US 20140097913A1

(19) **United States**

(12) **Patent Application Publication**

Cooper et al.

(10) **Pub. No.: US 2014/0097913 A1**

(43) **Pub. Date: Apr. 10, 2014**

(54) **MULTI-MODE FILTER**

(71) Applicant: **MESAPLEXXPTY LTD**, Eight Mile Plains (AU)

(72) Inventors: **Steven John Cooper**, Brisbane (AU); **David R. Hendry**, Brisbane (AU); **Chris Boyle**, Brisbane (AU); **Peter Blakeborough Kenington**, Chepstow (GB)

(73) Assignee: **MESAPLEXX PTY LTD**, Eight Mile Plains (AU)

(21) Appl. No.: **13/647,936**

(22) Filed: **Oct. 9, 2012**

Publication Classification

(51) **Int. Cl.**

H01P 1/213 (2006.01)

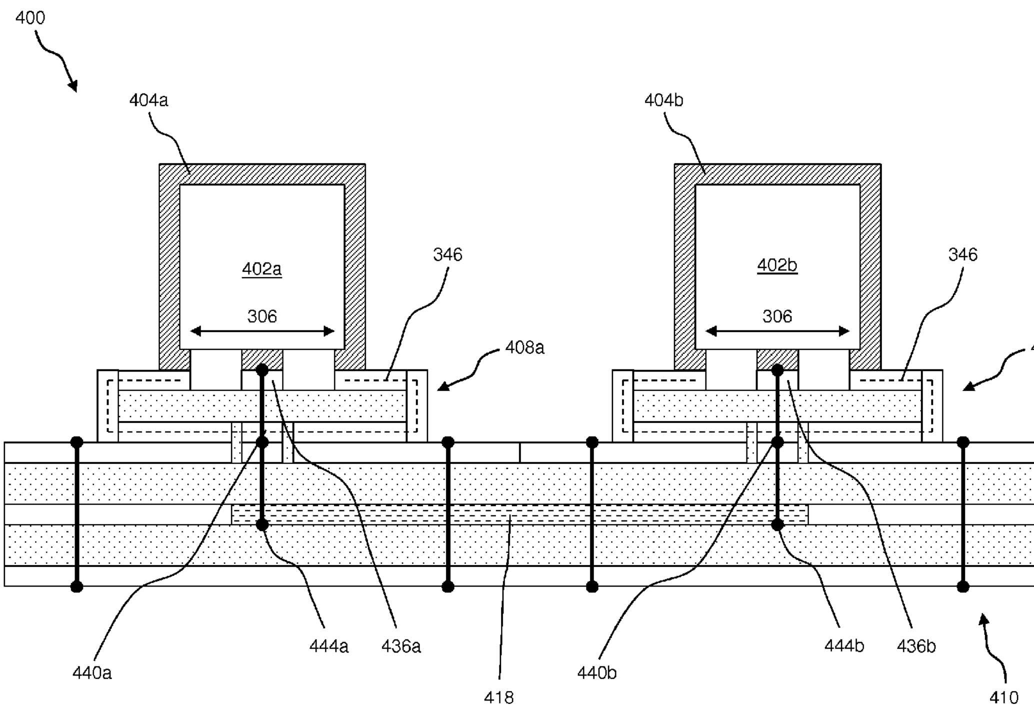
H01P 1/20 (2006.01)

(52) **U.S. Cl.**

USPC **333/134**; 333/202

(57) **ABSTRACT**

The present invention relates to a multi-mode filter comprising a carrier on which is mounted a dielectric resonator having a covering of an electrically conductive material in which there is provided an aperture and a coupling structure for coupling input signals to the dielectric resonator or for extracting filtered output signals from the dielectric resonator. The carrier is provided with an enclosing formation of electrically conductive material, which enclosing formation is electrically coupled to the electrically conductive covering of the dielectric resonator, such that the covering and the enclosing formation together form an electrically conductive enclosure for the dielectric resonator. The enclosure formed from the covering of the dielectric resonator and the enclosing formation increases the isolation of the filter and reduces leakage. The filter of the present invention is particularly suitable for use in cascaded resonator filter arrangements, and in duplex/diplex filters.



