

[54] **MECHANICAL TUNABLE BANDPASS FILTER**

[72] Inventor: **William A. Edson**, Los Altos Hills, Calif.

[73] Assignee: **American Electronic Laboratories, Inc.**, Colmar, Pa.

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[51] Int. Cl. **H03j 3/26**

[58] Field of Search **333/70, 73, 82 R**

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Primary Examiner—Eli Lieberman

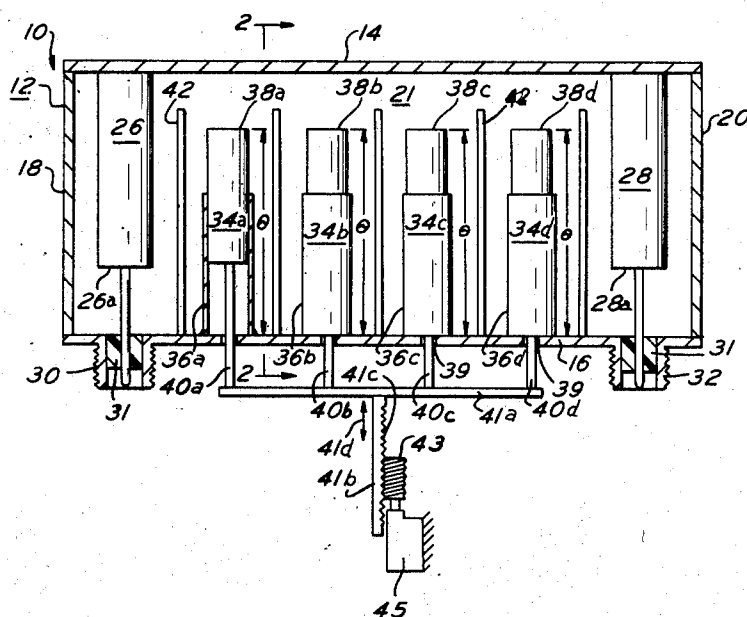
Assistant Examiner—C. Baraff

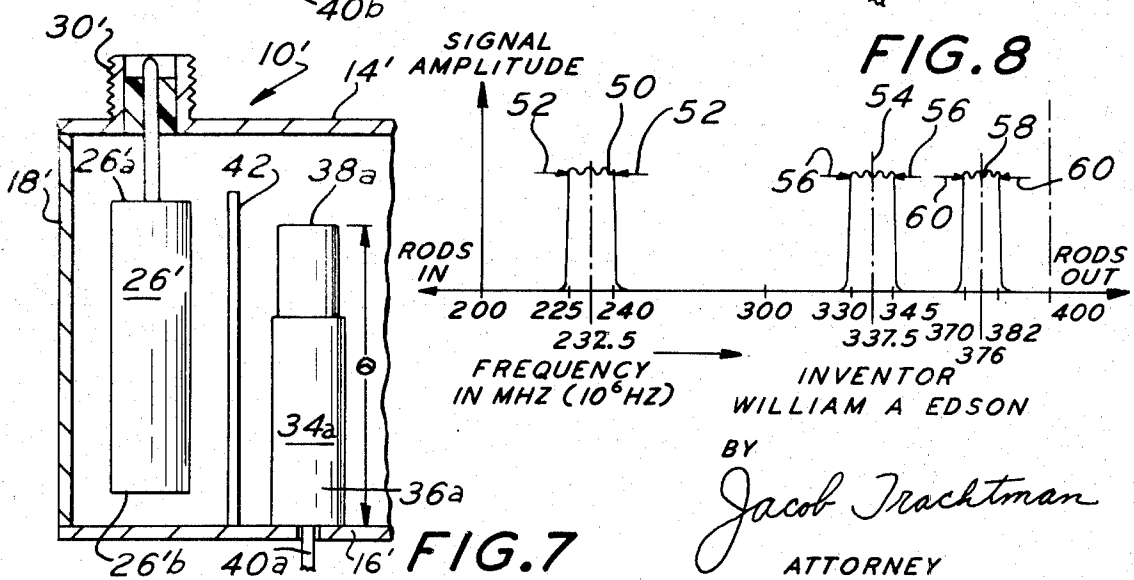
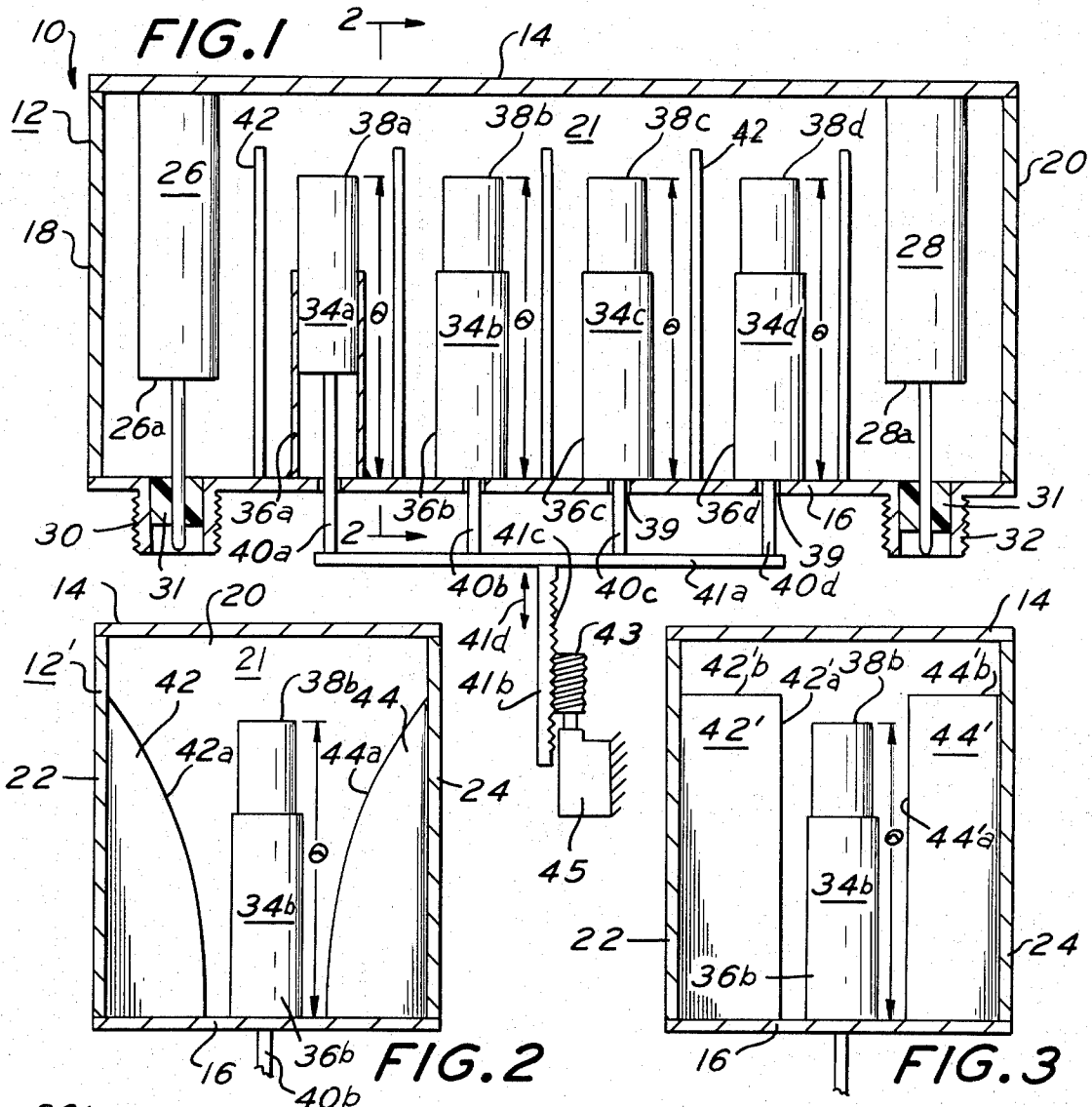
Attorney—Jacob Trachtman

