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(54) A resonator, a radio frequency filter and a method of filtering

(57) A resonator is provided comprising a resonant chamber, the resonant chamber comprising a first wall, a second wall opposite the first wall, and side walls. The resonant chamber houses a resonator post which is grounded on the first wall so as to extend into the chamber. The resonator post has a cap at the end of the resonator post that is away from the first wall. The cap has at least one arm extending in a direction transverse to the longitudinal axis of the resonator post.

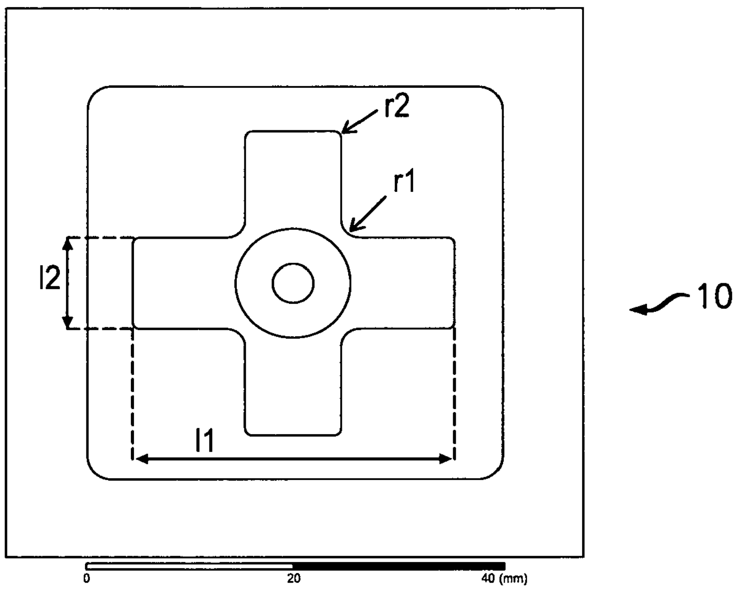

FIG. 3

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Description

Field of the Invention

[0001] The present invention relates to filters for telecommunications, in particular to radio-frequency filters.

Description of the Related Art

[0002] Combline filters, also known as coaxial cavity filters, are often used in base stations for cellular wireless telecommunications, in particular in Frequency Division Duplexer (FDD) systems. Typically the rejection levels required in a modern FDD system require a number of transmission zeros to be realised in a highly asymmetric filter. In coaxial cavity filters, cross couplings between the cavity resonators that make up the filter are used to produce the transmission zeros.

[0003] Transmission zeros are required to provide spectrum-efficient filtering by a limited number of resonators having reasonable size and insertion loss. Typically a number of cross-couplings between cavity resonators is required. That number can be less than half the total number of cavity resonators.

[0004] The known way to provide the coupling is to provide a machined slot between the cavity resonators into which a capacitive probe extends. The probe is made of conductive material and is supported mechanically by a plastic/dielectric material in the machined slot. In high power conditions, the probe may overheat, particularly as for electrical reasons the probe is thermally decoupled from any effective heat sink. When the probe heats up, in addition-to an overall reduction in the quality factor of the cavity resonator, arcing may even result. A known approach to address overheating and other thermal-tolerance issues is to manufacture the capacitive probes using suitable materials, for example silver plated steel. Each probe is, in practice, individually designed and manufactured to provide the required cross- coupling.

[0005] Another known approach to providing transmission zeros in coaxial cavity filters is to use an extracted pole technique, but this has disadvantages as compared to cross-coupling techniques including probes.

Summary

[0006] The reader is referred to the appended independent claims. Some preferred features are laid out in the dependent claims.

[0007] An example of the present invention is a resonator comprising a resonant chamber, the resonant chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which

the resonant chamber houses a resonator post which is grounded on the first wall so as to extend into the chamber;

the resonator post comprising a cap at its end that is away from the first wall,

the cap having at least one arm extending in a direction transverse to the longitudinal axis of the resonator post.

