

RADIO FREQUENCY FILTERS

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Background of the Invention

5 The present invention is related generally to radio frequency (RF) signal filters, and more particularly to an improved single-block ceramic filter that is particularly well adapted for use in radio transmitting and receiving circuitry.

10 Conventional multi-resonator filters include a plurality of resonators that are typically foreshortened short-circuited quarter-wavelength coaxial or helical transmission lines. The resonators are arranged in a conductive enclosure and may be inductively coupled one to
15 another by apertures in their common walls. Each resonator can be tuned by means of a tuning screw which inserts into a hole extending through the middle of the resonator. Once tuned, the overall response of the filter is primarily determined by the size of the interstage coupling
20 apertures. Since the tuning of such filters can be disturbed by a slight adjustment of the tuning screw, a lock nut is required to keep the tuning screw properly positioned at all times. The use of tuning screws not only renders these filters susceptible to becoming detuned, but also
25 creates additional problems including mechanical locking of the tuning screw and arcing between the tuning screw and the resonator structure. Furthermore, such filters tend to be rather bulky and therefore are relatively unattractive for applications where size is an important factor.

30 These problems have been solved to some degree by the single-block ceramic filters of the type shown and described in U.S. patent nos. 4,426,631, 4,431,977 and 4,464,098. In particular, the filter described in the U.S. patent no. 4,431,977 includes a dielectric block having a plurality of
35 circular holes coupled to one another primarily by the way of the dielectric between them. Coupling between the circular holes is adjusted by varying the depth of slots or the size and location of additional holes, rendering the tuning of such filters both complicated and difficult.

Furthermore, the location of the input and output electrodes near the ground plating creates undesired capacitive
5 loading.

Summary of the Invention

Accordingly, the present invention provides a
10 dielectric block comprised of a dielectric material and having top, bottom and side surfaces, said bottom and side surfaces of the dielectric block being substantially covered with a conductive material;

a plurality of holes, having surfaces substantially
15 covered with a conductive material, extending from the top surface of the dielectric block toward the bottom surface thereof and having openings on the top surface of the dielectric block, said openings being disposed at a predetermined distance from one another;

20 first and second coupling means coupled to a first hole and a second hole, respectively, of said plurality of holes; and

capacitive means including first and second electrode means each comprised of a conductive material covering a
25 portion of the top surface of said dielectric block, the conductive material of said first electrode means and the conductive material of said second electrode means being coupled to the conductive material of two holes, respectively, of said plurality of holes, and the conductive
30 material of said first electrode means and the conductive material of said second electrode means opposing one another and being separated from one another by a portion of the top surface of said dielectric block not covered by any conductive material and having a predetermined width for
35 capacitively intercoupling said two holes.

According to a further feature of the present invention, the coupling means may comprise first and second

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electrodes respectively, which may be isolated from the conductive material covering the dielectric block by
5 substantially surrounding the first and second electrodes with conductive material from the adjacent hole.

Thus, the filter has a pole/zero frequency response characteristic that is easily tuned to provide one or more desired pass and stop bands, the undesired electrical signal
10 coupling between the holes is substantially reduced and, in a preferred embodiment, the isolated input and output electrodes minimise undesired electrical signal coupling between the input and output electrodes and electrical signal ground.

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Description of the Drawings

Referring to Figure 1, there is illustrated a single-block dual-passband ceramic filter 100 embodying the
20 present invention. Filter 100 provides both pass and stop bands in a single block. Filter 100 includes a block which is comprised of a dielectric material that is selectively covered or plated with a conductive material. Filter 100 can be constructed of any suitable dielectric material that
25 has low-loss, a high dielectric constant and a low temperature coefficient of dielectric constant. In the preferred embodiment, filter 100 is comprised of ceramic compound including barium oxide, titanium oxide and zirconium oxide, the electrical characteristics of which are
30 similar to those described in more detail in an article by G.H. Jonker and W. Kwestroo, entitled "The Ternary Systems $\text{BaO-TiO}_2\text{-SnO}_2$ and $\text{BaO-TiO}_2\text{-ZrO}_2$, Published in the Journal of the American Ceramic Society, Volume 41, no. 10 at pages 390-394, October 1958. Of the ceramic compounds
35 described in this article, the compound in table VI having the composition 18.5 mole percent BaO ,

77.00 mole percent TiO_2 and 4.5 mole percent ZrO_2 and having a dielectric constant of approximately 40 is well suited for use in the ceramic filter 100 of the present invention.