[57] **ABSTRACT**

A filter including a closed conducting housing having a pair of side walls which are the ground planes of the filter. Input and output rods of fixed length are mounted in spaced relation between the side walls. A plurality of resonator bars are between the side walls and in spaced relation between the input and output rods. The electric and magnetic coupling between each pair of adjacent bars is controlled by fixed septa or partitions having a special shape. The resonator bars are movable and are adapted to be varied in length in unison so as to tune the filter. The various fixed dimensions and especially those of the partitions between adjacent resonators are chosen so as to maintain the width of the transmission passband substantially constant or variable in a desired manner, while the passband frequencies are shifted by tuning.

7 Claims, 8 Drawing Figures





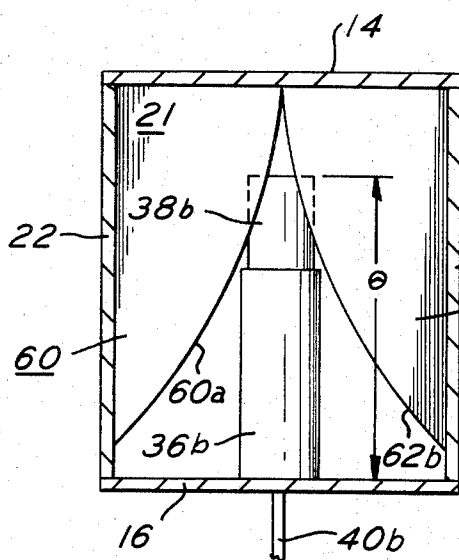


FIG. 4

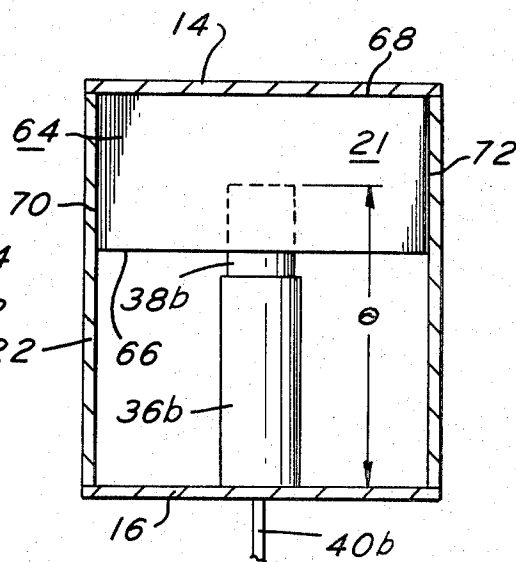


FIG. 5

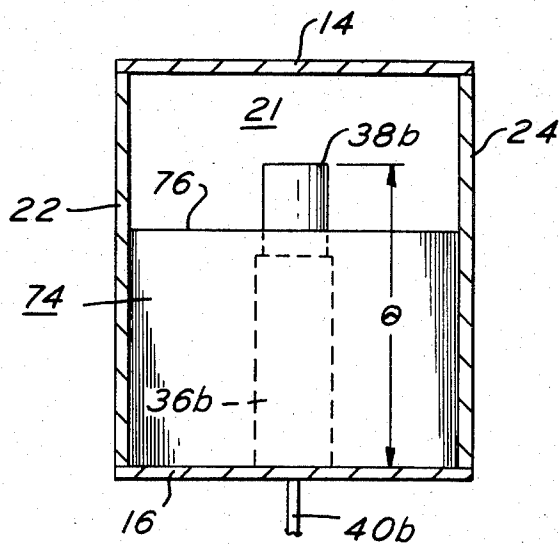


FIG. 6

INVENTOR
WILLIAM A. EDSON

BY
Jacob Trachtman
ATTORNEY

MECHANICAL TUNABLE BANDPASS FILTER

The present invention relates to a tunable bandpass filter, and more particularly to a mechanically tunable bandpass filter, which is tunable over a wide range with no significant variation in the width of the transmission passband, or in which the width of the passband varies in a unique prescribed manner.