[0008] Some embodiments provide coaxial cavity filters having improved negative (i.e. capacitive) cross coupling. In some embodiments, a coaxial resonator post is provided having an open end, namely an end away from the end grounded on the cavity, where the open end includes a bent out arm or arms. Each arm may be directed towards a side wall of the chamber. For example, there may be four arms (for example making a cross-shape) or three arms for example making a triangular shape. To aid understanding, in some embodiments, the post and one arm, when viewed in profile, may be considered as taking the form of greek letter r (capital gamma).

[0009] In some embodiments, the capacitance at the top of the resonator post follows the shape of the cap which has arms, and, in some embodiments, by using a pair of the caps having arms, capacitive coupling between two resonators is increased, (as compared to known resonators having circular caps). This increase in capacitance means that additional parts, such as auxiliary elements, sometimes known as probes or capacitive probes, in the vicinity of where the capacitive coupling takes place are advantageously not required. In consequence, filters are simpler and, due to the absence of probes which might overheat, suitable for high power applications.

[0010] Some embodiments provided a greater magnitude of capacitive (i.e. negative) coupling as compared to known filters using circular disc caps operating at the same resonant frequency. In consequence capacitive probes are not required.

[0011] Preferably, the cap has four arms so as to take a cross-shape. Alternatively preferably the cap has one, two or three arms. Alternatively preferably the cap has more than four arms.

[0012] Examples of the present invention also relates to corresponding radio frequency filters and methods of filtering.

[0013] For example, a radio frequency filter is provided comprising two of the resonators in which in the wall between the resonant chambers there is an opening for electrical coupling.

[0014] Preferably the opening is a slot proximal to the caps allowing capacitive coupling between the chambers.

[0015] Preferably one of the two resonators comprises arm which is at least substantially aligned with a corresponding arm of the other of the two resonators.

[0016] Preferably, the cap of at least one of the two resonators is rotatable around the longitudinal axis of its respective resonator post in order to tune the electrical coupling.

[0017] Preferably the filter further comprises at least one further resonator, for example two further resonators.

[0018] Preferably the resonators take a configuration, which may be considered a folded configuration, in which the further two resonators have respective resonant chambers interconnected by an opening and each resonant chamber of the additional two resonators is connected to a respective one of the first two resonant chambers by a respective opening, the openings being apertures for inductive coupling.

[0019] Preferably the resonators include resonator posts carrying caps; and the caps of the resonators separated by the slot are rotated to be at least substantially aligned and the caps of the resonators separated by apertures are rotated to be misaligned. Preferably the caps are cross-shaped caps, and the caps of the resonators separated by apertures are positioned so that the resonators have respective arms at least substantially 45 degrees or 90 degrees out of alignment. Preferably the apertures in the walls between resonant chambers are at least substantially the height of the walls between resonant chambers.

[0020] Another example of the present invention relates to a method of radio frequency filtering comprising passing a signal for filtering through two resonators, each resonator comprising a resonant chamber, each resonant chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which
the resonant chamber houses a resonator post which is grounded on the first wall so as to extend into the chamber;
the resonator post has a cap at its end that is away from the first wall;
the cap comprising at least one arm extending in a direction transverse to the longitudinal axis of the resonator post; and in which in the wall between resonant chambers there is an opening for electrical coupling.