5 In the preferred embodiment of filter 100, copper or silver is used to cover or plate the block with an electrically conductive material. Filter 100 includes seven holes 102, 104, 106, 108, 110, 112, and 114 having an elongated cross section, which each extend from the
10 top surface to the bottom surface thereof. Holes 102, 104, 106, 108, 110, 112 and 114 are likewise plated. Although filter 100 is shown with seven holes, only two holes need be utilized in practicing the present invention.

15 Each hole 102, 104, 106, 108, 110, 112 and 114 is further separated one from another by unplated capacitive strips such as 130 and 131. Moreover, each hole is completely surrounded by capacitive strips, such as strips 130, 131, 140, 141 surrounding hole 106. The
20 width of the capacitive strips 130, 131 is adjusted to resonate the odd mode transmission lines or zeros formed by holes 106, 108 and 104, 106 in the stop band of the transmitter filter. The width of capacitive strips 140, 141 is adjusted to resonate the transmission line or pole
25 formed by hole 106 and ground in the passband of the transmitter filter. According to an important feature of the present invention, strips 130 and 131 provide capacitive coupling between holes 106 and 108 and holes 104 and 106, respectively for producing a corresponding
30 zero either above or below the passband of filter 100. Strips 130 and 131 further include sinusoidal shaped portions so that the coupling between adjacent holes 106 and 108 and 104 and 106, respectively can be easily adjusted by simply removing plating. Although capacitive
35 strips have been utilized in the preferred embodiment, any suitable capacitive device or circuitry can be

utilized to resonate each hole for a pole and each pair of holes for a zero in practicing the present invention.

Filter 100 in Figure 1 also includes electrodes 120, 122 and 124 for coupling input/output signals thereto.

5 In the preferred embodiment, electrode 120 is coupled to the output of transmitter 170, electrode 122 is coupled to the input of receiver 180, and electrode 124 is coupled to antenna 190. In this duplexer embodiment, filter 100 provides two passbands for applying the RF
10 signal from transmitter 170 to antenna 190 and applying the RF signal received by antenna 190 to receiver 180. Filter 100 is likewise applicable to any suitable signal combining/sorting application where signals in two different frequency bands are applied to or received from
15 a common device.

According to another feature of the present invention, electrodes 120 and 122 in filter 100 in Figure 1 are substantially surrounded by the plating associated with holes 102 and 114, respectively. As a result,
20 electrodes 120 and 122 are substantially isolated from the rest of the plating on the dielectric block which is coupled to electrical signal ground. Since electrodes 120 and 122 are isolated from electrical signal ground, undesired capacitive coupling to electrical signal ground
25 is minimized thereby improving the electrical characteristics of filter 100.

Also illustrated in Figure 1 is a bracket 150 which is attached to filter 100 for facilitating mounting of filter 100 in other apparatus such as a radio transceiver
30 and also for further reducing undesired out-of-band responses. Bracket 150 includes strips 152 which are oriented above corresponding holes in filter 100. Since strips 152 only cover corresponding holes, capacitive strips 130, 131 may be tuned when bracket 150 is attached
35 to filter 100. Tabs 154, 156 and 157 assist in positioning and holding bracket 150 on filter 100.

Bracket 150 may be securely attached to filter 100 by means of soldering or any other suitable bonding means. Tabs 158 may be attached to corresponding input/output cables which are in turn coupled to electrodes 120, 122 and 124 of filter 100.

Referring to Figure 2, there is illustrated a corresponding electrical circuit for filter 100 in Figure 1. Filter 100 includes seven poles 202, 204, 206, 208, 210, 212 and 214 primarily created by corresponding holes 114, 112, 110, 108, 106, 104 and 102, respectively, which act as TEM mode transmission lines. Poles 202 and 204 primarily produce the receiver passband, and poles 208, 210, 212 and 214 primarily produce the transmitter passband. Pole 206 is primarily turned to match the antenna. The transmission line lengths of poles 202, 204, 206, 208, 210, 212 and 214 are adjusted primarily by adjusting the height of the ceramic block. The variable capacitance of poles 202, 204, 206, 208, 210, 212 and 214 may be adjusted by removing plating near capacitive strips (such as 140 and 141) near the sides of corresponding holes (such as 106). Filter 100 also includes six zeros 252, 254, 256, 258, 260 and 262 which are each represented by an odd mode transmission line created by adjacent holes and an adjustable capacitance created by the capacitive strips. Zeros 252 and 254 produce a stopband at the transmitter frequencies, and zeros 256, 258, 260 and 262 produce a stopband at the receiver frequencies. The capacitance of zeros 252, 254, 256, 258, 260 and 262 may be adjusted by removing plating near capacitive strips (such as 130) between adjacent holes (such as 106 and 108) in filter 100. Thus, by adjusting the height of the ceramic block and by removing plating near capacitive strips, filter 100 can be tuned to provide two different and selective electrical signal passbands.