In the electrical communication field, mechanically tunable bandpass filters are well known, and are made in a great variety of structures for use over various frequency ranges. For low frequencies, such filters generally use lumped elements and are ordinarily tuned by means of capacitors. Filters for higher frequencies generally use resonators having distributed elements. However, such filters commonly have the disadvantage that the bandwidth varies considerably as the filter is tuned.

It is therefore an object of the invention to provide a novel mechanically tunable filter.

Another object of the invention to provide a novel filter which can be mechanically tuned by a single control.

Another object of the invention to provide a novel filter which can be mechanically tuned over a wide range.

Another object of the invention to provide a novel filter which can be mechanically tuned over a wide range with no significant variation in the width of the transmission passband.

Another object of the invention is to provide a novel filter in which can be mechanically tuned over a wide range with the width of the transmission band varying in a desired manner as a function of such tuning.

Another object of the invention is to provide a novel filter which may easily be fabricated and in which insertion loss is minimized and the power handling capability is not degraded.

These objects are achieved by a filter having a plurality of extendable resonator rods mounted within a closed conducting housing which includes a pair of parallel conducting ground planes. Input and output bars are provided adjacent to the end resonator rods. Coupling between adjacent resonator rods and the input and output bars is provided by both magnetic and electric fields which surround them. The resonator rods are mechanically coupled so as to extend in unison to permit tuning the filter. Unison of motion may be achieved by joining all resonators to a simple plunger or by some suitable combination of gears, cams and levers. The essence of the invention is that the organization and fixed dimensions of the filter are such that no additional moving parts are required to provide a passband width that is substantially constant and independent of the tuning, or alternatively a passband width which varies in a desired manner as a function of such tuning.

The foregoing and other objects of the invention will become more apparent as the following detailed description of the invention is read in conjunction with the drawing, in which:

FIG. 1 is a transverse sectional view of a form of the filter of the present invention.

FIG. 2 is a sectional view taken along line 2—2 of FIG. 1.

FIGS. 3 through 6, inclusive are sectional views similar to that of FIG. 2 each respectively illustrating partitions of modified configuration.

FIG. 7 is a sectional view similar to FIG. 1 illustrating a modified form of the signal input and output bars of the filter.

FIG. 8 is a graphic illustration of the bandpass characteristics of filter of the invention.

Like reference numerals designate like parts throughout the several views.

Referring to FIGS. 1 and 2 of the drawing, a form of the filter of the present invention is generally designated as 10. Filter 10 comprises an electrically conductive metal housing 12 having parallel top and bottom walls 14 and 16, parallel end walls 18 and 20 and parallel side walls 22 and 24 providing a cavity 21 therewithin. Electrically conductive input and output bars 26 and 28 are mounted on and have their top ends in electrical contact with the top wall 14 and extend downward with their bottom ends toward the bottom wall 16. In another open-ended configuration the bars 26 and 28 may be electrically insulated from the walls of the filter. Coaxial terminals or jacks 30 and 32 are provided for delivering the signal input and output of the filter 10, with the outer shield or grounded portions of the jacks being connected to the bottom wall 16 of the housing 12, and the inner conductors being electrically insulated from and extending through the bottom wall 16 as by the insulating plugs 31 and being respectively connecting to the extending bottom ends 26a and 28a of the input and output bars 26 and 28 respectively.

A plurality of electrically conductive resonator rods 34a, 34b, 34c, and 34d are mounted in the housing 12 between the input bars 26 and 28. The resonator rods 34a-34d are mounted in spaced relation on and have their bottom ends in electrical contact with the bottom wall 16 of the housing 12, and extend upwardly with their top ends toward the top wall 14 in substantially parallel relation with each other and the input and output bars 26 and 28. As shown, each of the resonator rods 34a-34d comprises a fixed cylindrical sleeve 36a-36d mounted on and in electrical contact with the bottom wall 16, and a solid bar 38a-38d (which may be hollow if desired) fitting in the sleeve 36a-36d with a friction fit so as to be movable within the sleeve while maintaining electrical contact therewith. A respective one of the actuator rods 40a-40d is secured to the bottom end of each of the movable bars 38a-38d and extends through and beyond the bottom wall 16 of the housing 12 through openings 39. By moving the actuating rods 40a-40d, and bars 38a-38d can be moved within the sleeves 36a-36d so as to vary the amount that the bars project beyond the sleeves, and thereby vary the length of the resonators 34a-34d within the cavity 21 of the filter 10.