Brief Description of the Drawings

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

Figure 1 (PRIOR ART) is a diagram illustrating a known cavity resonator including a cap in the form of a circular disc to provide capacitive loading at the top of the resonator post: (a) is a cross sectional view from top, (b) is a diagrammatic three dimensional illustration of the cavity resonator, and (c) shows the electric filed magnitude for the cap which is a circular disc (PRIOR ART).
Figure 2 is a diagram illustrating according a cavity resonator to a first embodiment of the invention including a cap in the form of a cross to provide capacitive loading at the top of the resonator post: (a) is a cross sectional view from top, (b) is a diagrammatic three dimensional illustration of this cavity resonator, and (c) shows the electric filed magnitude for the cap which is in the form of a cross,
Figure 3 is a diagrammatic cross sectional view illustrating the layout and associated dimensions of the cavity resonator shown in Figure 2,
Figure 4 is a diagram showing a front view of a wall with slot suitable for use between two coupled cavity resonators in a filter,
Figure 5 is a diagrammatic cross section view of a filter according to a second embodiment made up of two cavity resonators basically as shown in Figure 2 but with a slot in the separating wall between them as shown in Figure 4,
Figure 6 is a graph of coupling coefficient against slot length (the slot width being 28.4 mm) for an arrangement as shown in Figure 5 having specific dimensions,
Figure 7 is graphs of coupling coefficient against slot width (the slot length being 18mm and 20 mm respectively) for an arrangement as shown in Figure 5 having specific dimensions,
Figure 8 is a diagrammatic cross sectional view of a filter according to a third embodiment made up of four cavity resonators having resonator posts having cross-shaped caps and with large apertures between cavities except between two of the cavities where instead there is a separating wall with a slot as shown in Figure 4,
Figure 9 (ALTERNATIVE PROPOSAL) is a diagrammatic cross sectional view of a filter made up of four cavity resonators including resonator posts having circular caps and having large apertures between cavities except between two of the cavities where instead there is a separating wall with a slot (Figure 9 (Alternative Proposal) provided for comparison with Figure 8),
Figure 10 shows a graph of S-parameters response of an example filter as shown in Figures 8 having specific dimensions including a slot length of 15mm (the corresponding graph for a corresponding example filter as shown in Figure 9 (ALTERNATIVE PROPOSAL) is also shown for comparison),
Figure 11 shows a graph of S-parameters response of another example filter as shown in Figures 8 but having a slot length of 20mm instead (the S-parameters response for the 15mm slot length shown in Figure 10 is also shown using a dashed line in Figure 11 for comparison),
Figure 12 is a diagrammatic cross sectional view of a filter including two cavity resonators separated by the wall

with the slot and where the cross caps are misaligned by a few degrees specifically one is axially rotated by X degrees and the other is axially rotated by X degrees in the opposite direction so that the arms of the caps are 2X degrees out of alignment (from the arms of the crosses being aligned),

Figure 13 is graphs of coupling coefficient as a function of axial rotation angle X, for example filters as shown in Figure 12, one where the slot is 15mm length and the other where the slot is 18mm length,

Figure 14 is a diagrammatic cross sectional view of a filter including two cavity resonators separated by an aperture and where the cross caps are each 45 degrees out of alignment (from the arms of the crosses being aligned),

Figure 15 is a front view of the aperture shown in Figure 14, and

Figure 16 is graphs of coupling coefficient as a function of axial rotation angle for two example filters as shown in Figures 14 and 15, one with a screw length of 20mm and the other with a screw leригth of 24 mm,

Figure 17 is a perspective view of another resonator post with cap according to a fourth embodiment of the present invention, and

Figure 18 is a side view of the resonator post with cap shown in Figure 17.

[0022] It should be noted that Figures 2 and 3 may be considered schematic (not to scale) even though they indicate some distances.

Detailed Description

[0023] When considering known coaxial cavity filters (also known as Comb-line filters), the inventors realised that they did not appear to address how to maintain Quality factor in high power applications and avoid having a large number of precisely-manufactured filter component parts.

[0024] The inventors realised that a known cavity resonator, as shown in Figure 1 PRIOR ART, included a resonator post having a cylindrical cap. Figure 1 (PRIOR ART) is a diagram illustrating the known cavity resonator including the cap in the form of a circular disc. This provide capacitive loading at the top of the resonator post. Figure 1 is in three parts (a) is a cross sectional view from top, (b) is a diagrammatic three dimensional illustration of the cavity resonator, and (c) shows the electric filed magnitude for the cap which is a circular disc (PRIOR ART).

[0025] The inventors found a useful alternative.

