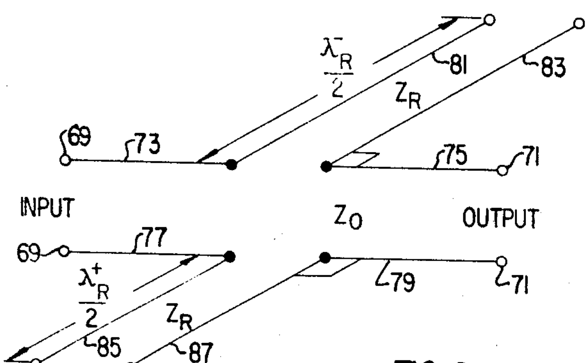


FIG. 9

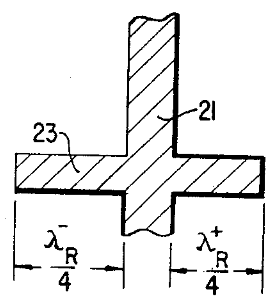
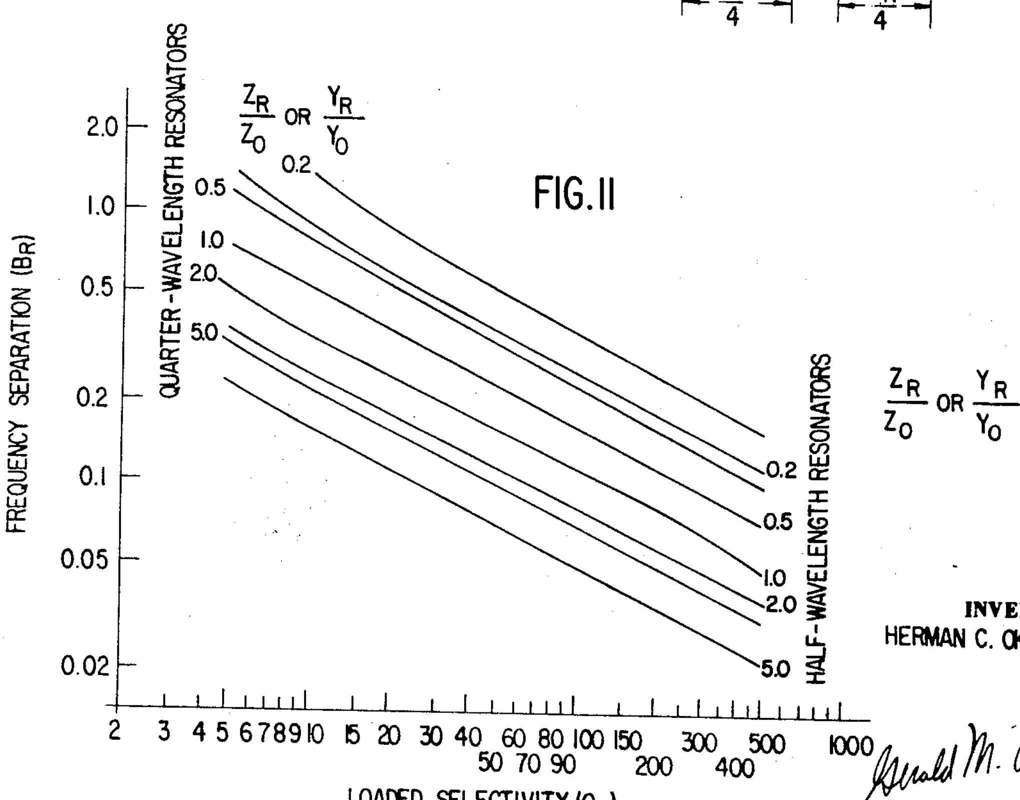


FIG. 10



INVENTOR
HERMAN C. OKEAN

Gerald M. Fisher

ATTORNEYS

HIGH-Q BANDPASS RESONATORS UTILIZING BANDSTOP RESONATOR PAIRS

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85–568 (72 Stat. 435; 42 U.S.C. 2457)

BACKGROUND OF THE INVENTION

This invention relates to bandpass resonators and, more particularly, to highly selective bandpass resonators suitable for operation in the microwave frequency range.