For the purpose of uniformly extending the movable bars 38a-38d and moving same in unison during the tuning of the filter, the ends of the actuating rods 40a-40d, may be, as illustrated in FIG. 1 in connection with the device 10, joined with a cross bar 41a, which in turn is joined at its center with a perpendicularly extending actuating rod 41b which carries a rack 41c along one side thereof. The rack is engaged by a worm gear 43 which is rotatably driven by a motor 45 for ac-

tuating the rod 41b in the back and forth directions as shown by the arrows 41d. Of course, any other suitable manner may be utilized for adjusting and varying the extension of the rods 34a-38d.

A plurality of thin electrically conductive metal partitions 42 and 44, are in electrical contact with and extend within the cavity 21 from the inner surfaces of the bottom wall 16 and respectively from the side walls 22 and 24 of the housing 12. Each of the partitions 44 on the side wall 24 is in co-planar alignment with a separate one of the partitions 42 on the side wall 22. Each pair of the co-planar partitions 42 and 44 is positioned between a pair of adjacent resonator rods 34a-34d, and also between the input and output bars 26 and 28 and their respective adjacent resonator rods.

In the operation of the filter 10, the partition pairs 42 and 44 and all outer walls 14, 16, 18, 20, 22 and 24 are electrically connected to ground so that they provide a completely shielded housing. An input signal is fed to the input bar 26 and an output signal is taken from the output bar 28 respectively by coaxial cable means joined with the input and output terminals or jacks 30, 32. Each of the resonator rods 34a-34d is partially decoupled from its adjacent resonator rod or the adjacent input or output bar by the intervening space and by the metal partitions 42 and 44 which provide septa or irises. Coupling between adjacent resonator rods and between the input and output bars and the adjacent resonator rods is provided by both magnetic and electric fields that surround them. The magnetic and electric couplings tend to cancel each other. The net sum of this coupling determines the transmission bandwidth of the filter. The essence of the present invention is the use of the partition plates having a shape which in combination with the fixed dimensions of the filter result in a filter with a transmission bandwidth which remains constant (or varies in a desired manner) while the filter is tuned by one mechanical control that moves the resonators 34a-34d in unison, without requiring any other mechanical motion.

FIG. 3 is a sectional view similar to FIG. 2, illustrating a modified form of the device 10 in which the partitions 42' and 44' have a rectangular configuration compared to the tapered configuration formed by the edges 42a and 44a shown for the partitions 42 and 44 in FIG. 2. In each case, the partitions have conducting surfaces and extend from the bottom surface of the bottom wall 16 upwardly without reaching the top surface of the upper wall 14. In FIG. 2, the opening provided between the co-planar partitions 42 and 44 increases in the upward direction at a rate determined by the configuration of the edges 42a and 44a of the partitions 42 and 44. In the form illustrated by FIG. 3, the partitions 42' and 44' have vertical edges 42'a and 44'a providing an opening space with constant horizontal dimension therebetween, and top horizontal edges 42'b and 44'b parallel to and respectively equally spaced from the surface of the upper wall 14. As examples, the configurations of the partitions 42, 44 and 42' and 44' provide respective shaped septa between the rods and bars in which respectively a constant bandwidth may be maintained during the tuning of the filter 10 or in which the bandwidth of the filter 10 may vary in a desired manner with the tuning of the filter.