[0026] The inventors realised that the resonator post with circular cap may be usefully replaced by a cap having one or more arms extending out in a direction transverse to the longitudinal axis of the resonator post. The inventors realised that this would allow greater capacitive (also known as 'negative') coupling (as compared to using a circular disc cap with the same fundamental operating resonant frequency). This is explained below.

Cavity Resonator Performance

[0027] As shown in Figure 2, a cavity resonator 10 is provided including a cap 12 in the form of a cross to provide capacitive loading at the top of the resonator post 14. The resonator post 14 with cap 12 is grounded on the bottom 16 of the cavity 18 having metallic walls 20 which constitute an enclosure 22. A tuning screw 15 is provided from the top which does not contact the cap 12 but is adjustable in length for frequency tuning. In Figure 2, (a) is a cross sectional view from top, (b) is a diagrammatic three dimensional illustration of this cavity resonator, and (c) shows the electric filed magnitude for the cap 12 which is in the form of a cross.

[0028] An example of the cavity resonator shown in Figure 2 was selected with dimensions listed in Table 1, some of which are indicated in Figure 3.

Table 1: Resonator dimensions, cross cap

Cavity (Width x Width x Length)	40mm x 40mm x 55mm (88 cm^3))
Post Diameter	11.2 mm
Post Length	46.8mm
Thickness of capacitive cross shaped cap	3mm
r1	2 mm
r2	1 mm
l1	31.2 mm
l2	9.2 mm

[0029] For comparison a known cavity resonator according to Figure 1 (PRIOR ART) was considered having dimensions as shown in Table 2:

Table2: Resonator dimensions, circular disc cap (PRIOR ART)

Resonator	**Circular Disc**
Cavity (Width x Width x Length)	40mm x40mm x55 mm (88 cm^3))
Post Diameter	11.2 mm
Post Length	46.8 mm
Thick of capacitive cap	3mm
Disc diameter	28.4 mm

[0030] Using the data shown in Tables 1 and 2, the performance (in terms of resonant frequency and Q factor) of both the example resonator with cross cap, and the resonator with circular disc cap (PRIOR ART), were evaluated (where gap size is the distance between the top of the cap and top wall of the enclosure) and the results are shown in Table 3:

Table 3: Performance of the resonators

Resonator Cap Shape	**Electrical Length (372.2 mm)**	**Gap Size/Cavity Length**	**Resonant frequency**	**Q-Factor (Al/Al)**	**Q/Vol (1/cm^3)**
Circular Disc (PRIOR ART)	~53 deg	5.2/55 (mm)	807.8 MHz	3288	37.36
Cross	~53 deg	5.2/55 (mm)	808.9 MHz	3280	37.27

[0031] The Q factor assumes that both the enclosure and resonator post are made of aluminium.

[0032] It will be seen from Table 3 that compared to the prior art resonator having a circular disc cap, the cavity resonator 10 with cross cap 12 has a slightly lower unloaded Quality factor due to what can be considered as a relative redistribution of capacitance, from between the open end of the resonator post 14 and the top lid (not shown in Figure 2) towards between the open end of the resonator post 14 and side walls 20. To quantify this, it will be seen from Table 3, that, in this example, the cavity resonator 10 with cross cap 12 has a Q factor reduced by 0.24% and a Q per unit volume that is only slightly reduced.

Further comparisons

[0033] Further comparisons were made between further cavity resonators similar to that shown in Figure 2 having cross caps and corresponding cavity resonators similar to that shown in Figure 1 having circular disc caps. Dimensions are as provided in Tables 1 and 2 except where indicated otherwise in Table 4, and the performance results are shown for ease of comparison in Table 4.

