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# [54] RESONATOR INTERCONNECTIONS IN MONOLITHIC CRYSTAL FILTERS

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[21] Appl. No.: **183,863**

[52] **U.S. Cl.** ........................ **333/72,** 310/9.8, 333/70
[51] **Int. Cl.** ........................ **H03h 7/10,** H03h 9/00
[58] **Field of Search** .................. 333/70, 72; 310/9.8

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*Assistant Examiner*—Saxfield Chatmon, Jr.
*Attorney*—W. L. Keefauver

## [57] ABSTRACT

In a multiresonator modified monolithic crystal filter employing a combination of mass loading and acoustic coupling, a direct nongrounded conductor, external to the piezoelectric body between two of the resonators, establishes a second transmission path through the filter. Attenuation peaks with control over their position are established thereby which enhances filter selectivity.

**14 Claims, 18 Drawing Figures**

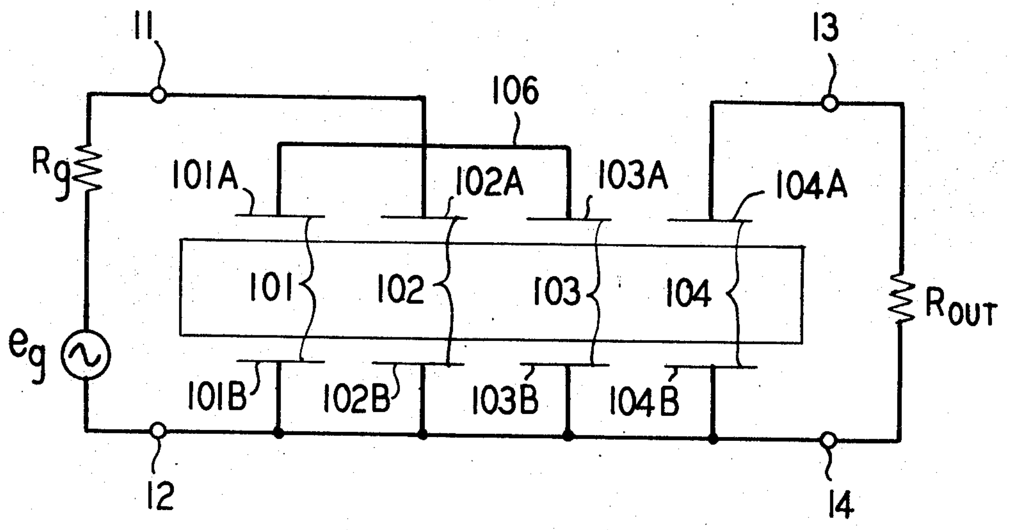
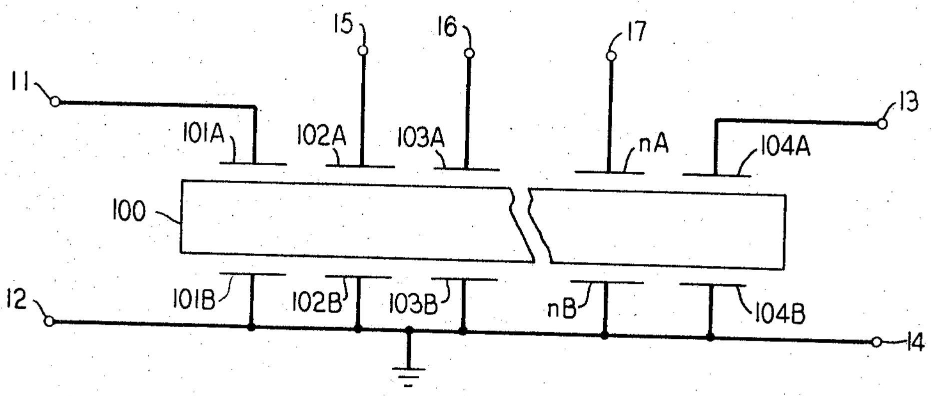


FIG. 1A


15
16
17
11
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101A
102A
103A
nA
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12
101B
102B
103B
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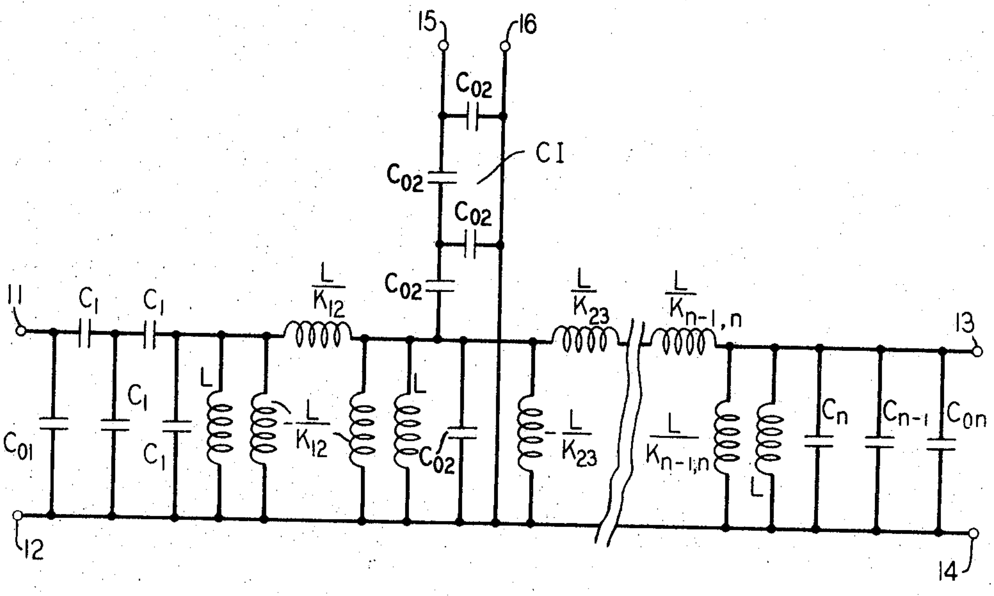
104B
14

FIG. 1B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16
C02
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CI
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11
C1
C1
L/K12
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C1
C1
L
-L/K12
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L
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Cn-1
C0n
12
14