Bandpass filters and impedance matching networks for components that operate in the microwave frequency range, such as circulators, parametric and tunnel diode amplifiers, and negative resistance oscillators, for example, frequently require the use of highly selective (high loaded Q) bandpass resonators. A highly selective (high loaded Q) resonator is a resonator that has a high susceptance or reactance slope at the bandpass resonant frequency when the susceptance or reactance of the resonator is appropriately graphically displayed versus frequency. The realization of such "high-Q_L" reasonators using conventional "bandpass-resonant" transmission line elements, such as parallel multiple half-wavelength open or quarter-wavelength short circuited or series multiple quarter-wavelength open or half-wavelength short circuited lines, is often impracticable and sometimes impossible. The reason the use of such transmission line elements to form high-Q_L resonators is often impractical or impossible is that they have excessively high or low values of characteristic impedance (or long line lengths) for high values of Q_L. This limitation is particularly true for symmetrical stripline and microstripline transmission lines when the range of conveniently realizable characteristic impedances is restricted to about 15–100 ohms. Such restriction is often placed on this type of resonator because multimoding problems occur at lower impedance values and fabrication tolerance difficulties occur at higher impedance values.

High-Q_L bandpass resonators may also be realized as loosely coupled half-wavelengths of transmission line in cascade with the main transmission path of the circuit, the loose coupling being accomplished by small series capacitors or shunt inductors at either end of this "in-line" resonator. These resonators, however, have the disadvantages that they add excessive phase shift to the main transmission path, are wasteful of space and are more difficult to incorporate at a specific reference plane in a given circuit.

For a more extensive description of prior art realizations of high-Q_L resonators reference is made to a book entitled "Design of Microwave Filters, Impedance Matching Networks and Coupling Structures" by G. L. Matthaei, L. Young and E. M. T. Jones, McGraw Hill, New York, N.Y. 1964.

Therefore, it is an object of this invention to provide new and improved bandpass resonator configurations.

It is another object of this invention to provide high-Q_L bandpass resonators that are formed of transmission line elements.

It is another object of this invention to provide high-Q_L bandpass resonators having characteristic impedances in the 15–100 ohm range that are formed of transmission line elements.

SUMMARY OF THE INVENTION

In accordance with the principles of this invention, high-Q_L bandpass resonators are provided. The resonators are formed of composite pairs of realizable transmission line elements which may be in stripline or microstripline form. The composite pairs are formed of parallel half-wavelength open or quarter-wavelength short circuited lines. Alternatively, the composite pairs are formed of series quarter-wavelength open of half-wavelength short circuited lines. In any event, the composite pairs of appropriately centered bandstop resonators form high-Q_L bandpass resonators at the desired center frequencies.

It will be appreciated from the foregoing brief summary of the invention that novel bandpass resonators are provided by the invention. Resonators thusly formed have realizable impedances in the 15–100 ohm range, hence they can be utilized in conventional stripline and microstripline circuits. In addition to having characteristic impedances within the desired range, bandpass resonators formed in accordance with the invention also have an extremely high susceptance or reactance slope, i.e., they have a high-Q_L.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing objects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood from the following detailed description of preferred embodiments of the invention when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a schematic diagram of a lumped element parallel bandpass resonator;

FIG. 2 is a schematic diagram of a lumped element parallel bandstop resonator pair (including circuit loses);

FIG. 3 is a schematic diagram of a lumped element series bandpass resonator;

FIG. 4 is a schematic diagram of a lumped element series bandstop resonator pair (including circuit loses);

FIG. 5 is a graph of input reactance or susceptance of composite bandstop resonator pairs verses frequency;

FIG. 6 is a schematic diagram illustrating a parallel resonator formed, in accordance with the invention, of quarter-wavelength open-circuited lines;