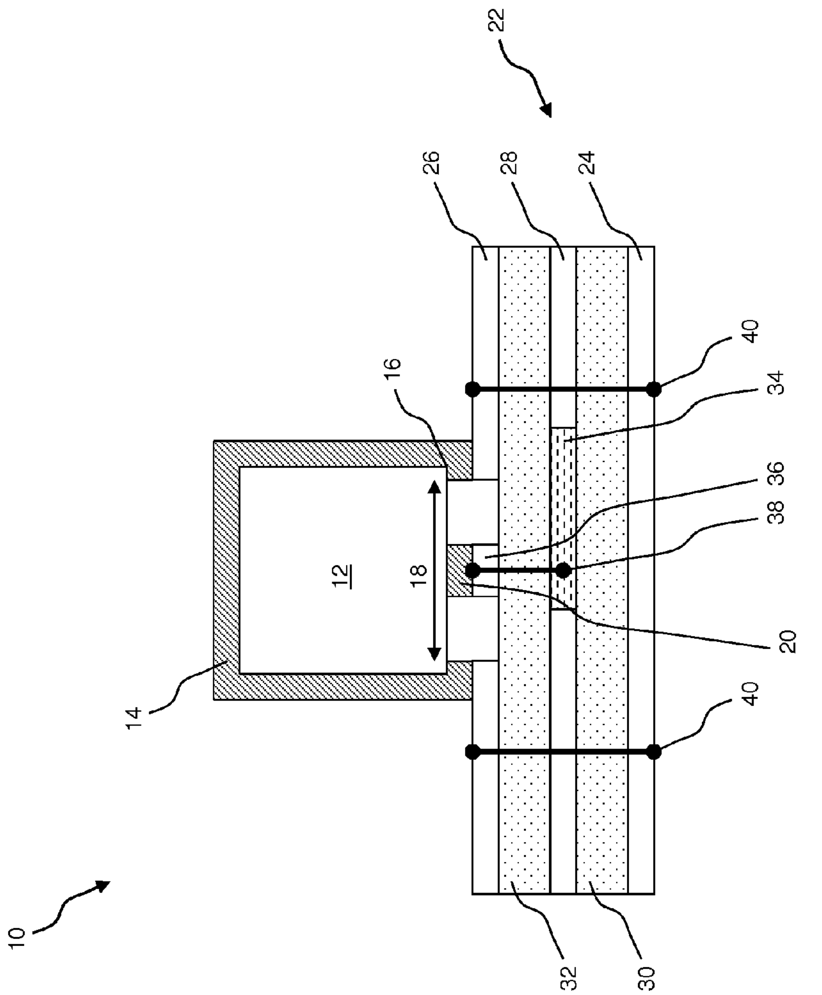


Figure 1

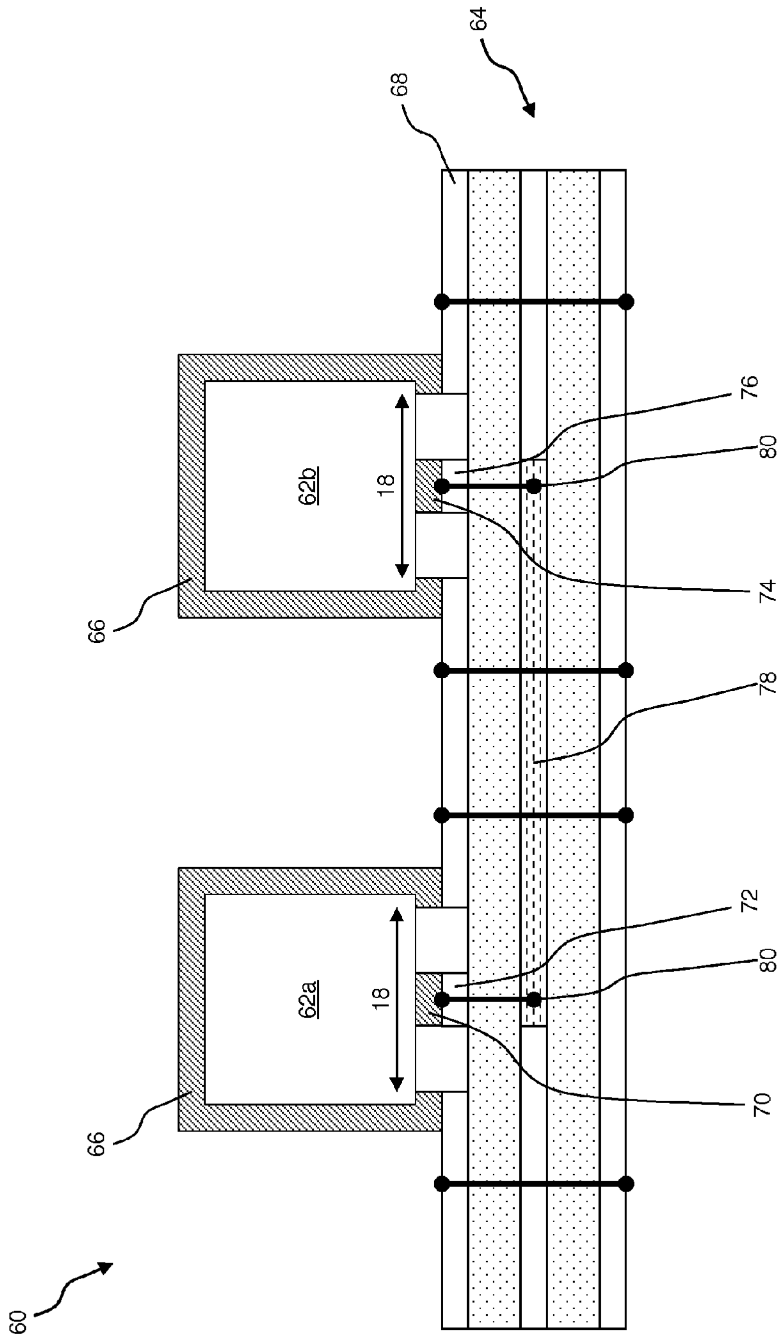


Figure 2

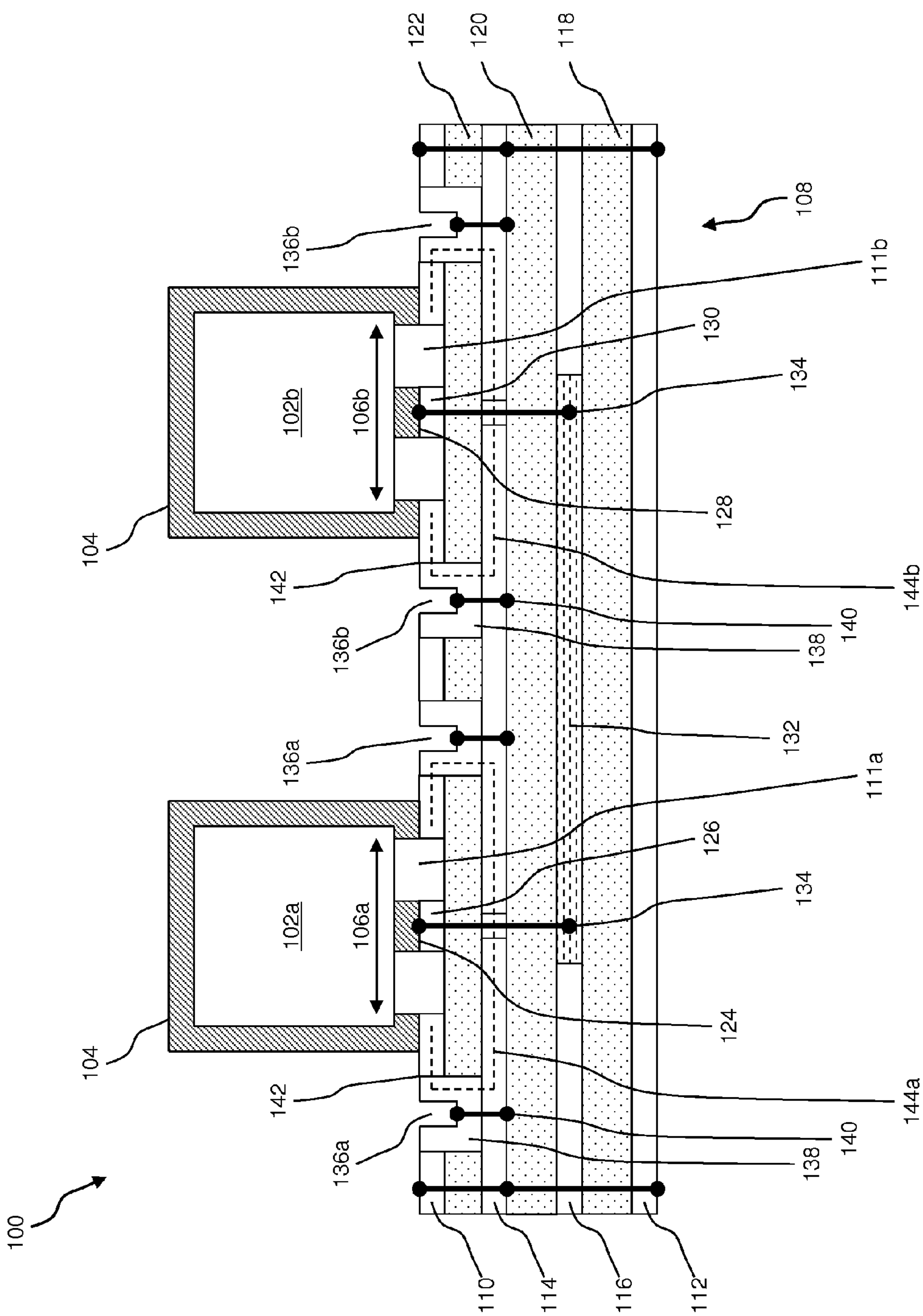

100
102a
102b
104
104
106a
106b
108
110
111a
111b
112
114
116
118
120
122
124
126
128
130
132
134
134
136a
136a
136b
136b
138
138
140
140
142
142
144a
144b