FIG. 2A

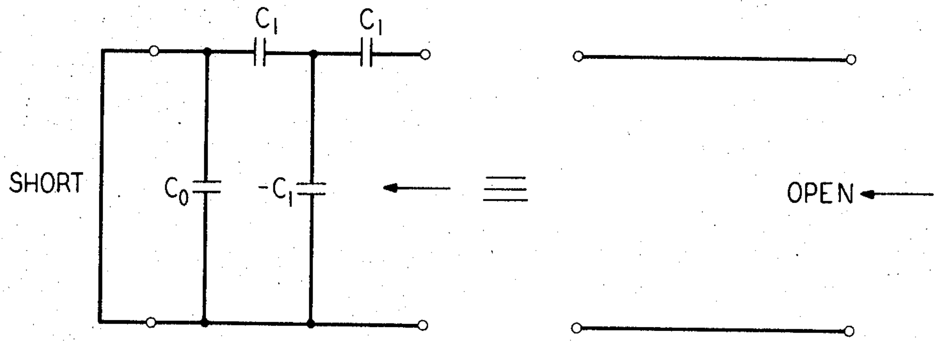


FIG. 2B

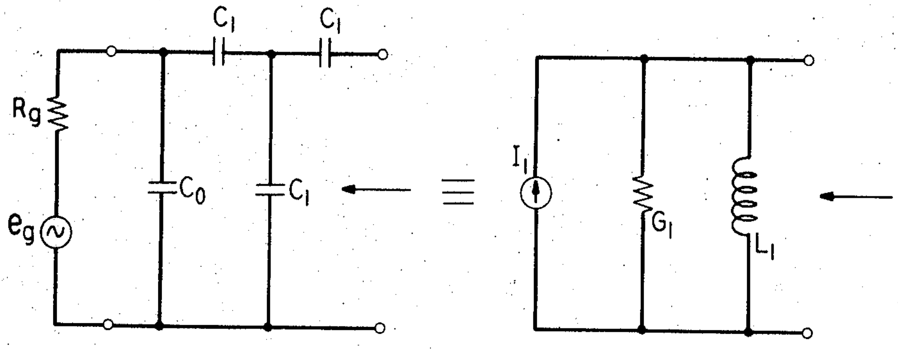


FIG. 2C

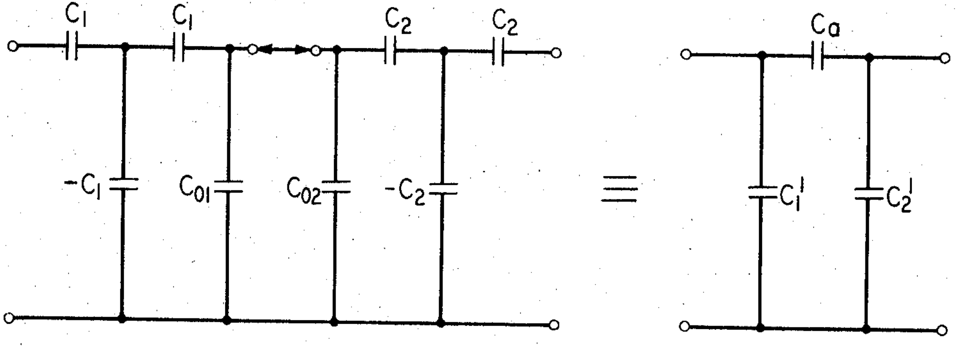


FIG. 3A

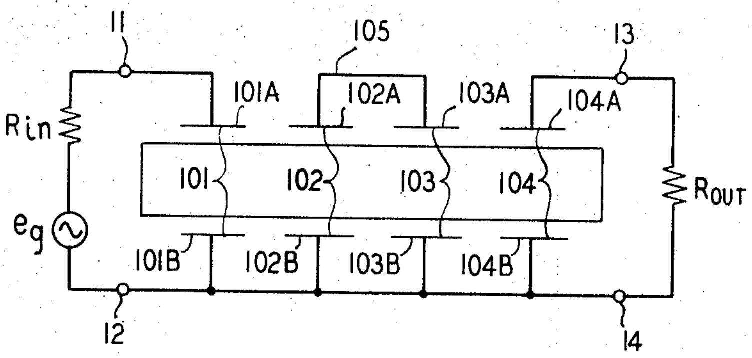


FIG. 3B

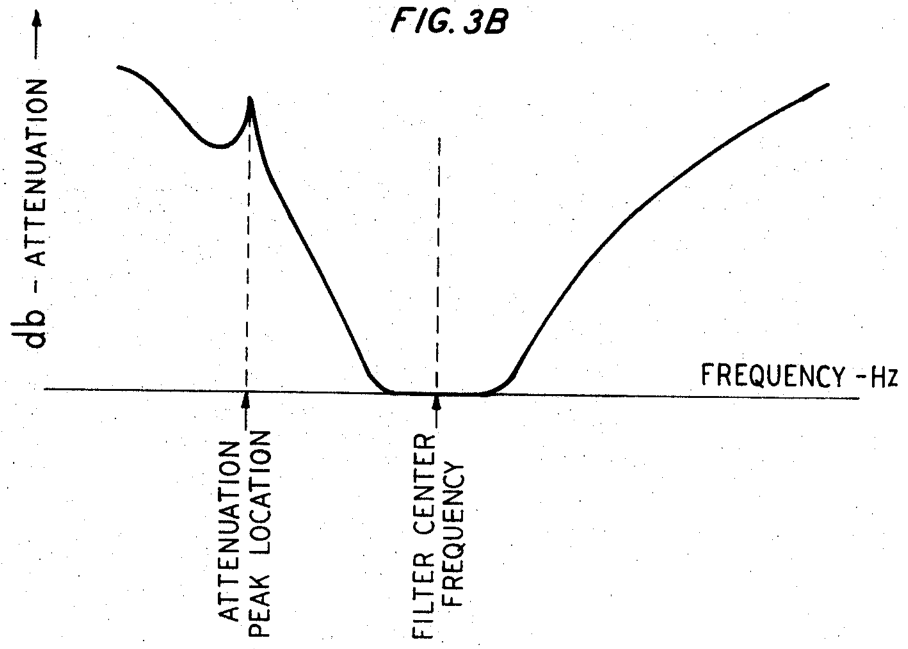


FIG. 4

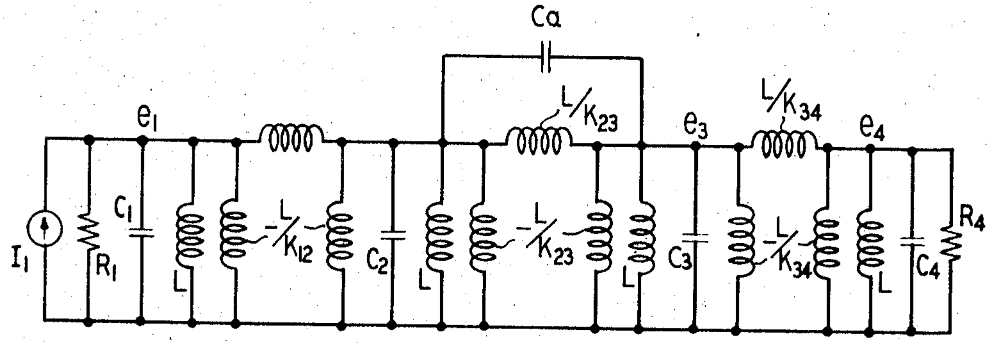


FIG. 5A

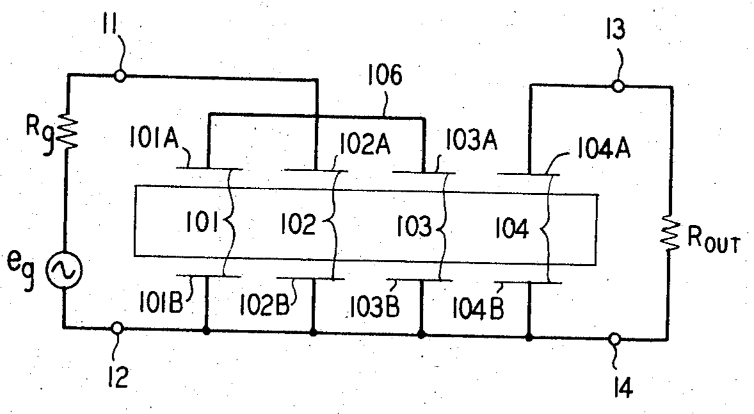