FIG. 7 is a schematic diagram illustrating a series resonator formed, in accordance with the invention, of quarter-wavelength short-circuited lines;

FIG. 8 is a schematic diagram illustrating a parallel resonator formed, in accordance with the invention, of half-wavelength short-circuited lines;

FIG. 9 is a schematic diagram illustrating a series resonator formed, in accordance with the invention, of half-wavelength open-circuited lines;

FIG. 10 is a pictorial diagram illustrating the conductor pattern of a microstripline composite quarter-wavelength pair, parallel resonator formed in accordance with the invention; and,

FIG. 11 is a log-log graph illustrating the bandstop resonance frequency separation as a function of Q_L.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a schematic diagram of a lumped element parallel connected bandpass resonator having a center frequency f_0 and comprises a capacitor designated C1 connected in parallel with an inductor designated L1. The parallel combination of C1 and L1 are connected in parallel between input and output terminals **11, 11** and **13, 13**, respectively. In accordance with conventional terminology, the center frequency f_0 of the pass band equals $1/(2\pi \sqrt{LC})$ where L is equal to the inductance of L1 and C is equal to the capacitance of C1. In addition, the loaded Q, Q_L, for this circuit equals $2\pi f_0 C Z_0$, where all of the items are as previously defined and z_0 is equal to the impedance of the resonator at the point of resonance, i.e., z_0 is the characteristic impedance of the main transmission path.

It will be appreciated by those skilled in the art and others, that the parallel bandpass resonator illustrated in FIG. 1 can be realized by a parallel combination of bandstop resonators. An equivalent circuit of a pair of bandstop resonators of this nature is illustrated in FIG. 2. More specifically, the equivalent circuit illustrated in FIG. 2 comprises; two inductors designated L2 and L3; two capacitors designated C2 and C3; and, two resistors designated R2 and R3 that designate circuit loses. L2, C2, and R2 are connected in series as are L3, C3 and R3. The two series circuits are connected in parallel between the input terminals **11, 11** and the output terminals **13, 13.** The bandstop resonators, one of which is formed of L2, C2 and R2, and the other of which is formed of L3, C3 and R3, are centered at frequencies f_R^+ above and f_R^- below the desired resonator pass band, as given by $1/(2\pi \sqrt{L_2C_2})$ and $1/(2\pi \sqrt{L_3C_3})$, respectively. In addition, the resonators are chosen such that the sum of their individual susceptances, added in parallel, yields a high susceptance-slope parallel bandpass resonance (a total susceptance passing through zero with a high positive rate of change) at the desired center frequency f_0.

In a similar manner, a series bandpass resonator can be formed as a series combination of bandstop resonator pairs. This arrangement is illustrated in FIGS. 3 and 4. More specifically, FIG. 3 illustrates a series connected bandpass resonator, shown in lumped element form, that comprises an inductor designated L4 and a capacitor designated C4. L4 and C4 are connected in series between a pair of input terminals **15, 15** and a pair of output terminals **17, 17.** In this circuit f_0 is again equal to $1/(2\pi \sqrt{LC})$. However, Q_L now equals $2\pi f_0 L/Z_0$.

FIG. 4 is a series combination of a bandstop resonator pair which realizes the series bandpass resonator of FIG. 3. More specifically, FIG. 4 comprises: two inductors designated L5 and L6; two resistors designated R5 and R6 (representing circuit loses); and, two capacitors designated C5 and C6. L5, R5, and C5 are all connected in parallel, as are L6, C6 and R6. The two parallel circuits are connected in series between the input terminals **15, 15** and the output terminals **17, 17.** In the case of FIG. 4, the center frequencies of the bandstop resonators, f_R^+ above $[1/(2\pi \sqrt{L_5C_5})]$ and f_R^- below $[1/(2\pi \sqrt{L_6C_6})]$ the desired resonator pass band, are chosen such that the sum of their individual reactances, added in series, yield a high reactance-slope bandpass resonance at the desired center frequency f_0 (zero reactance, high positive reactance rate-of-change), rather than a high susceptance-slope.