Figure 3

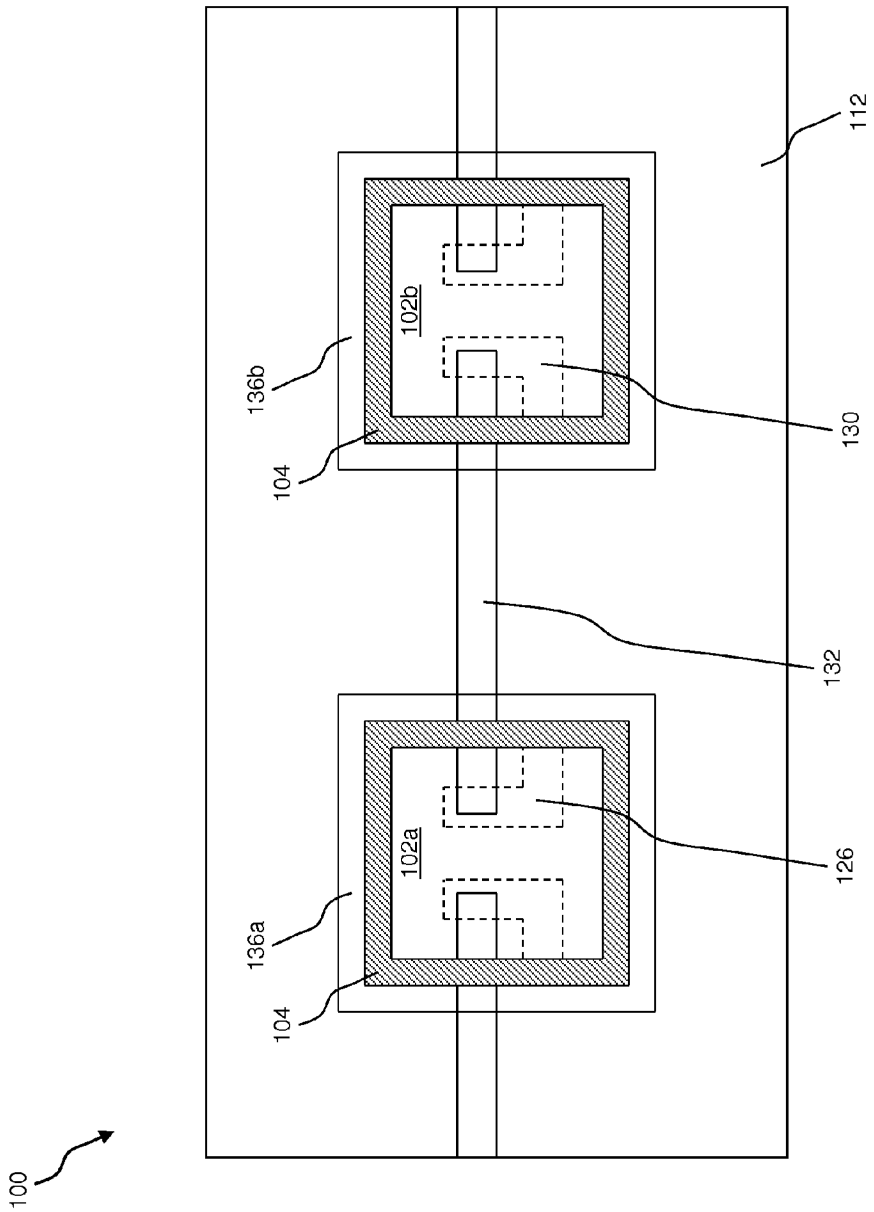


Figure 4

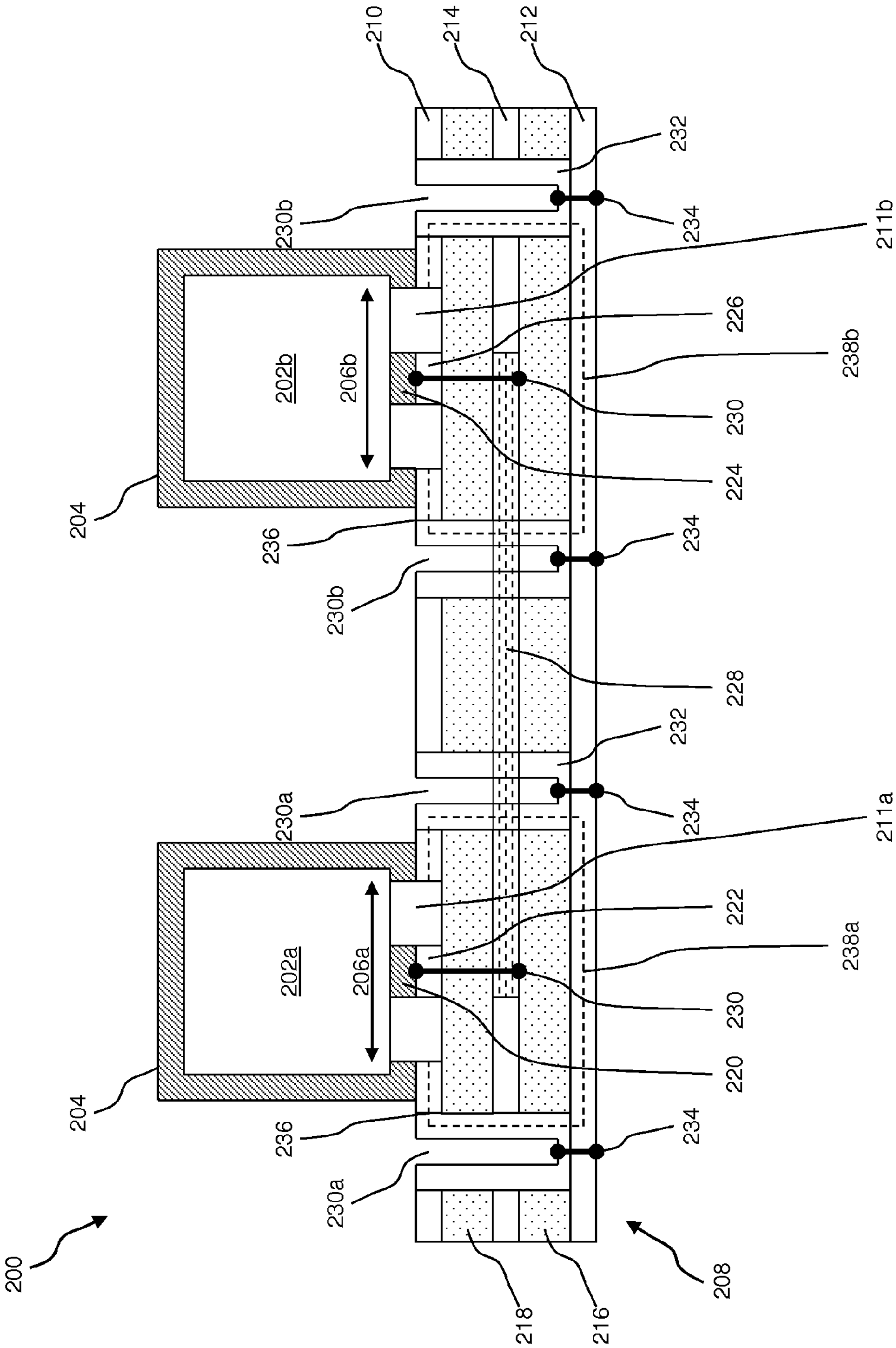

200
202a
202b
204
204
206a
206b
208
210
211a
211b
212
214
216
218
220
222
224
226
228
230
230
230a
230a
230b
230b
232
232
234
234
234
234
236
236
238a
238b