FIG. 4 is a sectional view similar to FIG. 2, illustrating a modified form of the device 10 in which the partitions 60 and 62 are substantially reversed from the partitions 42 and 44 shown in FIG. 2. Thus, the partitions 60 and 62 electrically engage and extend downwardly from the top wall 14 with curved edges which increase the horizontal spacing therebetween in the downward direction. The partition 60 also electrically engages and extends from the side wall 22, while the partition 62 electrically engages and extends from the side wall 24 of the filter. As shown by the analysis given below, the partitions 60 and 62 in the form which provide no shielding between the rods at their grounded ends on wall 16 and complete shielding therebetween at the opposite end or top wall 14, give results, with a reversal of sign, similar to that for the form of the partitions 42 and 44 of FIG. 2.

FIG. 5 is a sectional view similar to FIG. 2, illustrating still another form of the device 10, in which each pair of partitions 42 and 44 is replaced by a simple rectangular partition 64, with a bottom edge 66 parallel to end walls 18 and 20 and a top edge 68, and side edges 70 and 72 electrically bonded respectively to walls 14, 22, and 24. With this and other configurations, it may be possible and desirable to omit certain of the partitions, especially those adjacent to the input and output bars. The relative size, particularly the position of the lower edge 66 of the partition 64 shown in FIG. 5 controls the width of the electrical passband and its variation with tuning as controlled by rods 40a-40d. Substantially the same results are obtained if the position of the opening and closure in FIG. 5 are interchanged as shown in FIG. 6, so that the partition 74 is now bonded to walls 16, 22 and 24 and the upper edge 76 of partition 74 provides the lower boundary of the opening between the rods.

FIG. 7 illustrates a filter 10' which is a modified form of the filter 10 of FIG. 1 in which the input jack or terminal 30' is on the top wall 14' and the bar 26' has its upper end 26'a connected with the center conductor of the input jack or coaxial terminal 30' for receiving signals and its lower end 26'b spaced and insulated from the bottom wall 16' of the filter 10'. In another configuration the end 26'b may be grounded to the wall 16'. The output jack or terminal and the signal output rod (not illustrated) may be identical with the input jack 30' and rod 26' and symmetrically positioned at the opposite end of the filter 10'. The intermediate fixed rods 34a-34d, sleeves 36a-36d, and positioning and actuating means therefor may be identical to those of the filter 10.

FIG. 8 is a graphic illustration of the bandpass filter characteristics of a filter embodying the invention. In the example illustrated, the filter provides a tuning range of between 200 megahertz and 400 megahertz. Thus when the tuning rods are fully withdrawn to reduce the extension θ (see FIGS. 1 and 4), the bandpass has a center frequency of 400 megahertz, while when the actuating rods are inserted to the operable limit (short of contacting the top wall 14) the bandpass center frequency is 200 megahertz. The bandpass characteristic 50 with a center frequency of 232.5 megahertz illustrates the bandpass frequencies achieved with the actuating rods withdrawn slightly, reducing the extension of θ from the maximum opera-

ble limit and providing a passband between 225 megahertz and 240 megahertz with bandpass width of 15 megahertz at the equal-ripple points 52 of the transmission characteristic 50. Where the filter 10 is designed to provide a constant band width, the filter may be tuned by varying the extension dimension θ of the movable rods without changing the band width. Thus, the bandpass characteristic 54 illustrates the tuning of such a filter to provide a center frequency of 337.5 megahertz with the further withdrawal of the actuating rods to reduce the extension θ while maintaining the bandwidth of 15 megahertz at the equal-ripple points 56 giving a bandpass between 330 megahertz and 345 megahertz. The filter, thus can be tuned over a range which exceeds an octave by mechanically actuating the rods to vary the center frequency from 200 to 400 megahertz while the width of the bandpass remains constant.

The case where the passband width varies in a desired manner is illustrated by the bandpass characteristic 50 and the bandpass characteristic 58. With septa designed to provide variations from the constant bandwidth, the bandwidth characteristic illustrates the situation where where the rods are withdrawn the characteristic 50 varies so that when, for example, the filter provides a center bandpass frequency of 376 megahertz, the width at the equal-ripple points 60 is reduced from 15 megahertz to 12 megahertz, providing a bandpass range between 370 megahertz and 382 megahertz. The variations of bandwidth with tuning of the filter may be either linear or non-linear to provide the desired function as the center frequency is shifted.