The existance of bandpass resonance of the type described above arises from the requirement, usually referred to as Foster's reactance theorem, that the input reactance or susceptance of purely reactive one-port networks must, as a function of frequency, always exhibit positive slope and, therefore, must exhibit alternating zeros (bandpass resonances) and poles (bandstop resonances). This requirement is borne out by the representative susceptance-frequency and reactance-frequency behavoir illustrated in FIG. 5. This behavior characterizes parallel and series composite resonators. More specifically, FIG. 5 is a graph illustrating reactance or susceptance (depending upon whether a series or a parallel circuit is being considered) verses frequency. The solid lines represent the ideal situation where the resonator is entirely lossless. The dashed lines represent the practical situation where the resonator is slightly loosy. It is clear from the curves of FIG. 5 that the bandpass resonance at f_0, located between the bandstop resonances f_R^+ and f_R^-, has associated with it a susceptance or reactance slope at f_0 which increases with decreasing spacing between f_R^+ and f_R^-. Hence, the slope at f_0 and, hence, Q_L can be made arbitrarily high. It can also be seen from FIG. 5 that the presence of bandstop resonator losses have a negligible effect upon the composite resonator characteristic.

It will be appreciated by those skilled in the art and others and in accordance with the foregoing theory, as it is presently best understood, parallel and series composite resonators can be formed of transmission line components. Transmission line realizations of the parallel and series composite resonators using exclusively quarter-wave (at $f_R^{\pm}$) line lengths are illustrated in FIGS. 6 and 7. In addition, transmission line realizations of parallel and series composite resonators using exclusively half-wave (at $f_R^{\pm}$) line lengths are illustrated in FIGS. 8 and 9. FIG. 10 is an example of a conductor pattern in microstrip parallel resonator form. Such a resonator can be used, for example, as the signal circuit broadbanding element in an integrated circuit S-band parametric amplifier.

Turning now to a more specific description of the embodiments of the invention illustrated in FIG. 6–10, FIG. 6 illustrates a quarter-wavelength open-circuited transmission line bandstop resonator pair realization of a parallel bandpass resonator. More specifically, FIG. 6 comprises a pair of input terminals **19, 19** and a pair of output terminals **20, 20.** The upper input terminal **19** is connected to the upper output terminal **20** by an upper transmission line **21** and, the lower input terminal **19** is connected to lower output terminal **20** by a lower transmission line **22.** An upper resonator element **23** is connected to the upper transmission line **21** and extends orthogonally outwardly in opposite directions so as to define an upper plane. In one direction the line length of the upper resonator element is $\lambda^-/4$ and in the other direction the line length of the upper resonator element is $\lambda^+/4$. Similarly, a lower resonator element **25** is connected to the lower transmission line **22** and extends orthogonally outwardly in opposite directions so as to define a lower plane parallel to the upper plane. Again, in one direction the line length of the lower resonator element is $\lambda^-/4$ and in the other the line length is $\lambda^+/4$. $\lambda^-/4$ of the upper resonator element is parallel to $\lambda^-/4$ of the lower resonator element and $\lambda^+/4$ of the upper resonator element is parallel to $\lambda^+/4$ of the lower resonator element. In other words, FIG. 6 illustrates a pair of transmission lines each of which has coupled thereto a resonator element that extends a quarter-wavelength (either $\lambda^-/4$ or $\lambda^+/4$) from each transmission line in opposite directions. The resonator elements are open-circuited, i.e., they are not connected together. Hence, FIG. 6 illustrates a bandpass resonator formed of a pair of quarter-wavelength, open-circuited, parallel-connected bandstop resonators.