Table 4: Performance of a number of proposed resonators

Resonator	**Electrical Length (372.2 mm)**	**Gap Size/Cavity Length**	**Resonant frequency**	**Q-Factor (Al/Al)**	**Q/Vol (1/cm^3)**
806 MHz - Band 20 DL					
Circular Disc	~53 deg	5.2/55 (mm)	807.8 MHz	3288	37.36
Cross	~53 deg	5.2/55 (mm)	808.9 MHz	3280 (0.24%)	37.27
707.5 MHz-Band 12 UL					
Circular Disc	~46.7 deg	5.2/55 (mm)	709.5 MHz	3056	34.73
Cross	~46.7 deg	5.2/55 (mm)	708.4 MHz	3043 (0.43%)	34.58

(continued)

707.5 MHz-Band 12 UL					
Circular Disc	~44.2 deg	5.2/52 (mm)	708.7 MHz	3003	36.09
Cross	~44.2 deg	5.2/52 (mm)	709.9 MHz	3000 (0.01%)	36.06
Circular Disc	~41.6 deg	2.2/49 (mm)	709.6 MHz	3011	38.41
Cross	~41.6 deg	3.4/49 (mm)	709.9 MHz	2980 (1.03%)	38.01

[0034] Table 4 shows performance of a number of the proposed cavity resonators (having various electrical lengths and miniaturization factors) compared with the cavity resonators of known type having circular disc caps and the same respective electrical length. Gap size refers to the distance of the cap to the top lid of the resonator. A tuning screw (4mm diameter, 2mm long, made of aluminium) was present except in the last case (electrical length ~41.6 deg).

Filter having two cavity resonators

[0035] Using the same dimensions as shown in Table 1, a filter was then evaluated consisting of two cavity resonators basically as shown in Figures 2 and 3 but with a slot in the single separating wall between them as shown in Figure 4. This filter 11 is shown in Figure 5.

[0036] As shown in Figure 5, each of the cavity resonators 10' includes full walls 20' on three sides and a single separating wall 21 as shown in Figure 4.

[0037] As shown in Figure 4, the separating wall 21 includes a slot 23 in its upper portion 25. The slot is rectangular having a specified width and length.

[0038] In a first set of examples of this filter, the separating wall thickness was taken to be 1 mm, slot width 28.4 mm and resonator dimensions as listed in Table 1 above. In these examples, the slot length varied between 8 and 22 mm. In each case, the magnitude of the coupling coefficient (actually being capacitive hence negative) was determined and results are shown graphically in Figure 6. Figure 6 shows a smooth variation in the capacitive (i.e. negative) coupling as a function of slot length.

[0039] In a second set of examples of this filter shown in Figure 5, other dimensions are kept the same except the slot length is selected as 18 mm or 20 mm and in each case the slot width varies in a range between 18 and 28 mm. In each case, the magnitude of the coupling coefficient (actually being capacitive hence negative) was determined and results are shown graphically in Figure 7.

[0040] Figure 7 shows a smooth variation in the negative coupling as a function of slot width, and indicates the maximum magnitude of the coupling possible for this filter and slot configuration.

Alternative Proposal Filter with two cavity resonators - For Comparison

[0041] For purposes of comparison with the performance data shown in Figure 6 and 7, it was considered useful to consider the performance of an alternative proposal filter (not shown) consisting of two known cavity resonators having circular disc caps having a separating wall with a slot as shown in Figure 4. The dimensions of each resonator were as listed in Table 2.

[0042] This comparative filter having circular disc caps was found to have a maximum magnitude of capacitive coupling of 3.4×10^{-03} as compared to 7.1×10^{-03} for the corresponding filter shown in Figure 5. In other words the corresponding filter shown in Figure 5 had an approximately 108% higher maximum magnitude of capacitive coupling. It follows that the performance of the filter shown in Figure 5 having the cross shaped caps is substantially better for the same inter-resonator distance and slot width (which is 1 mm).

[0043] For the filter with circular disc caps to achieve the same magnitude of capacitive coupling as achieved using cross-shaped resonator caps, the circular disc caps would need to be 4 mm in diameter with a 6.8 mm long aluminium probe (not shown) being deployed. A probe is a metal rod extending into the slot from above in order to tune or enhance the capacitive coupling.

Filter having four cavity resonators

[0044] As shown in Figure 8, a further filter 11' consists of four cavity resonators 26 having resonator posts 14' having cross-shaped caps 12' and with large apertures 28 between cavities 18' except between two of the cavities 30,32 where instead there is a separating wall 21' with a slot 23' (as previously shown in Figure 4).