In Figure 5, there is illustrated typical transmitter and receiver frequency responses 402 and 404

of filter 100 which has been tuned to a transmitter passband of 453 MHz to 457.475 MHz and a receiver passband of 463 MHz to 467.475 MHz, respectively. The corresponding antenna return loss for the same filter is
5 illustrated by waveform 502 in Figure 6. A filter 100 exhibiting substantially the same electrical characteristics as illustrated by the waveforms in Figures 5 and 6 has the following approximate dimensions, 81.3 mm in length, 30.0 mm in width and 20.4 mm in
10 height, with elongated holes having approximate dimensions of 17.2 mm in length and 4.3 mm in width.

Referring to Figure 3, there is illustrated a top view of a portion of filter 100 in Figure 1. Capacitive strips 130-133 and 140-145 surround holes 102, 104 and
15 106 and isolate electrode 120 from electrical signal ground. According to a feature of the present invention, electrode 120 is substantially surrounded by the plating associated with hole 102. Also illustrated more clearly in Figure 3 are elongated holes 102, 104 and 106. Holes
20 102, 104 and 106 have an elongated cross section and are substantially parallel along the direction of elongation and colinear along their centers. According to yet another feature of the present invention, undesired coupling from hole 102 to non-adjacent hole 106 is
25 minimized by using holes having an elongated cross section.

Referring next to Figure 4, there is illustrated a top view of an alternative embodiment of the ceramic filter of the present invention. Filter 300 includes
30 unplated capacitive strips 320, a rectangular hole 302 and a circular hole 304. In addition, plated areas 306 and 310 associated with holes 302 and 304, respectively are separated from one another by plated area 308. As a result, the total capacitance coupling hole 302 to 304
35 is comprised of the combination of the capacitance of the capacitive strips between plated areas 306 and 308 and

plated areas 308 and 310. The equivalent capacitance between holes 302 and 304 is in this case the total of the capacitance for the capacitive strips 320 between plated areas 306 and 308 and plated areas 308 and 310.

- 5 Thus, the size and shape of the holes and additional strips can be utilized in various embodiments of the ceramic filter of the present invention.

- 10 In summary, a unique single-block ceramic filter has been described that may provide one or more desired pass and stop bands. By utilizing capacitive strips around each hole of the ceramic filter, a pole/zero frequency response characteristic is achieved. The inventive ceramic filter can be easily tuned simply by removing plating from the sinusoidal portions of the
- 15 capacitive strips around each hole. The single-block ceramic filter of the present invention may be advantageously utilized in any suitable signal combining/sorting application where one or more signals are applied to or received from a common device.

Claims

5 1. A filter comprising:

a dielectric block comprised of a dielectric material and having top, bottom and side surfaces, said bottom and side surfaces of the dielectric block being substantially covered with a conductive material;

10 a plurality of holes, having surfaces substantially covered with a conductive material, extending from the top surface of the dielectric block toward the bottom surface thereof and having openings on the top surface of the dielectric block, said openings being disposed at a
15 predetermined distance from one another;

first and second coupling means coupled to a first hole and a second hole, respectively, of said plurality of holes; and

capacitive means including first and second electrode
20 means each comprised of a conductive material covering a portion of the top surface of said dielectric block, the conductive material of said first electrode means and the conductive material of said second electrode means being coupled to the conductive material of two holes,
25 respectively, of said plurality of holes, and the conductive material of said first electrode means and the conductive material of said second electrode means opposing one another and being separated from one another by a portion of the top surface of said dielectric block not covered by any
30 conductive material and having a predetermined width for capacitively intercoupling said two holes.

2. The filter according to claim 1, wherein said first and second coupling means include first and second coupling
35 electrode means disposed on the top surface of the dielectric block near, and coupled to said first and second holes, respectively.

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3. The filter according to claim 2, wherein said first
and second coupling electrode means each include a portion
5 of the top surface of the dielectric block covered with said
conductive material.

4. The filter according to claim 1, further including
third electrode means interposed between and capacitively
10 intercoupling said first and second electrode means.

5. The filter according to claim 1, wherein said openings
of said plurality of holes each have two elongated sides
arranged substantially parallel to one another.

15 6. The filter according to claim 1, wherein the
conductive material of at least one of said first and second
electrode means is separated from the conductive coating on
one of the side surfaces of said dielectric block by a
20 second portion of the top surface of said dielectric block
not covered by any conductive material and having a
predetermined width for capacitively coupling said one of
said first and second electrode means to the conductive
coating on said one of the side surfaces of said dielectric
25 block.