FIG. 7 illustrates a pair of input terminals **27, 27** and a pair of output terminals **29, 29**. FIG. 7 also illustrates an upper transmission line broken into first and second sections **31** and **33** and a lower transmission line broken into first and second sections **35** and **37**. FIG. 7 further illustrates an upper resonator comprising first and second resonator elements **39** and **41** and a short circuiting element **43**. Finally, FIG. 7 illustrates a lower resonator element comprising first and second resonator elements **45** and **47** and a short circuiting element **49**. All of the resonator elements are quarter-wavelength resonator elements with the upper elements being $\lambda_R^+/4$ long and the lower resonator elements being $\lambda_R^-/4$ long.

The upper terminal **27** is connected via the first section **31** of the upper transmission line to one end of the first upper resonator element **39**. The other end of the first upper resonator element **39** is connected via the short circuiting element **43** to one end of the second upper resonator element **41**. The other end of the second upper resonator element **41** is connected via the second section **33** of the upper transmission line to the upper output terminal **29**. In a similar manner, the lower input terminal is connected via the first section **35** of the lower transmission line to one end of the first lower resonator element **45**. The other end of the first lower resonator element **45** is connected via the short circuiting element **49** to one end of the second lower resonator element **47**. The other end of the second lower resonator element **47** is connected via the second section **37** of the lower transmission line to the lower output terminal **29**. Hence, FIG. 7 illustrates a bandpass resonator formed of a pair of series-connected, quarter-wavelength, short-circuited bandstop resonators.

FIG. 8 schematically illustrates a pair of input terminals **51, 51** and a pair of output terminals **53, 53** interconnected by upper and lower transmission lines **55** and **59**, respectively. An upper resonator element **61** is connected to the upper transmission line **55** and extends orthogonally outwardly in opposite directions so as to define an upper plane. In one direction the line length of the upper resonator element is $\lambda_R^+/2$ and in the other direction the line length is $\lambda_R^-/2$. A lower resonator element **63** is connected to the lower transmission line **59** and extends orthogonally outwardly in opposite directions so as to define a lower plane parallel to the upper plane. Again, the line length is $\lambda_R^+/2$ in one direction and $\lambda_R^-/2$ in the other direction. Thus, the upper and lower resonator elements **61** and **63** are oriented in parallel. The adjacent ends of the resonator elements **61** and **63** are connected together via connecting elements **65** and **67**, respectively. Hence, FIG. 8 schematically illustrates a bandpass resonator formed of a pair of parallel-connected, short-circuited, half-wavelength bandstop resonators.

FIG. 9 illustrates an embodiment of the invention having input terminals **69, 69** and output terminals **71, 71**. FIG. 9 also illustrates an upper transmission line having first and second sections **73** and **75** and a lower transmission line having first and second sections **77** and **79**. FIG. 9 further illustrates an upper resonator comprising first and second resonator elements **81** and **83** and a lower resonator comprising first and second elements **85** and **87**. The upper input terminal **69** is connected via the first section **73** of the upper transmission line to one end of the first upper radiator element **31**. The upper output terminal **71** is connected via a second section **75** of the upper transmission line to one end of the second upper resonator element **83**. The other ends of the first and second upper resonator elements **81** and **83** are unconnected, however, they are arrayed in parallel. The lower input terminal **69** is connected to one end of the first lower resonator element **85** via the first section **77** of the lower transmission line. Similarly, the lower output terminal is connected to one end of the second lower resonator element **87** via the second section **79** of the lower transmission line. The other ends of the lower resonator elements **85** and **87** are unconnected. Again, the resonator elements are arrayed in parallel. The upper resonator elements are $\lambda_R^-/2$ long and the lower resonator elements are $\lambda_R^+/2$ long. It will be appreciated from the foregoing description and viewing FIG. 9 that a bandpass resonator formed of a pair of series-connected, open-circuited, half-wavelength bandstop resonators is described and illustrated.