[0045] In other words this filter 11' can be considered as a four resonator post filter, i.e. four pole filter, with resonator posts 14' having cross -shaped caps 12' , the cavity resonators 26 being disposed in a "folded" layout that employs negative cross-coupling (without a capacitive probe) between two of the cavities 30, 32.

[0046] The coupling paths are as shown in Figure 8, namely three apertures 28 with probes 29 which provide inductive coupling, and one slot 23' (without a probe) which provides capacitive coupling. As seen in Figure 8, the resonator posts are configured such that two of the resonators posts have arms 34 pointing to the slot 23' (for capacitive coupling) and two have arms 33 nearest apertures 28 that are at 45 degrees to the respective aperture (for inductive coupling).

[0047] Dimensions are as indicated in Table 1. Furthermore, the dimensions of the slot 23' are slot width 20mm, slot length 15mm, slot thickness 1mm. All four resonator posts with caps are identical in size.

[0048] The full height apertures 28 between cavity 1 and cavity 2, and between cavity 3 and cavity 4, have a width of 31mm. The full height aperture 28 between cavity 2 and cavity 3 has a width of 25.7mm.

[0049] For the sake of completeness, we would add that the cavity corners are rounded to a radius of 3mm, and the profile of the cross-shaped cap takes a curve of radius r1 of 2mm in passing from one arm to an adjacent arm and the arms have rounded end corners of radious r2= 1mm. All four resonator posts with caps are identical in shape and side.

[0050] The three apertures 28 are each as shown in Figure 15. As shown in Figure 15, each aperture 28 is full height and has a respective probe 29 extending into the aperture from above.

[0051] It was realised that the way to control or increase the magnitude of the negative (i.e. capacitive) coupling is to bring the two resonator posts with caps into closer proximity to each other, or to adapt the cap by appropriate selection of l_1 and l_2 arm dimensions so as to provide increased negative coupling. It should be noted that in the first approach, it is only the position of the resonator post with cap that is changed not the resonator post with cap itself. In the first approach, the positions can be accurately set using a robot in manufacture.

Alternative Proposal Filter for comparison having four cavity resonators

[0052] For comparison, an Alternative Proposal filter was considered which was similar to the one shown in Figure 8 except in two respects. Firstly, the caps are circular discs rather than being cross-shaped. Secondly a capacitive probe 31 is included.

[0053] This comparative filter is shown in Figure 9.

[0054] Figure 9 (ALTERNATIVE PROPOSAL) is a diagrammatic cross sectional view of this filter which is made up of four cavity resonators 26' having resonator posts 14" having circular caps having large apertures between cavities except between two of the cavities where instead there is a separating wall with a slot 23" (slot width 20mm, slot length 15mm).

[0055] The capacitive probe 31 is a metallic cylindrical rod (4mm diameter, 6 mm long) which lies in the centre of the slot 23" such that the longitudinal axis of the probe is perpendicular to the plane in which the slot lies.The probe 31 is supported in the slot and separated from the enclosure which is metal by a dielectric spacer (not shown). The slot width is 20mm and the slot height is 15mm. As regards other dimensions, each cavity has a width of 40mm, length of 40mm and height of 55 mm. Each resonator post 14" has a diameter of 11.2 mm. The resonator post lengths are as follows: 46.9 mm in cavity 1 and cavity 4 as shown in Figure 9, 46.3 mm in cavity 2 and cavity 3 as shown in Figure 9. Each capacitive cap is a circular disc having a diameter of 28.4mm and a thickness of 3mm. The full height apertures between cavity 1 and cavity 2, and between cavity 3 and cavity 4, each have a width of 29.9mm. The full height aperture between cavity 2 and cavity 3 has a width of 25.3mm. The tuning screws at the apertures between cavities each have a diameter of 4mm and a length of 20mm. For the sake of completeness, we would add that the cavity corners are rounded to a radius of 3mm.