Figure 5

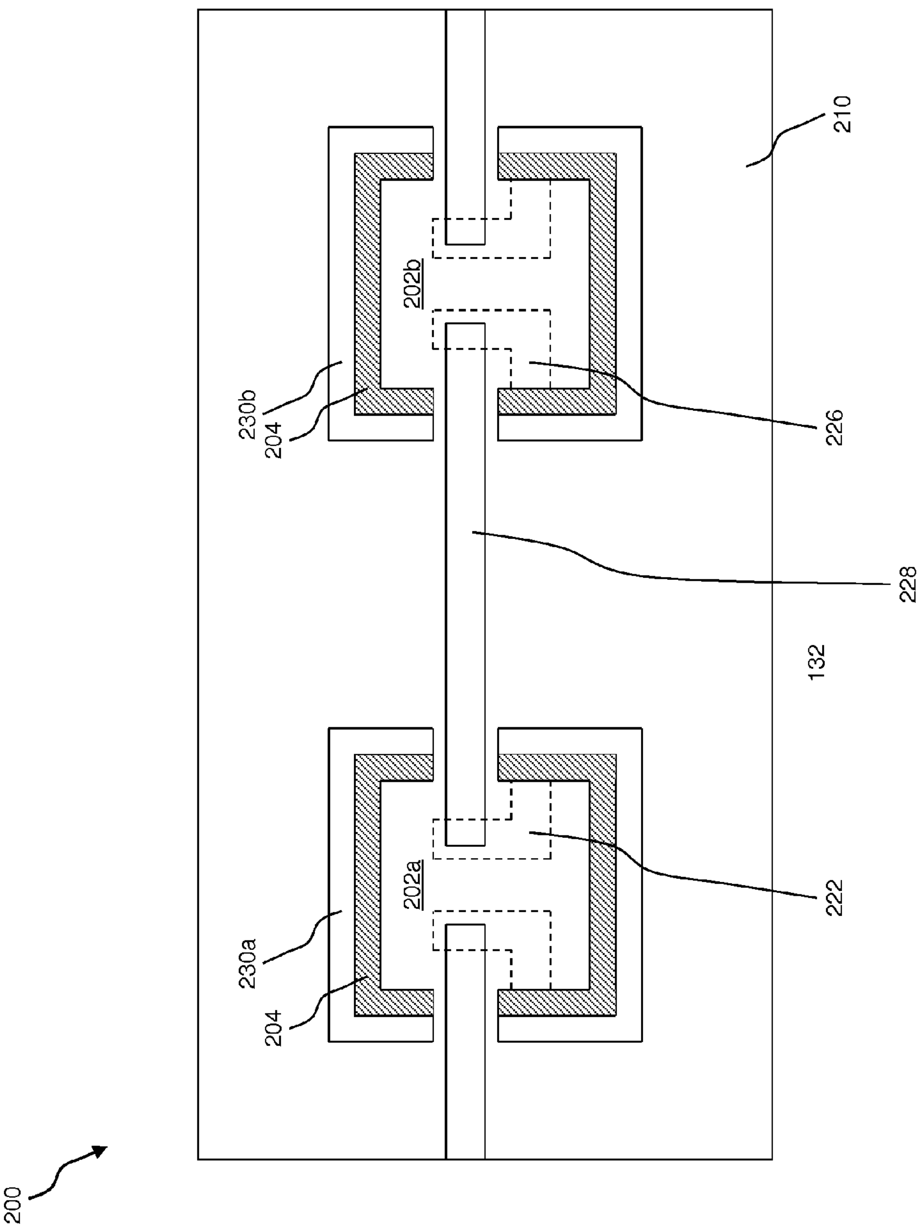


Figure 6

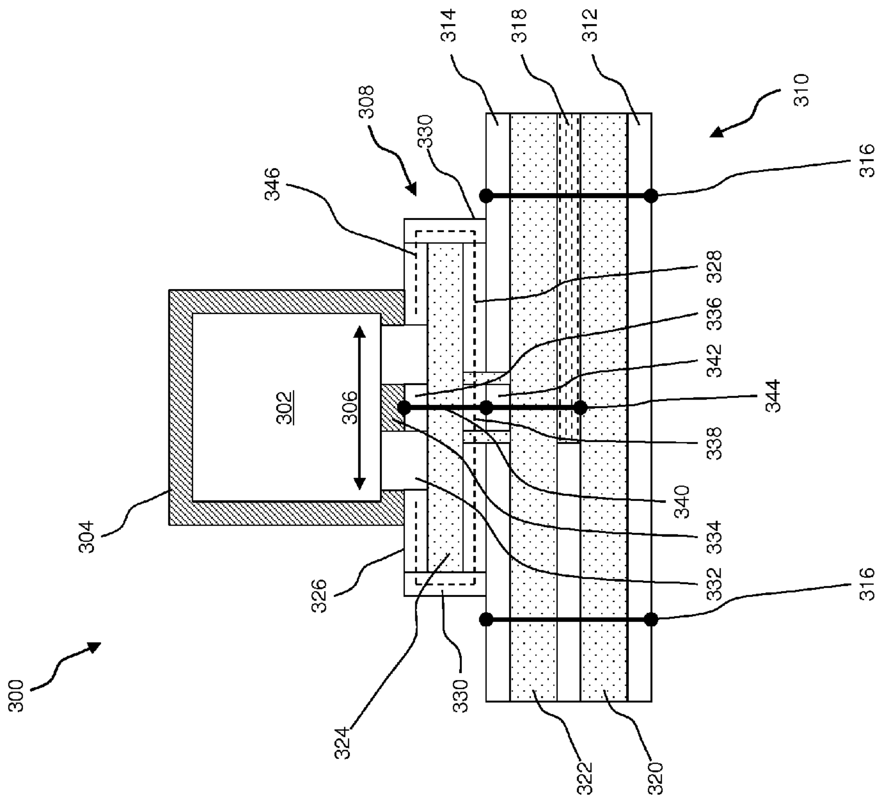

300
302
304
306
308
310
312
314
316
316
318
320
322
324
326
328
330
330
332
334
336
338
340
342
344
346

Figure 7

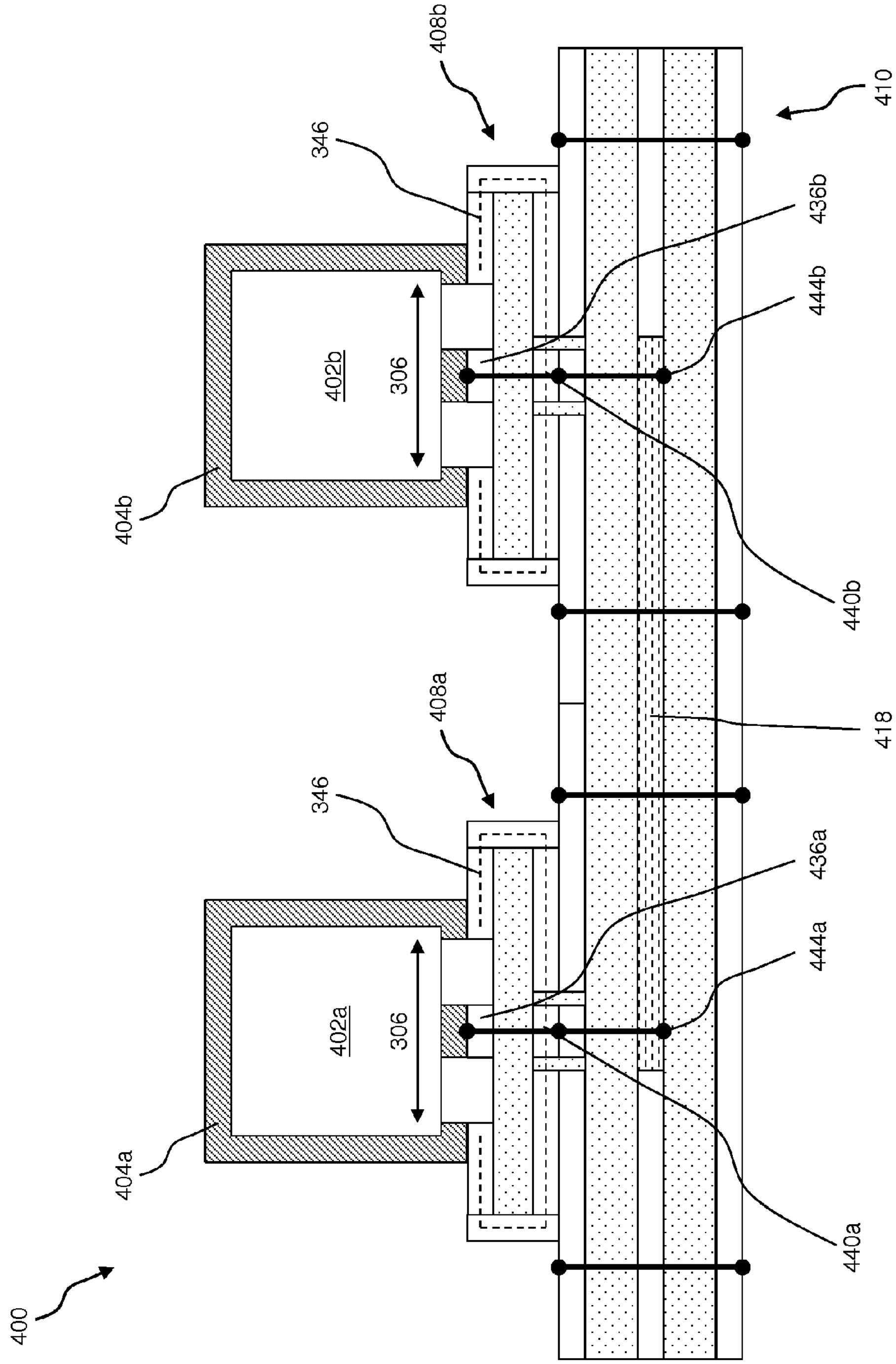

400
404a
402a
306
346
408a
436a
444a
440a
418
404b
402b
306
346
408b
436b
444b
440b
410

Figure 8

MULTI-MODE FILTER

BACKGROUND

[0001] The present invention relates to a multi-mode filter.

DESCRIPTION OF PRIOR ART

[0002] The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that the prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

[0003] Single mode dielectric filters are in widespread use in many communications systems, and are used in both in low power and high power applications within the cellular communications industry. In particular, duplex filters, which are used in many cellular telephone handsets, typically employ single mode dielectric filter technology.