7. The filter according to claim 1, wherein said first
and second electrode means are separated from one another by
a sinusoidal shaped portion of the top surface of said
30 dielectric block.

8. The filter according to claim 1, further including
bracket means coupled to said dielectric block for at least
partially enclosing the top surface of said dielectric
35 block, said bracket means further including at least first
and second tab means for attaching said bracket means to
utilization means.

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9. A multi-passband filter for coupling a radio-frequency (RF) signal from a RF transmitter to an antenna and coupling
5 another RF signal from the antenna to an RF receiver, comprising:

a dielectric block comprised of a dielectric material having top, bottom and side surfaces, said bottom and side surfaces of the dielectric block being substantially covered
10 with a conductive material;

at least three holes, having surfaces substantially covered with a conductive material, extending from the top surface of the dielectric block toward the bottom surface thereof and having openings on the top surface of the
15 dielectric block, said openings being disposed at predetermined distances relative to one another and substantially aligned with one another;

first, second and third coupling means coupled to a first hole, a second hole and a third hole, respectively, of
20 said at least three holes, said first coupling means further being coupled to the RF transmitter, said second coupling means further being coupled to the antenna, and said third coupling means further being coupled to the RF receiver; and

capacitive means including first and second electrode
25 means each comprised of a conductive material covering a portion of the top surface of said dielectric block, the conductive material of said first electrode means and the conductive material of said second electrode means being coupled to the conductive material of at least two holes,
30 respectively, of said at least three holes, and the conductive material of said first electrode means and the conductive material of said second electrode means opposing one another and being separated from one another by a portion of the top surface of said dielectric block not
35 covered by any conductive material and having a predetermined width for capacitively intercoupling said two holes.

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10. The filter according to claim 9, wherein said first,
second and third coupling means include first, second and
5 third coupling electrode means disposed on the top surface
of the dielectric block near, and coupled to said first,
second and third holes, respectively.

11. The filter according to claim 10, wherein first,
10 second and third coupling electrode means each include a
portion of the top surface of the dielectric block covered
with said conductive material.

12. The filter according to claim 9, further including
15 third electrode means interposed between and capacitively
intercoupling said first and second electrode means.

13. The filter according to claim 9, wherein said openings
of said at least three holes each have two elongated sides
20 arranged substantially parallel to one another.

14. The filter according to claim 9, wherein the
conductive material of at least one of said first and second
electrode means is separated from the conductive coating on
25 one of the side surfaces of said dielectric block by a
second portion of the top surface of said dielectric block
not covered by any conductive material and having a
predetermined width for capacitively coupling said one of
said first and second electrode means to the conductive
30 coating on said one of the side surfaces of said dielectric
block.

15. The filter according to claim 9, wherein said first
and second electrode means are separated from one another by
35 a sinusoidal shaped portion of the top surface of said
dielectric block.

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16. The filter according to claim 9, further including bracket means coupled to said dielectric block for at least partially enclosing the top surface of said dielectric block, said bracket means further including at least first and second tab means for attaching said bracket means to utilization means.

10 17. A radio transceiver comprising:

- a) a radio receiver having an input;
- b) a radio transmitter having an output;
- c) an antenna; and
- d) a multi-passband filter comprising:

15 a dielectric block comprised of a dielectric material having top, bottom and side surfaces, said bottom and side surfaces of the dielectric block being substantially covered with a conductive material;

at least three holes, having surfaces substantially covered with a conductive material, extending from the top surface of the dielectric block toward the bottom surface thereof and having openings on the top surface of the dielectric block, said openings being disposed at predetermined distances relative to one another and substantially aligned with one another;

first, second and third coupling means coupled to a first hole, a second hole and a third hole, respectively, of said at least three holes, said first coupling means further being coupled to the RF transmitter, said second coupling means further being coupled to the antenna, and said third coupling means further being coupled to the RF receiver; and

capacitive means including first and second electrode means each comprised of a conductive material covering a portion of the top surface of said dielectric

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block, the conductive material of said first electrode means
and the conductive material of said second electrode means
5 being coupled to the conductive material of at least two
holes, respectively, of said at least three holes, and the
conductive material of said first electrode means and the
conductive material of said second electrode means opposing
one another and being separated from one another by a
10 portion of the top surface of said dielectric block not
covered by any conductive material and having a
predetermined width for capacitively intercoupling said two
holes.

15 18. A filter substantially as hereinbefore described with
reference to the drawings.

19. A radio transceiver substantially as hereinbefore
described with reference to the drawings.

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