FIG. 5B

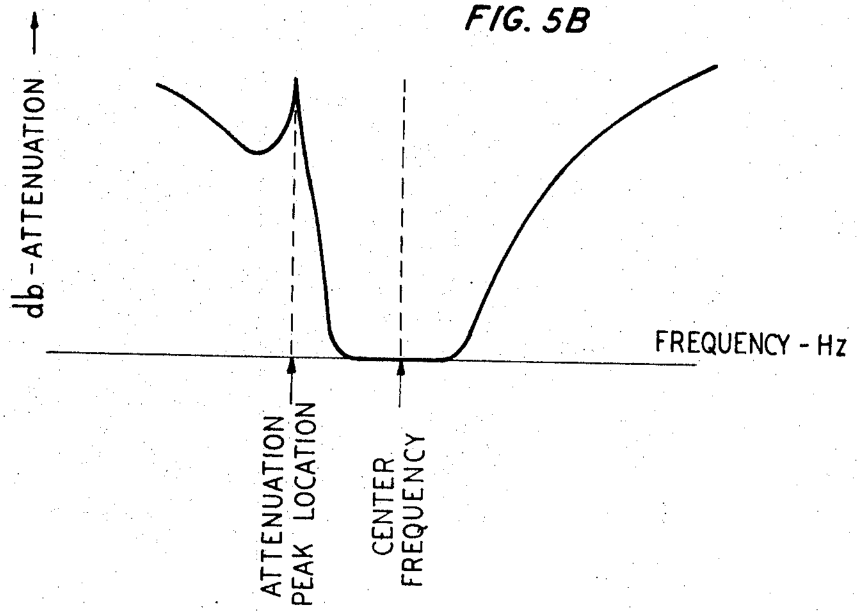


FIG. 6

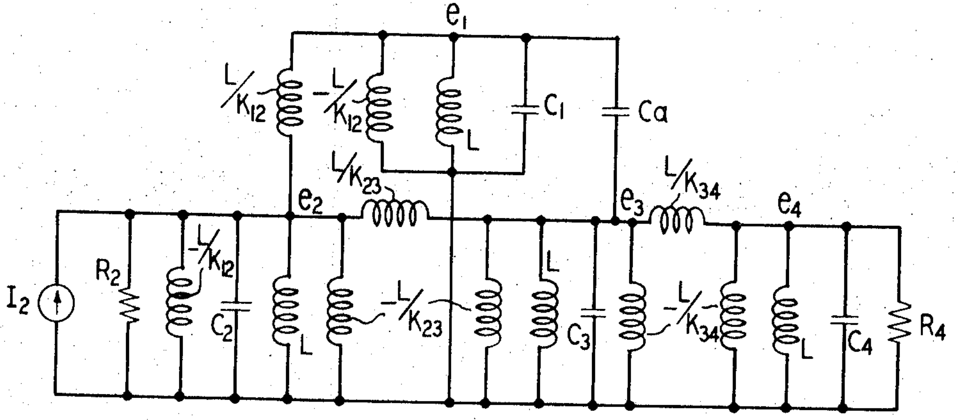


FIG. 7A

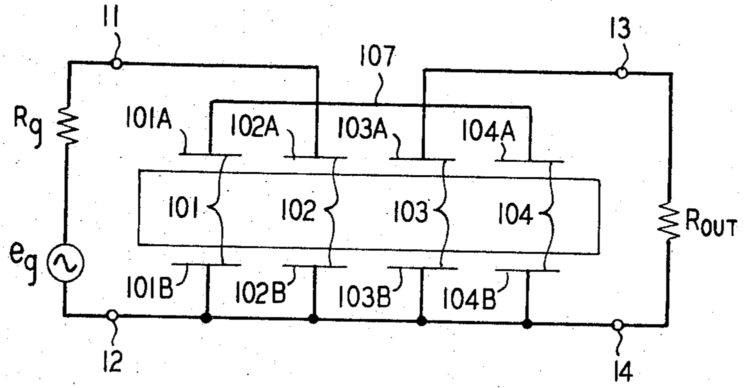


FIG. 7B

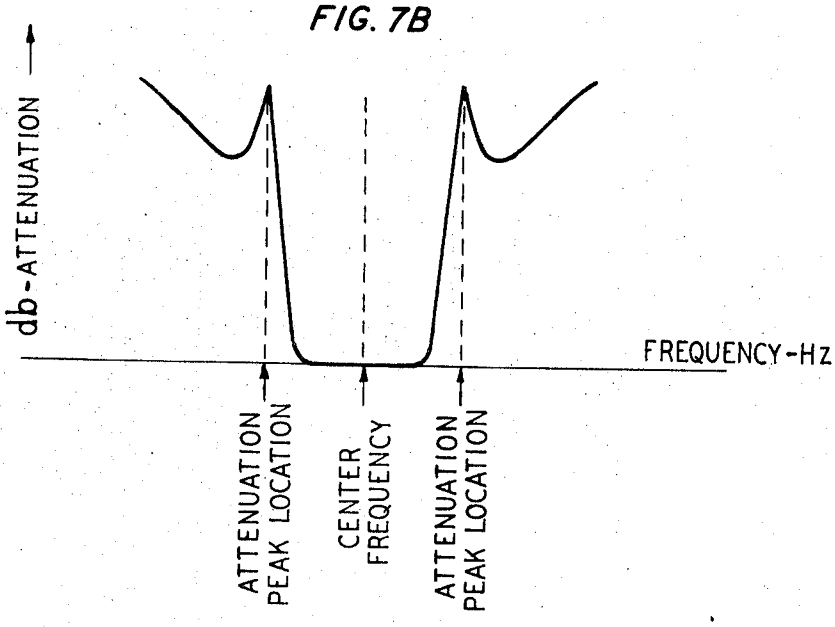


FIG. 8

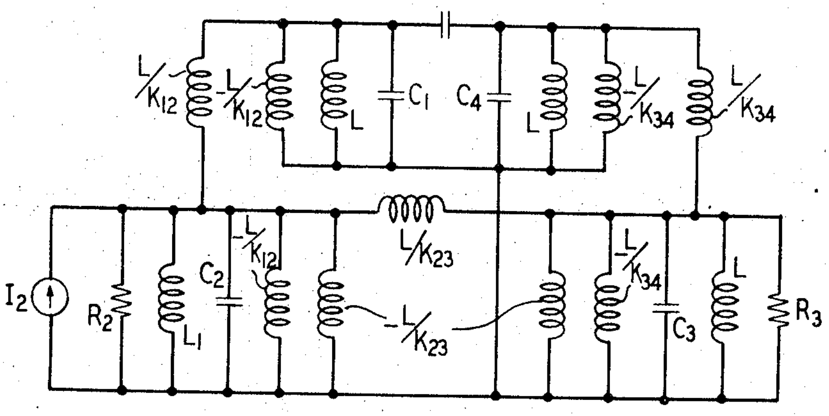


FIG. 9A

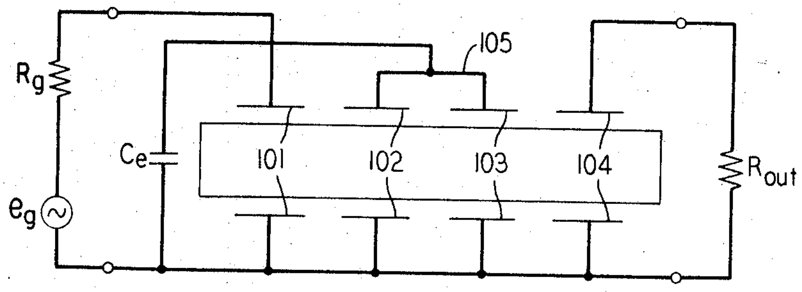


FIG. 9B