It will be appreciated that while FIGS. 6–9 illustrate schematically the preferred forms of the invention, there are various ways of practically creating a transmission line and resonator elements in the desired manner. One such way is using microstripline technology as illustrated in FIG. 10. More specifically, FIG. **10** illustrates, in pictorial form, the upper transmission line **21** of FIG. **6** and the upper resonator element **23** that extends orthogonally outwardly a quarter-wavelength ($\lambda_R^+/4$ and $\lambda_R^-/4$) in either direction in microstripline form. By separating two such elements into parallel planes, separated by a dielectric, a physical embodiment of the invention is created. In a similar manner, physical structures of the invention corresponding to FIG. **7, 8** and **9** can be practically formed. However, it should be noted that the invention is not limited to utilization in microstripline form. Striplines and other transmission lines, such as co-axial transmission lines can also be used to structurally form the invention.

Turning now to a further description of the theory of operation of the invention, it will be shown that each of the transmission line resonators illustrated in FIGS. 6–9 can yield an arbitrarily high Q_L with reasonable values of characteristic impedance Z_R, where Z_R is the characteristic impedance of the resonator transmission lines. Quantitatively, the "load selectivity", Q_L, and the center frequency, f_O, of a composite bandpass resonator are obtained from the expression for total resonator susceptance, B_{inT}, or reactance, X_{inT}, in terms of the resonant frequencies ($f_R^{\pm}$) and Q_R's or characteristic impedances Z_R of the individual bandstop resonators. More specifically, Q_L can be calculated from the following formula:

$$Q_L \approx (1/2Q_R)\,(1 + (4/B_R^2)) \tag{1}$$

In addition, the center frequency, f_O, can be calculated from the following equation:

$$f_O = (2f_R^+ f_R^-)/(f_R^+ + f_R^-) \qquad (2)$$

Conversely, the requirements on Q_R and $f_R \pm$ to achieve a specified Q_L and f_O, obtainable by the simultaneous solution of equations 1 and 2, are given by:

$$f_R \pm \cong (f_O/2)\,[1 \pm K + \sqrt{1 + K^2}] \qquad (3)$$

$$B_R = [(f_R^+ - f_R^-)/2] = K \equiv (2\sqrt{2Q_L Q_R - 1}) \qquad (4)$$

For the equations herein used, the following relationship and definitions hold:

$$X_{inT} = X_{inR}^+ = X_{inR}^-$$

$$B_{inT} = B_{inR}^+ + B_{inR}^-$$

$$Q_L = \frac{f_0}{2Z_0}\frac{dx_{inT}}{df}\Big]_{f_0} \text{ or } \frac{f_R}{2} Z_0 \frac{dB_{inT}}{df}\Big]_{f_R}$$

$$Q_R = \frac{f_R^{\pm}}{2} Z_R \frac{dB_{inR}^{\pm}}{df}\Big]_{f_R^{\pm}} \text{ or } \frac{f_R^{\pm}}{2Z_R}\frac{dX_{inR}^{\pm}}{df}\Big]_{f_R^{\pm}}$$

$$\sqrt{2Q_L/Q_R}$$

f_R^+, f_R^- = the resonant frequencies of the individual bandstop resonators

Z_O = the reference impedance level of the circuit

Z_R = the characteristic impedances of the resonators

B_R = the bandstop resonant separation bandwith

$$[(f_R^+ - f_R^-)\,/\,f_O]$$

$B^{\pm}_{inR}$ ($X^{\pm}_{inR}$) = input suceptances (reactances) of individual bandstop resonators

The fractional or bandstop resonant separation bandwidth, B_R, between stop-band resonances is generally considerably greater than B_L, useful bandwidth of the filter or impedence matching network in which the composite resonator is being utilized (B_L is in the order of $1/Q_L$ and $B_R Q_L \sim \sqrt{2Q_L/Q_R} >> 1$). Therefore, the stop band "skirt" resonances will generally not perturb the resonator passband.