For the purpose of providing a mathematical analysis of the filter embodying the invention, consider two parallel bars connected in the interdigital configuration as particularly illustrated in FIG. 7. The first bar 26' is fed from a matched source, is open circuited at the far end, and is of constant (i.e. unvarying) length. The second bar 34a serves as a resonator and its length is varied for tuning. Between the two bars are tapered coupling septa like those shown in FIG. 2 and analyzed by C. G. Cristal, "Data for Partially Decoupled Round Rods Between Parallel Ground Planes," IEEE Trans. MTT-16, pp. 311-313, May 1968. Our interest centers on the frequency at which the second bar 34a is resonant — i.e. one-quarter of a wavelength long. The governing equations are:

$$I_1 = \sin \phi, V_1 = \cos \phi \quad (1)$$

$$V_2 = \sin \phi, I_2 = \cos \phi \quad (2)$$

where I_1 and V_1 represent the current and voltage distributions along the fixed bar; and I_2 and V_2 represent the current and voltage distributions along the adjacent (adjustable) bar. In these expressions the currents are normalized to their maximum values. The angular variable ϕ represents any point along the bars and has a maximum value of $\pi/2$.

The proportions of the partitions or iris plates are chosen so that the local coupling coefficient between the two bars increases linearly with the distance ϕ away from the bottom wall.

It is assumed that the bars are rather widely separated so that the self impedance of each bar is substantially constant with length. The applicable coupling parameter H is described by the integral

$$\frac{\pi}{4} H = \int_0^{\pi/2} 2(n\phi) \sin \phi \cos \phi d\phi \quad (3)$$

where n is the coupling taper parameter, treated as an undetermined coefficient. Successive manipulation and introduction of the variable $X=2\phi$, gives

$$\frac{\pi}{4} H = \frac{n}{4} \int_0^{\pi/2} (2\phi) (\sin 2\phi) d(2\phi) = \frac{n}{4} \int_0^{\pi} X \sin X dX \quad (4)$$

Integration yields

$$\frac{\pi}{4} H = \frac{n}{4} [\sin X - X \cos X]_0^{\pi} = \frac{n\pi}{4} \quad (5a)$$

$$\text{or } H = n \quad (5b)$$

This is the condition for a bandwidth that is absolutely constant with respect to frequency. The parameter n is constrained by an upper limit.

$$n = \leq 2/\pi \quad (6)$$

corresponding to septa which vanish toward the sides of the case where the input jack or terminal is shown. When the filter is tuned to its lowest frequency the resonator extends almost to the opposite side. In this case the bandwidth corresponds to a coupling parameter which has its maximum value of

$$H_n = 2/\pi \quad (7)$$

The interdigital configuration is especially useful for the input and output circuits of constant-bandwidth mechanically tunable filters.

To analyze the coupling between adjacent resonators the situation discussed above is now modified only to the extent that both members are grounded to the bottom wall of the filter and are movable. The governing equations are

$$I_1 = I_2 = \cos \phi \text{ and } V_1 = V_2 = \sin \phi \quad (8)$$

The applicable coupling parameter is given by the integral

$$\frac{\pi}{4} H = \int_0^{\pi/2} (n\phi) (\cos^2 \phi - \sin^2 \phi) d\phi \quad (9)$$

Manipulation and change of variable yields

$$\frac{\pi}{4} H = \frac{n}{4} \int_0^{\pi/2} 2\phi (\cos 2\phi) d(2\phi) = \frac{n}{4} \int_0^{\pi} X \cos X dX \quad (10)$$

Integration yields

$$\frac{\pi}{4} H = \frac{n}{4} [\cos X + X \sin X]_0^{\pi} = -\frac{n}{2} \quad (11)$$

That is

$$H = (2n)/\pi \quad (12)$$

As in the preceding section, this is the condition for a bandwidth that is absolutely constant with respect to frequency. Again, n is limited to a maximum value of $2/\pi$ and the coupling parameter for the lowest frequency is given by

$$H_n = 4/\pi^2 \quad (13)$$

As in the interdigital configuration, it is practical to preserve operation over a tuning range exceeding one octave. Here as in other situations, the coupling provided by the combline configuration is substantially weaker than that provided by the interdigital form.