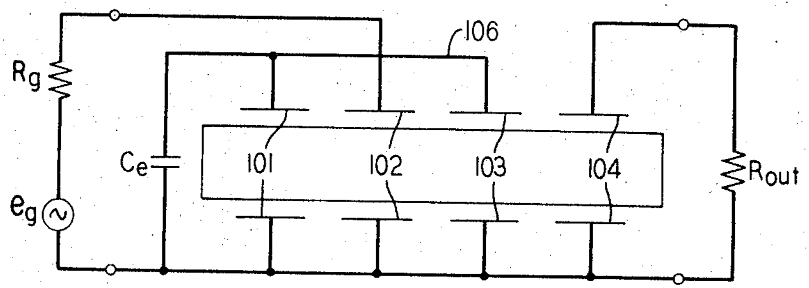


FIG. 9C

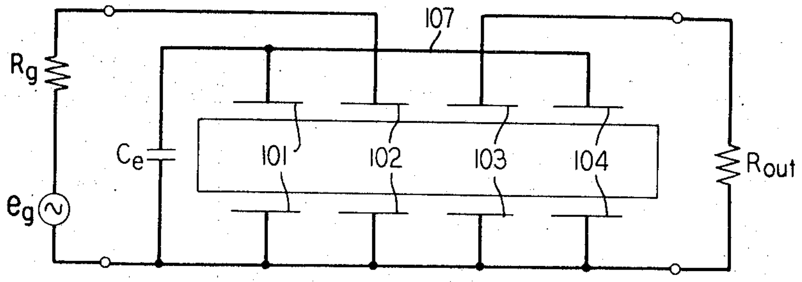
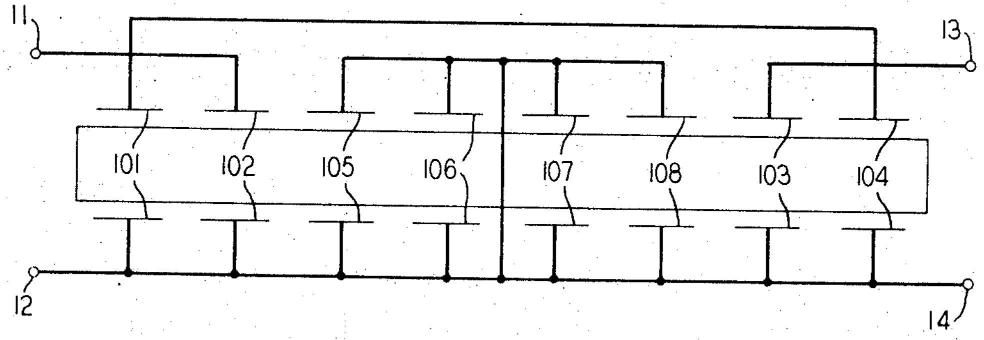


FIG. 10



# RESONATOR INTERCONNECTIONS IN MONOLITHIC CRYSTAL FILTERS

## BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to energy translating devices and, more particularly, to monolithic crystal filters.