[0004] Single mode dielectric filters typically include a resonator made of a dielectric material such as a ceramic. In many filtering applications a steep roll-off and a wide pass-band bandwidth are desired filter characteristics. In order to achieve these characteristics in a single mode dielectric filter, it is typically necessary to cascade a number of resonators in series. Cascading resonators in this way typically results in a significant increase in the loss in the (wanted) pass-band, due to both the insertion loss of the dielectric material itself (i.e. the dielectric losses within that material) and the coupling losses in transferring energy into and out of the dielectric.

[0005] Interest in the use of multi-mode dielectric filters is growing, since these filters allow the same piece of dielectric material (or "puck") to be effectively re-used multiple times, to form a more complex filter characteristic. A multi-mode dielectric filter typically has a steeper roll-off and a wider pass-band bandwidth than an equivalent single-mode dielectric filter could achieve. Use of a multi-mode dielectric filter in place of cascaded single mode resonators will typically also result in lower losses, due to the reduction in the number of times the signal needs to be coupled into and out of the dielectric material.

SUMMARY

[0006] According to some embodiments, the invention provides a multi-mode filter comprising: a carrier on which is mounted a dielectric resonator, the dielectric resonator having a covering of an electrically conductive material in which there is provided an aperture; and a coupling structure for coupling input signals to the dielectric resonator or for extracting filtered output signals from the dielectric resonator, wherein the carrier is provided with an enclosing formation of a grounded electrically conductive material, which enclosing formation is electrically coupled to the electrically conductive covering of the dielectric resonator, such that the covering and the enclosing formation together form an electrically conductive enclosure for the dielectric resonator.

[0007] The enclosure formed by the combination of the enclosing formation and the covering of the dielectric resonator has the effect of substantially reducing leakage from the resonator, thereby permitting an improvement in filter characteristics of the filter. Moreover, this improved leakage performance permits the filter to be used in a cascaded filter arrangement without compromising characteristics such as stop band isolation of the cascaded filter arrangement.

[0008] The enclosing formation is preferably electrically grounded.

[0009] In some embodiments, the enclosing formation may comprise a continuous or almost continuous formation of electrically conducting material.

[0010] The carrier may be provided with a trench of electrically conductive material which surrounds the resonator in a plane of the carrier, the trench being electrically grounded.

[0011] The trench may comprise a side wall and a base portion, such that the enclosing formation comprises a side wall and a base portion of the trench.

[0012] The carrier may be provided with a conductive layer on which the dielectric resonator is mounted, the conductive layer being electrically coupled to the trench such that the enclosing formation comprises a portion of the conductive layer and the side wall and base portion of the trench.

[0013] The carrier on which the dielectric resonator is mounted may be a first carrier, in which case the filter may comprise a second carrier on which the first carrier is mounted, the second carrier having a groundplane layer to which the enclosing formation is electrically coupled to electrically ground the enclosing formation.

[0014] The enclosing formation may have an aperture generally corresponding to the aperture of the covering of the dielectric resonator, the enclosing formation being electrically coupled to the covering of the dielectric resonator such that the aperture of the covering is aligned with the aperture of the enclosing formation.

[0015] The coupling structure may be electrically coupled to a corresponding contact track provided within the aperture of the enclosing formation.

[0016] The carrier may be of a printed circuit board material.

[0017] A further embodiment of the invention provides a cascaded resonator filter arrangement comprising: a first filter of the type described above and a second filter of the type described above, wherein an output of the first filter is electrically coupled to an input of the second filter.

[0018] In this case, the carrier of the first filter and the carrier of the second filter may comprise a single carrier that is common to the first and second filters.

[0019] A further embodiment of the invention provides a duplex or diplex filter comprising a transmit filter according of the type described above and a receive filter of the type described above.

[0020] In this case, the carrier of the first filter and the carrier of the second filter may comprise a single carrier that is common to the transmit and receive filters.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] An example of the present invention will now be described, strictly by way of example, with reference to the accompanying drawings, in which:

[0022] FIG. **1** is a schematic cross-sectional representation of a multi-mode dielectric filter;

[0023] FIG. **2** is a schematic cross-sectional representation of a filter arrangement using cascaded resonators;

[0024] FIG. **3** is a schematic cross-sectional representation of a filter arrangement using cascaded resonators according to an embodiment of the present invention;

[0025] FIG. **4** is a schematic view from below of the arrangement illustrated in FIG. **3**;

[0026] FIG. **5** is a schematic cross-sectional representation of a filter arrangement using cascaded resonators according to an alternative embodiment of the present invention;

[0027] FIG. **6** is a schematic view from below of the arrangement of FIG. **5**;

[0028] FIG. **7** is a schematic cross-sectional representation of a filter according to an alternative embodiment of the present invention; and

[0029] FIG. **8** is a schematic representation of a cascaded filter arrangement using the filter illustrated in FIG. **7**.

DETAILED DESCRIPTION

[0030] FIG. **1** is a schematic cross-sectional representation of a multi-mode dielectric filter. In the example illustrated in FIG. **1**, the multi-mode filter (shown generally at **10**) comprises a dielectric resonator **12**, which in the example is in the form of a generally cuboidal "puck" of dielectric material such as a ceramic material having a high dielectric constant. The cuboidal puck of dielectric material **12** is provided on five of its six faces with a coating or covering **14** of an electrically conductive material such as silver or another electrically conductive metal. The coating **14** extends also partially over a sixth face **16** of the dielectric material **12**, thereby defining an aperture **18** in the coating **14** on the sixth face **16**. One or more coupling structures **20** are provided on the sixth face **16** of the dielectric material to permit a signal to be filtered to be input to the dielectric material **12** and/or to permit filtered output signals to be extracted from the dielectric material **12**.

[0031] The dielectric resonator **12** is mounted on a carrier **22**, which in the example illustrated in FIG. **1** is a printed circuit board (PCB), but which may alternatively be of another dielectric material such as ceramic or glass. The PCB has lower and upper groundplane layers **24**, **26** and a central connection layer **28**. Lower and upper layers **30**, **32** of PCB dielectric material having a low dielectric constant are disposed between the lower groundplane layer **24** and the central connection layer **28** and between the central connection layer **28** and the upper groundplane layer **26** respectively. The upper groundplane layer **26** includes an aperture generally corresponding in shape and size to the aperture **18** in the coating **14** of the dielectric resonator **12**. The central connection layer **28** includes an input or output connection track **34** which is electrically connected by means of a via **38** to a PCB connection track **36** disposed within the aperture of the upper groundplane layer **26**, the PCB connection track **26** being electrically isolated from the upper groundplane layer **26**. Further vias **40** electrically connect the upper and lower groundplane layers **24**, **26**.

[0032] With the dielectric resonator **12** positioned on the carrier **22** as illustrated in FIG. **1**, the coating **14** of the dielectric resonator **12** is electrically coupled to the upper groundplane **26** of the carrier, and the coupling structure **20** of the dielectric material **12** is electrically coupled to the PCB connection track **36**, which is in turn electrically coupled to the input or output connection track **34**. Thus, a signal to be filtered can be input to the dielectric resonator **12** or a filtered output signal can be extracted from the dielectric resonator **12** as appropriate by means of the input or output connection track **24**.

[0033] Multi-mode filters such as the one illustrated in FIG. **1** typically have a low cost structure, a low loss and a small size. This is essential in active antenna applications where many filters are required in each active antenna product. For example, a 900 MHz active antenna product typically requires 16 filters. Unless small, low-cost, low-loss filters are used, the product becomes either too heavy or too expensive to be deployed on a large scale.

[0034] Some applications require a sharp roll-off between the pass-band and the stop band(s) of a filter, which may not be realisable using a single filter, even where a multi-mode filter such as that illustrated in FIG. **1** is used. In such applications it is typical to cascade multiple resonators **12**.