The cancelling of electric and magnetic coupling that is inherent in combline filters permits one to reserve the position of the inter-resonator shield as shown by the partitions in FIG. 4. In this case there is no shielding at the grounded end and complete shielding at the opposite end. The governing equation is now

$$\frac{\pi}{4} H = \int_0^{\pi/2} (1 - n\phi) (\cos^2 \phi - \sin^2 \phi) d\phi \quad (14)$$

It is easily shown that

$$\int_0^{\pi/2} (\cos^2 \phi - \sin^2 \phi) d\phi = 0 \quad (15)$$

Therefore, except for a reversal of sign, the result is identical with that just derived.

As a practical matter this form of coupling may be preferable to the other in that end loading of the resonators is more readily accommodated. The combline configuration is especially useful for the several resonators 34a-34d that make up the main body of constant-bandwidth mechanically tunable filters.

Thus in the operation of the filter, it is tuned by changing the lengths of the resonator rods 34a-34d, by pushing or pulling on the actuating rods 40a-40d so as to move the bars 38a-38d in the sleeves 36a-36d. When the several fixed dimensions are properly chosen, the filter can be tuned over a wide range with no significant variation in the width of the transmission passband. Or, alternatively, the bandwidth can be made to vary in a desired manner as the center frequency is changed.

What is claimed is:

1. A filter tunable between upper and lower frequency limits comprising a pair of spaced parallel ground planes, spaced input and output bars positioned between said ground planes, resonator bars positioned between said ground planes and arranged in spaced parallel relation between said input and output bars, means for adjusting said resonator bars to tune the filter over a wide range of frequencies, said tuning means including means for adjusting the length of said resonator bars, and a plurality of metal partitions between and partially decoupling respective adjacent bars, said metal partitions being thin metal members providing a restricted opening between a pair of adjacent bars, said metal partitions having an opening

which increases in size in the direction transverse to the direction of the adjustment of the length of said resonator bars, the coupling between adjacent bars increasing linearly with the adjustment of said resonator bars.

2. A filter tunable between upper and lower frequency limits comprising a pair of spaced parallel ground planes, spaced input and output bars positioned between said ground planes, resonator bars positioned between said ground planes and arranged in spaced parallel relation between said input and output bars, means for adjusting said resonator bars to tune the filter over a wide range of frequencies, said tuning means including means for adjusting the length of said resonator bars, and a plurality of metal partitions between and partially decoupling respective adjacent bars, said metal partitions being thin metal members providing a restricted opening between a pair of adjacent bars, said metal partitions having an opening which increases in size in the direction transverse to the direction of the adjustment of the length of said resonator bars, the coupling between adjacent bars increasing non-linearly with the adjustment of length of said resonator bars.

3. A filter tunable between upper and lower frequency limits comprising a pair of spaced parallel ground planes, spaced input and output bars positioned between said ground planes, resonator bars positioned between said ground planes and arranged in spaced parallel relation between said input and output bars, means for adjusting said resonator bars to tune the filter over a wide range of frequencies, said tuning means including means for adjusting the length of said resonator bars, and a plurality of metal partitions between and partially decoupling respective adjacent bars, said metal partitions being thin metal members providing a restricted opening between a pair of adjacent bars, said partitions including a pair of thin coplanar metal members projecting respectively from said ground planes and being positioned between adjacent bars providing a restricted opening therebetween for partially decoupling said bars.

4. The filter of claim 3 in which the opening between the coplanar members varies in size in the direction transverse to the direction of adjustment of the length of said resonator bars.

5. The filter of claim 4 in which the opening between the coplanar members has at least a portion of its boundary which provides a constant size in the direction transverse to the direction of adjustment of the length of said resonator bars.

6. The filter of claim 4 in which the opening between the coplanar members has at least a portion of its boundary which is perpendicular to the direction of adjustment of the length of said resonator bars.

7. The filter of claim 5 in which the members have rectangular configurations.

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