2. Description of the Prior Art

The term "monolithic crystal filter" as used herein is meant to define the basic filter structure disclosed in U.S. Pat. No. 3,564,463, issued on Feb. 16, 1971 to W. B. Beaver and R. A. Sykes. In its broadest terms, the Beaver-Sykes apparatus is an energy translating device for translating input oscillatory electrical energy having first characteristics into output oscillatory electrical energy having second characteristics. One specific use to which such a structure may be put is that of a filter, typically a bandpass filter. In terms of structure, such a filter involves the use of a plurality of resonators which share a common piezoelectric body or wafer. The Beaver-Sykes structure is distinguished from other outwardly similar structures by the combination of two features, namely, mass loading and acoustic coupling. The term "mass loading" refers to a particular electrode mass which is determined by the nature of the piezoelectric body and its thickness, and by the size and density of the electrodes which make up each of the resonators.

Mass loading, which conforms to the principles taught by Beaver and Sykes, is evidenced by a number of specific conditions. For example, acoustic energy supplied in or near to one of the resonators is essentially confined or trapped within the boundaries of the resonator so that very little escapes to the surrounding piezoelectric body. Also, the relatively limited amount of acoustic energy that does escape from the energy trapping action of the resonators decreases exponentially in magnitude as the distance from the resonator increases. Further, the contour and dimensions of the outer perimeter of the piezoelectric body have no effect on the nature of the energy transmission accomplished. Finally, with the proper mass loading, there is a substantial difference between the resonant frequency of the resonators and the resonant frequency of the unloaded portions of the piezoelectric body.

Acoustic coupling, the second of the key distinguishing features of a Beaver-Sykes-type filter, refers to the existence of an energy channel in the piezoelectric body which effects the transmission of acoustic energy between input and output electrodes. Such coupling is evidenced or manifested by a number of conditions which include, for example, the placing of all resonators within the acoustic field of adjacent resonators. Heretofore, in monolithic crystal filters of the type described, the only physical connecting path between the input and output resonators is in the piezoelectric body and substantially all of the energy transferred from one resonator to another is acoustic energy.

By virtue of the combination of the features of mass loading and acoustic coupling, the image impedance of the structure or circuit, as a whole, conforms to a specifically defined pattern. Additionally, the structure or circuit, as a whole, has an equivalent circuit in the form of a lattice network with resonant and antiresonant frequencies characterized by a specifically defined relation.

In order to ensure the sharpest possible cutoff action, and a corresponding high degree of selectivity, the transfer characteristics of any effective band filter, including a monolithic crystal filter, should be marked by steep skirts of attenuation and the passband should be bracketed by distinct attenuating peaks. Monolithic crystal filters have been traditionally designed and used as all pole devices and, in those instances where sharper skirts are desired, it is conventional to increase the order of the transfer function which physically means to increase the number of resonators. Although 16th order (8 resonator) monolithic crystal filters (MCFs) are known in commercial use, it is evident that increases in the order of the filtering function necessarily increases the complexity and cost of manufacture.

An alternate method for realizing sharper skirts in MCFs, is to introduce transmission zeros close to the passband. In the past, this method has been carried out by both charge cancellation and by phase cancellation. Charge cancellation depends on the interconnection of split electrodes to transfer charge from one resonator to another. At certain frequencies, however, charge cancellation has the effect of inhibiting the electric field across the resonators used to generate the charge transfer, thereby realizing transmission zeros at these frequencies. Attenuation peak location has been shown to depend on and therefore to be controlled by the area ratio of the split electrode. Thus far, however, the effectiveness of this technique has been limited to a two-resonator MCF.

Phase cancellation, on the other hand, depends on generating two outputs equal in magnitude and opposite in phase at specified frequencies. Upon tying these two outputs together, transmission zeros may be realized at the specified frequencies. In the employment of the phase cancellation technique, however, an example of which is shown in my copending application, Ser. No. 63,204, filed Aug. 12, 1970, it has been found that the peak locations can generally be realized only at discrete frequencies.

A general object of the invention, therefore, is to improve the transmission characteristics of monolithic crystal filters by the establishment of controllable transmission zeros relatively close to the passband while avoiding, however, the shortcomings encountered in the charge and phase cancellation methods.

## SUMMARY OF THE INVENTION

The stated object and related objects are achieved in accordance with the principles of the invention by modifying an otherwise conventional MCF by the employment of resonator interconnections that, in effect, establish a second transmission path through the filter. This supplemental path is in addition to the normal or direct path that is provided solely by the common piezoelectric body. The invention is not restricted to any single or specific resonator interconnection but, instead, may be practiced in a variety of different forms or circuit configurations. A single key feature, however, characterizes all of the embodiments of the invention. Specifically, that feature, as indicated, is the use of an ungrounded conducting path which is connected between two nonshorted resonators and which is external to the piezoelectric body. Thus, a filter in accordance with the invention has two transmission paths in parallel one being the conventional path from one acoustically coupled resonator to the next, which path is restricted to the piezoelectric body, and the other being the ungrounded path utilizing the external conductor that is connected between the two nonshorted resonators. The phase differences that arise by virtue of the two transmission paths result in selective cancellation or reinforcement of various frequencies. Stated otherwise, the passband is shaped by the introduction of transmission zeros relatively close to the passband so that the skirts of the characteristic filter transmission plot are steepened or sharpened, thereby enhancing filter selectivity. The wide number of forms in which the invention may be practiced stems from the fact that either high order filters (many resonators) or low order filters (few resonators) may be employed and further from the fact that a variety of resonator interconnection combinations fall within the principles of the invention.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1A is a sketch of a conventional n-resonator MCF;