[0035] Such an arrangement of cascaded resonators is shown generally at **60** in FIG. **2**, which is a schematic cross-sectional view of a filter arrangement which uses two cascaded resonators. In the arrangement illustrated in FIG. **2**, first and second dielectric resonators **62***a*, **62***b* are mounted on a common carrier **64**, in a manner similar to that described above with reference to FIG. **1**. Thus, each of the dielectric resonators **62***a*, **62***b* has an apertured coating or covering **66** of an electrically conductive material such as silver or another electrically conductive metal. The first and second dielectric resonators **62***a*, **62***b* are mounted on the carrier such that their coatings electrically couple to an upper groundplane **68** of the carrier **64**.

[0036] The first dielectric resonator **62***a* is provided with a coupling structure **70** which is electrically coupled to a PCB connection track **72** of the carrier **64** to permit a filtered output signal to be extracted from the first dielectric resonator **62***a*. The second dielectric resonator **62***b* is provided with a coupling structure **74** which is electrically coupled to a PCB connection track **76** of the carrier **64** to permit a signal to be filtered to be input to the second dielectric resonator **62***b*. The PCB connection tracks **72** and **76** are each connected to a common connector track **78** by vias **80**, such that a signal extracted from the first dielectric resonator **62***a* is input to the second dielectric resonator **62***b* for further filtering. In this way, the required filter characteristics can be realised using the cascaded dielectric resonators **62***a*, **62***b*.

[0037] One disadvantage of the cascaded dielectric resonator arrangement illustrated in FIG. **2** is that the overall filter losses due to the insertion loss within the dielectric resonators **62***a*, **62***b* and the coupling losses in transferring energy into and out of the dielectric resonators **62***a*, **62***b* is too high for some applications, such as diplexers for use in transceivers. It can also be difficult to achieve sufficient isolation between the individual dielectric resonators **62***a*, **62***b* in a cascaded arrangement of the type illustrated in FIG. **2** for the overall filter to achieve its theoretical capabilities, particularly with regard to stop band isolation, as leakage occurs through the carrier **64** on which the cascaded dielectric resonators **62***a*, **62***b* are mounted. In the particular case of a duplex or diplex filter configuration for use in a transceiver, leakage may also occur between the transmit and receive portions of the filter.

[0038] Referring now to FIG. **3**, an arrangement of cascaded dielectric resonators forming a filter is shown generally at **100**. The filter **100** is made up of two generally similar dielectric resonators **102***a*, **102***b*, each being formed as a generally cuboidal puck of a dielectric material such as a ceramic having a high dielectric constant. Each of the dielectric resonators **102***a*, **102***b* has a coating or covering of an electrically conductive material such as silver or another electrically conductive metal. The coating **104** extends over all six faces of the dielectric resonators **102***a*, **102***b*, although apertures **106***a*, **106***b* are provided in the coating **104** in one face (shown as the lower face in FIG. **3**) of each of the dielectric resonators **102***a*, **102***b*, to permit connections to be made to the dielectric material of the dielectric resonators **102***a*, **102***b*.

[0039] The first and second dielectric resonators **102***a*, **102***b* are mounted on a common carrier **108**, which may be, for example, a printed circuit board (PCB), but which may alternatively be of another dielectric material such as ceramic or glass. The carrier **108** has an upper conductive layer **110** of a conductive material such as copper, lower and upper groundplane layers **112**, **114** and a central connection layer **116**. Lower and upper layers **118**, **120** of PCB dielectric material having a low dielectric constant are disposed between the lower groundplane layer **112** and the central connection layer **116** and between the central connection layer **116** and the upper groundplane layer **114** respectively. A further layer **122** of dielectric material such as PCB material, ceramic or glass is disposed between the upper groundplane layer **114** and the upper conductive layer **110**.

[0040] The upper conductive layer **110** is provided with apertures **111***a*, **111***b* which correspond generally in shape and size to the apertures **106***a*, **106***b* of the dielectric resonators **102***a*, **102***b*. It will be appreciated that the apertures **111***a*, **111***b* in the upper conductive layer **110** need not correspond exactly to the apertures **106***a*, **106***b* of the dielectric resonators **102***a*, **102***b*. For example, the apertures **106***a*, **106***b* of the dielectric resonators **102***a*, **102***b* may be slightly larger than the apertures **111***a*, **111***b* in the upper conductive layer **326**. The lower faces of the first and second dielectric resonators **102***a*, **102***b* are mounted on the upper conductive layer **110**, with the apertures **106***a*, **106***b* in the coatings **104** of the dielectric resonators **102***a*, **102***b* aligned with the apertures **111***a*, **111***b* in the upper conductive layer **110**, such that that portion of the electrically conductive coatings **104** which surrounds each of the apertures **106***a*, **106***b* electrically couples the coatings **104** of the dielectric resonators **102***a*, **102***b* to the upper conductive layer **110** of the carrier **108**.

[0041] The first dielectric resonator **102***a* is provided with one or more coupling structures **124** which are electrically coupled to one or more corresponding PCB connection tracks **126** provided within the aperture **111***a* of the upper conductive layer **110** of the carrier **108**, to permit a signal to be filtered to be input to the first dielectric resonator **102***a*, and/or to permit a filtered output signal to be extracted from the first dielectric resonator **102***a*. Similarly, the second dielectric resonator **102***b* is provided with one or more coupling structures **128** which are electrically coupled to PCB connection tracks **130** provided within the aperture **111***b* of the upper conductive layer **110** of the carrier **108**, to permit a signal to be filtered to be input to the second dielectric resonator **102***b*, and/or to permit a filtered output signal to be extracted from the second dielectric resonator **102***b*. The PCB connection tracks **126** and **130** are each connected to a common connector track **132** by vias **134**, such that a signal extracted from the first dielectric resonator **102***a* is input to the second dielectric resonator **102***b* for further filtering.

[0042] The upper conductive layer **110** of the carrier **108** is formed with first and second trenches **136***a*, **136***b* of an electrically conductive material such as copper which presents a low impedance to radio frequency currents. The trenches **136***a*, **136***b* surround the lower faces of the first and second dielectric resonators **102***a*, **102***b* in the plane of the upper conductive layer **110**, as can be seen more clearly from FIG. **4**, and extending from an upper surface of the upper conductive layer **110** into the carrier **108**. Each of the first and second trenches **136***a*, **136***b* has a base portion **138** which is positioned adjacent the upper groundplane **114**, and is electrically coupled to the upper groundplane **114** by means of vias **140** or by directly bonding the base portion **138** of the trench **136***a*, **136***b* to the upper groundplane **114**, for example using a conductive bond such as solder, or plating using an electroplating process. Thus, as can be seen most clearly in FIG. **3**, the combination of the upper conductive layer **110**, side walls **142** and base portions **138** of the trenches **136***a*, **136***b* and the upper groundplane **114**, forms respective first and second continuous electrically conductive enclosing formations, as shown in dashed outline at **144***a* and **144***b*. These electrically conductive enclosing formations **144***a*, **144***b* are electrically grounded by virtue of the upper groundplane **114**, and are electrically coupled to the electrically conductive coatings **104** of the first and second dielectric resonators **102***a*, **102***b*, and thus the first and second dielectric resonators **102***a*, **102***b* are substantially enclosed in respective first and second grounded electrically conductive enclosures made up of the coatings **104** and the respective first and second enclosing formations **144***a*, **144***b*. These grounded electrically conductive enclosures have the effect of enclosing fields (electric or magnetic) present in the dielectric resonators **102***a*, **102***b*, thus improving isolation of, and reducing leakage from, the dielectric resonators **102***a*, **102***b*, and thus lead to improved characteristics of the filter **100** in comparison to filters such as that illustrated in FIG. **2**. In the example illustrated in FIG. **3** the trenches **136***a*, **136***b* take the form of open-topped channels with a generally rectangular cross-section, but it will be appreciated that the same effect can be achieved using trenches of any cross-sectional shape, for example a trench with a generally U-shaped cross-section, such that the base portion is curved, a trench having a generally V-shaped cross-section, or a trench with substantially parallel sides and a base portion having a generally V-shaped cross-section.