The relationship between Q_R and the characteristic impedence, Z_R, of the various bandstop transmission line elements comprising the composite resonator as illustrated in FIGS. 6–9 are summarized as follows:

parallel $\lambda_R/4$ open-circuited resonator: $Q_R = (\pi/4)(Z_R/Z_O)$

parallel $\lambda_R/2$ short-circuited resonator: $Q_R = (\pi/2)(Z_R/Z_O)$

series $\lambda_R/4$ short-circuited resonator: Q_R $(\pi/4)(Z_O/Z_R)$

series $\lambda_R/2$ open-circuited resonator: $Q_R = (\pi/2)(Z_O/Z_R)$

As an example of the orders of magnitude involved, a family of curves depicting the normalized frequency separation or fractional bandwidth, B_R, between stop band resonances $f_R \pm$ as a function of the loaded selectivity Q_L of the resulting bandpass resonator is illustrated in FIG. 11. A curve is illustrated for each of the above described stop band resonators with the impedance ratio Z_R/Z_O as a curve parameter. In FIG. 11, this parameter is illustrated for the quarter-wavelength resonators on the left side and for the half-wavelength resonators on the right side.

Examination of FIG. 11 indicates that, as an example, bandpass resonators for 5 percent bandwidth circuits ($Q_L \approx 20$) can be realized in a transmission line at the given circuit impedance level ($Z_R \approx Z_O$) using composite bandstop resonators with center frequencies spaced about f_O with greater than 25 percent separation bandwidth ($B_R > 0.25$). It will be appreciated that realization of the same Q_L using a single transmission line bandpass resonator would require an unrealizable resonator characteristic impedance ($Z_R/Z_O \geq 10$ or ≤ 0.1).

A microstrip parallel-connected composite bandstop type bandpass resonator such as herein described has been utilized as the signal circuit broad banding element in a microstrip single-stage S-band parametric amplifier. The resonator was formed in the manner illustrated in FIG. 10 and met the following design parameters:

Z_O = 8 ohms (circulator junction impedance level)

Z_R = 20 ohms

f_O = 2.25 GHz

Q_L = 15 (for ldb overcoupled gain response in the amplifier)

$Q_R = \pi 4\,(ZR/Z_O) \approx 1.95$

Using the foregoing parameters and equations 4 and 5 yields that the bandstop resonator center frequencies are:

$$f_R^+ \approx 2.85 \text{ GHz}, f_R^- \approx 2.00 \text{ GHz}$$

The use of this broadbanding resonator enabled the realization of a 1db equiripple amplifier gain response having 15db maximum gain in about a 100 MHz equiripple bandwidth. To achieve equivalent results using a pair of parallel-connected, half-wavelength, open-circuited (at f_O) bandpass resonators would have required a resonator characteristic impedance of less than 2 ohms. It will be appreciated that such a characteristic impedance cannot be realized in microstrip transmission lines without introducing intolerable junction and multimoding effects.

In addition to its use in parametric amplifiers, it will be appreciated that composite bandstop resonator pairs used as high-Q_L bandpass resonators will similarly facilitate the realization of narrow band transmission line filters and impedance matching networks. In addition, they can also be utilized to realize high selectivity oscillator resonators.

It will be appreciated from the foregoing description that the invention provides novel bandpass resonators formed from a pair of composite bandstop resonators that can be formed of quarter of half-wavelength components. While the preferred structural embodiments of the invention are in microstripline form, they can also be embodied in stripline or other transmission line forms. Hence, the invention can be practiced otherwise than as specifically described herein.

What is claimed is:

1. A high-Q bandpass resonator having a center frequency fo comprising:

first R resonator having $(\pi/4)$ frequency Z_{fR+}, f_{R+} being greater than f_o, which is a composite transmission line element that is a half wavelength long at frequency f_{R+} and is short-circuited; and

a second bandstop resonator having a center frequency f_{R-}, f_{R-}being less than f_o, which is a composite transmission line element that is half wavelength long at frequency f_{R-} and is short-circuited; where said first and second bandstop resonators are parallel-connected.

2. A high-Q bandpass resonator as claimed in claim 1 formed of microstipline transmission line elements.

* * * * *