FIG. 1B is a schematic circuit diagram of an equivalent circuit for the MCF of FIG. 1A;

FIGS. 2A, 2B and 2C are schematic circuit diagrams illustrating network transformations;

FIG. 3A is a schematic circuit diagram of a first embodiment of the invention;

FIG. 3B is a plot of the transfer characteristics to be expected from the filter of FIG. 3A;

FIG. 4 is a schematic circuit diagram of an equivalent circuit of the MCF filter of FIG. 3A;

FIG. 5A is a schematic circuit diagram of a second embodiment of the invention;

FIG. 5B is a plot of the transfer characteristics to be expected from the filter of FIG. 5A;

FIG. 6 is a schematic circuit diagram of an equivalent circuit for the filter of FIG. 5A;

FIG. 7A is a schematic circuit diagram of a third embodiment of the invention;

FIG. 7B is a plot of the transfer characteristics to be expected from the filter of FIG. 7B;

FIG. 8 is a schematic circuit diagram of an equivalent circuit for the filter of FIG. 7A;

FIGS. 9A, 9B and 9C illustrate the use of an external capacitor to control the position of transmission zeros in different embodiments of the invention; and

FIG. 10 is a schematic circuit diagram of an 8-resonator MCF in accordance with the invention.

## DETAILED DESCRIPTION

As indicated above, prior art MCFs typically employ a plurality of internal resonators (i.e., excluding the input and output resonators) which are normally shorted to ground since it is known that the short circuit provides the simplest and most reliable type of resonator termination. In accordance with the invention, however, filters with other than all pole designs are realized by selectively interconnecting certain ones of the internal resonators without, however, grounding the interconnected portions of those resonators. The underlying theory of the invention may best be explained in terms of the sketch of a conventional monolithic crystal filter shown in FIG. 1A as supplemented by its equivalent circuit shown in FIG. 1B. As shown in the sketch, a conventional MCF employs a piezoelectric body **100** sandwiched between a plurality of electrode pairs **101A–B, 102A–B, 103A–B,** ***n*****A–B** and **104A–B** to form an input resonator **101,** an output resonator **104** and intermediate or auxiliary resonators **102, 103** – – – *n*. A signal source, not shown, is normally connected across the input points **11–12** and a load or utilization circuit is connected across the output points **13–14.** One side of the filter, which includes the input terminal **12,** the electrodes **101B, 102B,** ***n*****B** and **104B** and the output terminal **14** is connected to a source of reference potential such as ground. In FIG. **1A** the auxiliary resonators **102, 103** and *n* are shown open circuited simply by way of illustration. More generally, these resonators are shorted and connected to ground.

In the equivalent circuit of an n-resonator MCF shown in FIG. **1B**, series capacitors $C_1$– – – $C_n$ and series inductors $L/K_{12}, L/K_{23}, \ldots L/K_{n-1,\,n}$ are combined with shunt capacitors $C_{02}, -C_1, C_1, C_2, \ldots C_n, -C_n, C_{on}$ and shunt inductors $L, -L/K_{12}, -L/K_{23} \ldots L/K_{n-1}, n$, where Kij is the coupling coefficient. The branch including the two series capacitors $C_2$ and the shunt capacitors $-C_2$ and $C_{02}$ is a capacitive inverter CI which represents the piezoelectric coupling.

In analyzing the foregoing circuits it is necessary at the outset to define two sets of terminals, namely, the external terminals and the internal terminals. The external terminals comprise the terminal set **11–12** and **13–14** located between the outside world and the MCF, i.e., the physical leads. The internal terminals, on the other hand, consist of the nodes of the resonator such as nodes **15, 16** and **17** of FIG. **1A**. In terms of the equivalent circuit of FIG. **1A**, which is shown in FIG. **1B**, however, the only difference between the two sets is the capacitive inverter CI which, as stated above, represents the piezoelectric coupling. For reasons which will become apparent, it is desirable to write the matrix description of the network in terms of the internal terminals. Accordingly, the effect of interconnecting the external terminals must be transformed onto the internal terminals through the capacitive inverter CI.

It is evident that the only termination that can appear across the external terminals of a resonator is:

1. a short circuit,
2. a source or a load, or
3. another resonator.

The effect of these terminations as seen by the internal terminals is illustrated by the transformations shown in FIGS. **2A, 2B** and **2C**, respectively. Thus, in FIG. **2A** the resonator equivalent consisting of the two series capacitors $C_1$ and the shunt capacitors $C_0$, $-C_1$ is transformed into an open circuit by the shorting termination. In FIG. **2B** a source $R_g$ termination is transformed into an inductance $L_1$ and a conductance $G_1$ in shunt with a current source $I_1$ where:

$$I_1 = j\,(e_g/K);\ K = 1/\omega_0 C_1; \qquad (1)$$

$$G_1 = R_g/K^2;\ \omega_0 = \text{center frequency; and} \qquad (2)$$

$$L_1 = (K^2/C_0)\cdot[1/(R_g\omega_0)^2]. \qquad (3)$$

In FIG. **2C** the resonator termination results in the transformation represented by a capacitor *Ca* shunted by capacitors $C_1$ and $C_2$ where:

$$Ca = (C_1C_2)/(C_{01}+C_{02}); \tag{4}$$

$$C_1' = -C_1 \cdot [(C_1+C_2)/(C_{01}+C_{02})]; \text{ and} \tag{5}$$

$$C_2' = -C_2 \cdot [(C_1+C_2)/(C_{01}+C_{02})]. \tag{6}$$

Based on the transformations shown, one may conclude that the internal terminals of the input resonator can only be terminated in the shunt combination of a conductance, an inductance and a current source, and the internal terminals of the output resonator can only be terminated in the shunt combination of a conductance and an inductance. Furthermore, the internal terminals of the auxiliary or remaining resonators can only be terminated in an open circuit or coupled to another resonator through a capacitive $\pi$. In other words, interconnecting the external terminals of two resonators is equivalent to capacitively coupling their respective internal terminals and slightly mistuning the resonators being interconnected, the mistuning being the result of the shunt capacitors of the capacitive $\pi$. This arrangement has the effect, in accordance with the invention, of generating transmission zeros in a MCF. Three cases will be discussed to illustrate how these transmission zeros are established and, from these illustrative cases, it will be evident that the same principles may be applied in accordance with the invention to any monolithic crystal filter that includes two or more auxiliary (non-input or output) resonators. The first two cases realize one transmission zero below the passband and the third case realizes a pair of transmission zeros, one on either side of the band.