[0043] FIG. **5** is a schematic cross-sectional view of an alternative arrangement of cascaded dielectric resonators forming a filter **200**. As in the embodiment illustrated in FIG. **3**, the filter **200** is made up of two generally similar dielectric resonators **202***a*, **202***b*, each being formed as a generally cuboidal puck of a dielectric material such as a ceramic having a high dielectric constant. Each of the dielectric resonators **202***a*, **202***b* has a coating or covering of an electrically conductive material such as silver or another electrically conductive metal. The coating **204** extends over all six faces of the dielectric resonators **202***a*, **202***b*, although apertures **206***a*, **206***b* are provided in the coating **204** in one face (shown as the lower face in FIG. **5**) of each of the dielectric resonators **202***a*, **202***b*, to permit connections to be made to the dielectric material of the dielectric resonators **202***a*, **202***b*.

[0044] The first and second dielectric resonators **202***a*, **202***b* are mounted on a common carrier **208**, which may be, for example, a printed circuit board (PCB), but which may alternatively be of another dielectric material such as ceramic or glass. The carrier has an upper conductive layer **210** of a conductive material such as copper, a lower groundplane layer **212** and a central connection layer **214**. Lower and upper layers **216**, **218** of dielectric material such as PCB material, ceramic or glass are disposed between the lower groundplane layer **212** and the central connection layer **214** and between the central connection layer **214** and the upper conductive layer **210** respectively.

[0045] The upper groundplane layer **210** is provided with apertures **211***a*, **211***b* which generally correspond in shape and size to the apertures **206***a*, **206***b* of the dielectric resonators **202***a*, **202***b*. It will be appreciated that the apertures **211***a*, **211***b* in the upper groundplane layer **210** need not correspond exactly to the apertures **206***a*, **206***b* of the dielectric resonators **202***a*, **202***b*. For example, the apertures **206***a*, **206***b* of the dielectric resonators **202***a*, **202***b* may be slightly larger than the apertures **211***a*, **211***b* in the upper groundplane layer **210**. The lower faces of the first and second dielectric resonators **202***a*, **202***b* are mounted on the upper conductive layer **210**, with the apertures **206***a*, **206***b* of the first and second dielectric resonators **202***a*, **202***b* aligned with the apertures **211***a*, **211***b* of the upper groundplane **210** of the carrier **208**, such that that portion of the electrically conductive coatings **204** which surrounds each of the apertures **206***a*, **206***b* electrically couples the coating **204** of the dielectric resonators **202***a*, **202***b* to the upper conductive layer **210** of the carrier **208**.

[0046] The first dielectric resonator **202***a* is provided with one or more coupling structures **220** which are electrically coupled to one or more corresponding PCB connection tracks **222** disposed within the aperture **211***a* of the upper groundplane layer **210** of the carrier **208** to permit a signal to be filtered to be input to the first dielectric resonator **202***a*, and/or to permit a filtered output signal to be extracted from the first dielectric resonator **202***a*. Similarly, the second dielectric resonator **202***b* is provided with one or more coupling structures **224** which are electrically coupled to a PCB connection track **226** disposed within the aperture **211***b* of the upper groundplane **210** of the carrier **208** to permit a signal to be filtered to be input to the second dielectric resonator **202***b* and/or to permit a filtered output signal to be extracted from the second dielectric resonator **202***b*. The PCB connection tracks **222** and **226** are each connected to a common connector track **228** by vias **230**, such that a signal extracted from the first dielectric resonator **202***a* is input to the second dielectric resonator **202***b* for further filtering.

[0047] The carrier **208** is formed with first and second trenches **230***a*, **230***b* of an electrically conductive material such as copper which presents a low impedance to radio frequency currents. The trenches **230***a*, **230***b* surround the lower faces of the first and second dielectric resonators **202***a*, **202***b* in the plane of the upper groundplane layer **210**, as can be seen more clearly from FIG. **6**. The trenches **230***a*, **230***b* extend from an upper surface of the upper conductive layer **210** into the carrier **208** through the upper and lower PCB dielectric layers **218**, **216** and the central connection layer **214**, such that a base portion **232** of each trench **230***a*, **230***b* is positioned adjacent the lower groundplane **212**. The base portion **232** of each trench **230***a*, **230***b* is electrically coupled to the lower groundplane **212** by means of a via **234** or by directly bonding the base portion **232** of the trench **230***a*, **230***b* to the lower groundplane **212**, for example using a conductive bond such as solder, or plating using an electroplating process. Thus, the combination of the upper conductive layer **210**, side walls **236** and base portions **232** of the trenches **230***a*, **230***b* and the lower groundplane **212**, forms respective first and second electrically conductive enclosing formations, as indicated in dashed outline at **238***a* and **238***b* in FIG. **5**. These electrically conductive enclosing formations **238***a*, **238***b* are electrically grounded by virtue of the lower groundplane **212**, and are electrically coupled to the electrically conductive coatings **204** of the first and second dielectric resonators **202***a*, **202***b*, and thus the first and second dielectric resonators **202***a*, **202***b* are substantially enclosed in respective first and second grounded electrically conductive enclosures made up of the coatings **204** and the respective first and second enclosing formations **238***a*, **238***b*. These grounded electrically conductive enclosures have the effect of enclosing fields (electric or magnetic) present in the dielectric resonators **202***a*, **202***b*, thus improving isolation of, and reducing leakage from, the dielectric resonators **202***a*, **202***b*, and thus lead to improved characteristics of the filter **200** in comparison to filters such as that illustrated in FIG. **2**. It will be noted that, in the embodiment illustrated in FIGS. **5** and **6**, the common connector track **228** extends through the side walls **236** of the trenches **230***a*, **230***b*. Thus, a gap exists in each of the enclosures enclosing the dielectric resonators **202***a*, **202***b*. Nevertheless, the combination of the enclosing formations **238***a*, **238***b* and the coverings **204** to form the enclosures enclosing the dielectric resonators **202***a*, **202***b* provides improved performance compared to the filter arrangement of FIG. **2**. In the example illustrated in FIG. **5** the trenches **230***a*, **230***b* take the form of open-topped channels with a generally rectangular cross-section, but it will be appreciated that the same effect can be achieved using trenches of any cross-sectional shape, for example a trench with a generally U-shaped cross-section, such that the base portion is curved, a trench having a generally V-shaped cross-section, or a trench with substantially parallel sides and a base portion having a generally V-shaped cross-section.

[0048] FIG. **7** is a schematic cross-sectional representation of an alternative dielectric resonator filter **300**. In the arrangement illustrated in FIG. **7**, the filter **300** uses a single dielectric resonator **302** formed as a generally cuboidal puck of a dielectric material such as a ceramic having a high dielectric constant. The dielectric resonator **302** has a coating or covering **304** of an electrically conductive material such as silver or another electrically conductive metal. The coating **304** extends over all six faces of the dielectric resonator **302**, although an aperture **306** is provided in the coating **304** in one face (shown as the lower face in FIG. **7**) of the dielectric resonator **302**, to permit connections to be made to the dielectric material of the dielectric resonator **302**.

[0049] The dielectric resonator **302** is mounted on a first carrier **308**, which in turn is mounted on a second carrier **310**, such that the second carrier **310** may be regarded as a "mother" carrier and the first carrier **308** may be regarded as a "daughter" carrier.

[0050] The second carrier **310** is of a dielectric material such as, for example PCB material, ceramic or glass, having lower and upper groundplane layers **312**, **314**, which are electrically connected by vias **316**, and a central connection layer **318**. Lower and upper layers **320**, **322** of dielectric material such as PCB material, ceramic or glass are disposed between the lower groundplane layer **312** and the central connection layer **318** and between the central connection layer **318** and the upper groundplane layer **314** respectively.

[0051] The first carrier **308** comprises a central layer **324** of a dielectric material such as PCB substrate material, ceramic or glass. Disposed on upper and lower faces of the central layer **324** are upper and lower conductive layers **326**, **328** of an electrically conductive material such as copper or another metal which presents a low impedance to radio frequency currents. The lower conductive layer **328** is disposed on and electrically coupled to the upper groundplane layer **314** of the second carrier **310**. The central layer **324** of the first carrier **310** also has walls **330** of an electrically conductive material such as copper or another metal, which are electrically coupled to the upper and lower conductive layers **326**, **328**.