Case 1

Consider, first, the case of the filter structure shown in FIG. 3A, which includes an input resonator **101**, an output resonator **104**, and two auxiliary resonators **102** and **103**. Each of the latter two resonators has a respective top electrode **102A** and **103A** which are connected together by a floating conducting path **105**, whereas the bottom electrodes **102B** and **103B**, along with electrodes **101B** and **104B**, are connected to a common reference potential point which may be ground. Using the transformations of FIGS. 2A, 2B and 2C on the equivalent circuit shown in FIG. 1B, one obtains the equivalent circuit shown in FIG. **4**, i.e., a circuit which is equivalent to the filter of FIG. 3A.

The matrix description for this four node circuit is given by:

$$\begin{bmatrix} I_1 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{11} & -Y_{12} & -Y_{13} & -Y_{14} \\ -Y_{21} & Y_{22} & -Y_{23} & -Y_{24} \\ -Y_{31} & -Y_{32} & Y_{33} & -Y_{34} \\ -Y_{41} & -Y_{42} & -Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix} \tag{7}$$

where: $Y_{ii}$ is the admittance common to node $i$.

$Y_{ij}$ is the admittance between nodes $i$ and $j$.

From these equations one can obtain the transfer impedance as follows:

$$Z_t \overset{\Delta}{=} (e_4/I_1) \tag{8}$$

$$Z_t = \frac{\begin{vmatrix} -Y_{21} & Y_{22} & -Y_{23} \\ -Y_{31} & -Y_{32} & Y_3 \\ -Y_{41} & -Y_{42} & -Y_{43} \end{vmatrix}}{|\Delta|} = N/D \tag{9}$$

where:

$Z_t$ = transfer impedance and

$|\Delta|$ = determinant of admittance matrix.

Using $S$ as the complex frequency in the circuit of FIG. 4 one has:

$$Y_{11} = G_1 + SC_1 + 1/SL\ ; \tag{10}$$

$$Y_{22} = SC_2 + 1/SL + S\ Ca\ ; \tag{11}$$

$$Y_{33} = SC_3 + 1/SL + S\ Ca\ ; \tag{12}$$

$$Y_{44} = G_4 + SC_4 + 1/SL\ ; \tag{13}$$

$$Y_{13} = Y_{14} = Y_{24} = 0\ ; \tag{14}$$

$$Y_{12} = k_{12}/SL\ ; \tag{15}$$

$$Y_{23} = S\ Ca + k_{23}/SL\ ; \tag{16}$$

and

$$Y_{34} = k_{34}/SL\ . \tag{17}$$

Using the equations (10) through (17), the numerator of equation (9) becomes:

$$N = (k_{12}/SL) \cdot (k_{34}/SL) \cdot [S\ Ca + (k_{23}/SL)]. \tag{18}$$

Note that in this case the numerator of the transfer function is no longer a constant independent of frequency but a polynomial in the complex variable $S$. This necessarily implies that transmission zeros have been realized at those frequencies where equation (12) goes to zero. For the present case the location of these transmission zeros is given by:

$$S\ \mathrm{Ca} + (K_{23}/SL) = 0 \tag{19}$$

or:

$$S = \pm j\ \sqrt{k_{23}/LCa}\ . \tag{20}$$

It is clear, therefore, that the transmission zero, realized in accordance with the invention in the manner described, may be controlled by the coupling coefficient $K_{23}$ and by the capacitance $Ca$. Furthermore, as indicated above, the transmission zero will lie below the passband.

Case 2

The four resonator MCF of FIG. 5A differs from the MCF of FIG. 3A only in the resonator interconnections. In FIG. 5A the functions of the resonators **101** and **102** are reversed so that resonator **101** is an auxiliary resonator and **102** is the input resonator. Auxiliary resonators **101** and **103** are connected by a floating conducting path **106**. Employing the transformations illustrated in FIGS. **2A**, **2B** and **2C** on the equivalent circuit shown in FIG. **1B** results in the circuit of FIG. **6** which is the equivalent of the MCF of FIG. **5A**, the filter with two interconnected nonadjacent resonators. The matrix description for this circuit becomes:

$$\begin{bmatrix} 0 \\ I_2 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{11} & -Y_{12} & -Y_{13} & -Y_{14} \\ -Y_{21} & Y_{22} & -Y_{23} & -Y_{24} \\ -Y_{31} & -Y_{32} & Y_{33} & -Y_{34} \\ -Y_{41} & -Y_{42} & -Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix} \tag{21}$$

and the transfer impedance becomes:

$$Z_t = \frac{\begin{vmatrix} Y_{11} & -Y_{12} & -Y_{13} \\ -Y_{31} & -Y_{32} & Y_{33} \\ -Y_{41} & -Y_{42} & -Y_{43} \end{vmatrix}}{|\Delta|} = N/D \tag{22}$$

For the circuit in FIG. **6** one has:

$$Y_{11} = S\,Ca + SC_1 + 1/SL\ ; \tag{23}$$

$$Y_{22} = G_2 + SC_2 + 1/SL\ ; \tag{24}$$

$$Y_{33} = SC_3 + 1/SL\ ; \tag{25}$$

$$Y_{44} = G_4 + S\,Ca + SC_4 + 1/SL; \tag{26}$$

$$Y_{12} = k_{12}/SL\ ; \tag{27}$$

$$Y_{14} = Y_{24} = 0\ ; \tag{28}$$

$$Y_{23} = k_{23}/SL\ ; \tag{29}$$

$$Y_{34} = k_{34}/SL\ ; \tag{30}$$

$$Y_{13} = S\,Ca\ . \tag{31}$$

The numerator of (15) becomes:

$$N = \begin{vmatrix} Y_{11} & -Y_{12} & -Y_{13} \\ -Y_{31} & -Y_{32} & Y_{33} \\ 0 & 0 & -Y_{43} \end{vmatrix} \tag{32}$$

The zeros of $N$ can be found from:

$$Y_{11}Y_{32} + Y_{12}Y_{13} = 0 \tag{33}$$

or:

$$[S(Ca+C_1) + (1/SL)]\,(k_{23}/SL) + k_{12}/SL \cdot S\,Ca = 0\ . \tag{34}$$

The location of these zeros is given by:

$$S = \pm j\sqrt{\frac{1}{LC_1\left[\frac{Ca}{C_1}\left(1+\frac{k_{12}}{k_{23}}\right)+1\right]}} \tag{35}$$

In contrast to the result in Case 1, the location of the transmission zeros in Case 2 can be controlled by two coupling coefficients, $k_{12}$ and $k_{23}$ and the two capacitances $C_1$ and $Ca$. As in the first case the peak appears below the passband although its position is substantially closer to the passband.

Case 3

The MCF of FIG. **7A** is identical to that shown in FIGS. **3A** and **5A** with the exception of the specific resonator interconnections. In FIG. **7A**, resonators **102** and **103** are connected as the input and output elements, respectively, while the end resonators **101** and **104** are connected as the auxiliary elements. Using the transformation of FIGS. **2A**, **2B** and **2C** on the equivalent circuit of FIG. **1B** results in the equivalent circuit for the MCF of FIG. **7A** which is shown in FIG. **8.** Although in this instance the mathematical analysis becomes somewhat more complex than these involved in Cases 1 and 2, it can be shown by the same general method of procedure that for Case 3 two transmission zeros are realized, one on either side of the passband. In this instance the zeros are somewhat closer to the passband and it can be shown that their location can be precisely controlled by the tuning frequency of the auxiliary resonators **101** and **104** and by either one or all three of the coupling coefficients $k_{12}$, $k_{23}$ and $k_{34}$.

## USE OF AN EXTERNAL CAPACITOR

In all cases in accordance with the invention one additional parameter, namely the capacitance ratio, may be employed effectively to control the transmission zero location and hence the location of attenuation peaks in relation to the passband. It is found that by increasing this ratio the peaks can be moved closer to the band. In accordance with the invention it has been discovered that the capacity ratio may be increased advantageously by the use of an external capacitor which increases the static capacity of the resonators that it interconnects. Additionally, it has been found that this method moves the attenuation peaks closer to the band without in any way disturbing the parameters of the filter.

Examples of the use of an external capacitor in accordance with the invention are shown in FIGS. **9A**, **9B** and **9C**. The MCFs in these figures correspond, respectively, to the MCFs in FIGS. **3A**, **5A** and **7A**, the difference in each instance being the use of an external capacitor $C_e$ connected in the manner shown.

## MCFS EMPLOYING MORE THAN FOUR RESONATORS

It should be pointed out that by using schemes similar to those described above, transmission zeros can also be realized in MCFs having more than four resonators. Also, when more than four resonators are used the number of zeros realized and the possible cases to be considered increase. For example, it can readily be verified that for an eight resonator MCF a maximum of four transmission zeros can be realized, with two appearing on either side of the passband. The interconnections required for such a filter are illustrated in FIG. **10** where the auxiliary resonators **101** and **104** are tied together in the manner shown in FIG. **7** and the resonators **102** and **103** are connected as input and output elements. Additionally, however, each of four auxiliary resonators **105, 106, 107** and **108** is shorted and grounded in conventional fashion.

It is to be understood that the embodiments disclosed herein are merely illustrative and that various modifications may be effected by persons skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A monolithic crystal filter comprising, in combination,
   a plurality of resonators each including a respective portion of a common piezoelectric body sandwiched between a respective pair of electrodes,
   said resonators including an input resonator, an output resonator and at least two auxiliary resonators,
   a nongrounded, floating, short circuiting, conducting path external to said body connecting one electrode of one of said auxiliary resonators to a corresponding electrode of another of said auxiliary resonators, both of said auxiliary resonators being nonshorted
   an input point and means independent of said path directly connecting said input point to an electrode of said input resonator, and
   an output point and means independent of said path directly connecting said output point to an electrode of said output resonator.

2. Apparatus in accordance with claim 1 wherein the number of said auxiliary resonators exceeds two, and
   means shorting each of said auxiliary resonators that is otherwise unconnected.

3. Apparatus in accordance with claim 2 including means connecting one side of each of said resonators to a source of reference potential.

4. Apparatus in accordance with claim 1 wherein said auxiliary resonators are positioned substantially between said input and output resonators.

5. Apparatus in accordance with claim 1 wherein said resonators are in substantial alignment and said input resonator is positioned substantially between two of said auxiliary resonators.

6. Apparatus in accordance with claim 1 wherein said input and output resonators are positioned between two of said auxiliary resonators.

7. A monolithic crystal filter comprising, in combination,
   a plurality of resonators each including a respective portion of a common piezoelectric body sandwiched between a respective pair of electrodes,
   said resonators including an input resonator, an output resonator and at least two auxiliary resonators,
   a nongrounded, short circuiting conducting path external to said body connecting one electrode of one of said auxiliary resonators to a corresponding electrode of another of said auxiliary resonators, both of said auxiliary resonators being nonshorted
   an input point and means independent of said path directly connecting said input point to an electrode of said input resonator, and
   an output point and means independent of said path directly connecting said output point to an electrode of said output resonator.

8. Apparatus in accordance with claim 7 wherein said auxiliary resonators are positioned substantially between said input and output resonators.

9. Apparatus in accordance with claim 7 wherein said resonators are in substantial alignment and said input resonator is positioned substantially between two of said auxiliary resonators.

10. Apparatus in accordance with claim 7 wherein said input and output resonators are positioned between two of said auxiliary resonators.

11. Apparatus in accordance with claim 7 including a capacitor connected between said path and a source of reference potential.

12. Apparatus in accordance with claim 11 wherein said auxiliary resonators are positioned substantially between said input and output resonators.

13. Apparatus in accordance with claim 18 wherein said resonators are in substantial alignment and said input resonator is positioned substantially between two of said auxiliary resonators.

14. Apparatus in accordance with claim 11 wherein said input and output resonators are positioned between two of said auxiliary resonators.

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