[0052] The upper conductive layer **326** is provided with an aperture **332** of a shape and size generally corresponding to the aperture **306** in the coating **304** of the dielectric resonator

302. It will be appreciated that the aperture **332** in the upper conductive layer **326** need not correspond exactly to the aperture **306** in the coating **304** of the dielectric resonator **302**. For example, the aperture **306** in the coating **304** may be slightly larger than the aperture **332** in the upper conductive layer **326**. The lower face of the dielectric resonator **302** is mounted on the upper conductive layer **326**, with the aperture **306** of the dielectric resonator **302** aligned with the aperture **332** of the upper conductive layer **326** of the first carrier **308**, such that that portion of the electrically conductive coating **304** which surrounds the aperture **306** electrically couples the coating **304** of the dielectric resonator **302** to the upper conductive layer **326** of the first carrier **308**.

[0053] The dielectric resonator **302** is provided with one or more coupling structures **334** which are electrically coupled to one or more corresponding PCB connection tracks **336** disposed within the aperture **332** of the upper conductive layer **326** of the first carrier **308** to permit a signal to be filtered to be input to the dielectric resonator **302**, and/or to permit a filtered output signal to be extracted from the dielectric resonator **302**. The PCB connection track **336** is electrically connected to a further PCB connection track **338** provided on the lower conductive layer **328** of the first carrier **308** by a via **340**. This further PCB connection track **338** is electrically coupled to a PCB connection pad **342** provided in the upper groundplane layer **314** of the second carrier **310**, which PCB connection pad **342** is electrically coupled to the central connection layer **318** by means of a via **344**, to permit input and output signals to be input to and extracted from the dielectric resonator **302** through the central connection layer **318**.

[0054] It will be appreciated that the upper conductive layer **326**, the lower conductive layer **328** and the walls **330** of the first carrier **308** together constitute a continuous electrically conductive enclosing formation, as indicated in dashed outline at **346**. This electrically conductive enclosing formation **346** is electrically grounded, by virtue of the electrical connection between the lower conductive layer **328** and the upper groundplane layer **314** of the second carrier **310**, and is electrically coupled to the electrically conductive coating **304** of the dielectric resonators **302**, and thus the dielectric resonator **302** is substantially enclosed in a grounded electrically conductive enclosure made up of the coating **304** and the enclosing formation **346**. This grounded electrically conductive enclosure has the effect of enclosing fields (electric or magnetic) present in the dielectric resonator **302**, thus improving isolation of, and reducing leakage from, the dielectric resonator **302**, and thus leads to improved characteristics of the filter **300** in comparison to filters such as that illustrated in FIG. **1**.

[0055] FIG. **8** is a schematic cross-sectional representation of a filter arrangement **400** made up of two cascaded filters of the type described above with reference to FIG. **7**.

[0056] The filter arrangement illustrated in FIG. **8** uses first and second dielectric resonators **402***a*, **402***b* of the type described above, and so like reference numerals have been used in FIG. **8** to refer to like elements. The first and second dielectric resonators **402***a*, **402***b* are mounted on respective first ("daughter") carriers **408***a*, **408***b*, which are in turn mounted on a second carrier **410**. The dielectric resonators **402***a*, **402***b* and the first carriers **408***a*, **408***b* are of the type described above, and so will not be described again in detail here.

[0057] The second carrier **410** is similar in structure and construction to the second carrier **310** described above, and so will not be described again in detail here. However, the second carrier **410** differs from the second carrier **310** described above in that that the central connection layer **418** is used to connect an output of the first dielectric resonator **402***a* to an input of the second dielectric resonator by means of vias **440***a*, **444***a* and **440***b*, **440***b* which connect PCB connection tracks **436***a*, **436***b* to each other, thereby permitting transfer of signals between the first and second dielectric resonators **402***a*, **402***b*.

[0058] As in the single resonator filter **300** illustrated in FIG. **7**, the upper conductive layer **326**, the lower conductive layer **328** and the walls **330** of the first carrier **308** together constitute a continuous electrically conductive enclosing formation, as indicated in dashed outline at **346**. This electrically conductive enclosing formation **346** is electrically coupled to the electrically conductive coating **304** of the dielectric resonators **302**, and thus the dielectric resonator **302** is substantially enclosed in a conductive enclosure made up of the coating **304** and the enclosing formation **346**. This electrically conductive enclosure has the effect of enclosing fields (electric or magnetic) present in the dielectric resonator **302**, thus improving isolation of, and reducing leakage from, the dielectric resonator **302**, and thus leads to improved characteristics of the filter **300** in comparison to filters such as that illustrated in FIG. **1**. In the filter **400** illustrated in FIG. **8**, which uses two cascaded dielectric resonators **402***a*, **402***b*, this improved isolation and reduced leakage results in improved filter characteristics over known cascaded dielectric resonator arrangements.

[0059] It will be appreciated that the filter arrangement of the present invention provide improved isolation and reduced leakage, which gives rise to improved filter characteristics and performance, particularly in the cascaded resonator filter arrangements discussed above by reference to FIGS. **3**, **5** and **8**. Additionally, the filter arrangement of the present invention may be employed in a duplex or diplex filter arrangement in which a transmit filter and a receive filter are mounted on a common carrier, by electrically isolating the connecting structures of the transmit and receive structures from each other. In such an arrangement the improved isolation and reduced leakage of the filter of the present invention gives rise to improved filter characteristics and performance of both the transmit filter and the receive filter.

1. A multi-mode filter comprising;

a carrier on which is mounted a dielectric resonator, the dielectric resonator having a covering of an electrically conductive material in which there is provided an aperture; and

at least one coupling structure for coupling input signals to the dielectric resonator or for extracting filtered output signals from the dielectric resonator,

wherein the carrier is provided with an enclosing formation of electrically conductive material, which enclosing formation is electrically coupled to the electrically conductive covering of the dielectric resonator, such that the covering and the enclosing formation together form an electrically conductive enclosure for the dielectric resonator.

2. A multi-mode filter according to claim **1** wherein the enclosing formation is electrically grounded.

3. A multi-mode filter according to claim **1** wherein the enclosing formation comprises a continuous or almost continuous formation of grounded electrically conducting material.

4. A multi-mode filter according to claim **3** wherein the carrier is provided with a trench of electrically conductive material which surrounds the resonator in a plane of the carrier, the trench being electrically grounded.

5. A multi-mode filter according to claim **4** wherein the trench comprises a side wall and a base portion, such that the enclosing formation comprises the side wall and the base portion of the trench.

6. A multi-mode filter according to claim **5** wherein the carrier is provided with conductive layer on which the dielectric resonator is mounted, the conductive layer being electrically coupled to the trench such that the enclosing formation comprises a portion of the conductive layer and the side wall and base portion of the trench.

7. A multi-mode filter according to claim **1** wherein carrier on which the dielectric resonator is mounted is a first carrier, the filter comprising a second carrier on which the first carrier is mounted, the second carrier having a groundplane layer to which the enclosing formation is electrically coupled to electrically ground the enclosing formation.

8. A multi-mode filter according to claim **1** wherein the enclosing formation has an aperture generally corresponding to the aperture of the covering of the dielectric resonator, the enclosing formation being electrically coupled to the covering of the dielectric resonator such that the aperture of the covering is aligned with the aperture of the enclosing formation.

9. A multi-mode filter according to claim **8** wherein the coupling structure is electrically coupled to a corresponding contact track provided within the aperture of the enclosing formation.

10. A multi-mode cavity filter according to claim **1** wherein the carrier is of a printed circuit board material, or a ceramic material, or glass.

11. A cascaded resonator filter arrangement comprising:

a first filter according to claim **1**; and

a second filter according to claim **1**, wherein an output of the first filter is electrically coupled to an input of the second filter.

12. A cascaded resonator filter arrangement according to claim **11**, wherein the carrier of the first filter and the carrier of the second filter comprise a single carrier that is common to the first and second filters.

13. A duplex or diplex filter comprising a transmit filter according to claim **1** and a receive filter according to claim **1**.

14. A duplex or diplex filter according to claim **13** wherein the carrier of the first filter and the carrier of the second filter comprise a single carrier that is common to the transmit and receive filters.

* * * * *