Comparison of the filters having four cavity resonators

[0056] Figure 10 shows a graph of S-parameters response of an example filter as shown in Figures 8 having specific dimensions including a slot length of 15mm. The corresponding graph for a corresponding example filter shown in Figure 9 (ALTERNATIVE PROPOSAL) is also shown for comparison. It will be seen that the use of the cross-shaped caps provides greater capacitive coupling for the same fundamental operating resonant frequency so eliminates the need for a capacitive probe. Also it will be seen that the two types of couplings (one being between cross caps and having no probe, the other being between circular caps and having a probe) provide broadly similar performance characteristics.

[0057] Figure 11 shows a graph of S-parameters response of another example filter as shown in Figures 8 but having a slot length of 20mm instead so as to increase negative coupling (the S-parameters response for the 15mm slot length shown in Figure 10 is also shown using a dashed line in Figure 11 for comparison). This increase in slot length results in the transmission zeros being closer to the passband.

[0058] More generally this Figure 11 can be considered to show how a performance characteristic of the coupling mechanism varies the magnitude of negative coupling is increased.

Tolerance to resonator post rotation (e.g. rotational misalignment)

[0059] It was thought useful to evaluate the extent to which coupling varied as a function of degrees of axial rotation of the resonator posts having cross-shaped caps. Accordingly the situations shown in Figure 12 and Figure 14 were as considered.

[0060] Taking Figure 12 first, Figure 12 is a diagrammatic cross sectional view of a filter including two cavity resonators separated by the wall with the slot and where the cross caps are misaligned by a few degrees specifically one is axially rotated by X degrees and the other is axially rotated by X degrees in the opposite direction so that the arms of the caps are 2X degrees out of alignment (from the arms of the crosses being aligned). As seen in Figure 12, viewed from above, one resonator post 14" is rotated anticlockwise and the other resonator post 14"' is rotated clockwise. The arms may be out of alignment in practice by accident or intentionally.

[0061] Some dimensions are as follows. Each cavity is 40mm in width and 40 in length and has a height of 55.4 mm. The slot has a width of 20mm and a height of 15mm. The full height apertures 28" are 31.4mm wide into which protrudes a tuning screws of 4mm diameter and 20mm length. The cross shaped caps 12" have arms 33' of span (/1 as shown in Figure 3) of 32.9 mm and width (12 in Figure 3) of 9.2 mm. Walls between cavities are 4mm thick.

[0062] Some results are shown in Figure 13.

[0063] Figure 13 shows graphs of magnitude of (capacitive/negative) coupling coefficient as a function of axial rotation angle X in degrees, for example filters as shown in Figure 12, one where the slot is 15mm length and the other where the slot is 18mm length. These results show a low sensitivity of coupling performance (capacitive coupling) to small rotational misalignments. In other words, capacitive coupling is relatively stable for small rotations of the resonator posts, that are typically a consequence of assembly-level inaccuracies in the alignment of the resonators.

[0064] In filters, post-fabrication tuning is commonly required to tune the resonant frequency as well as the electrical couplings. Looking at Figures 12 and 13, it can be seen that although the capacitive coupling demonstrates low sensitivity for a few degrees of misalignment, there is a small variation on capacitive coupling as the rotation angle increases. This is useful in allowing post-fabrication fine-tuning of the capacitive coupling by angular rotation by a few degrees of the resonator post with cap.

[0065] Post-fabrication tuning may involve, for example, removing the lid of the enclosure to reveal the resonator posts with caps, turning a resonator post with cap manually through an angle, such as a small angle of a few degrees for fine-tuning, then reapplying the lid.

[0066] We now turn to Figure 14.

[0067] To consider mainline (inductive) couplings using the apertures, the situation shown in Figure 14 was considered. Figure 15 is a front view of the aperture shown in Figure 14. In this example, the aperture 28', which is of full height has an aperture width of 26.1 mm and includes a probe 29'.

[0068] As mentioned previously, the probe 29' is a metallic cylindrical rod which extends into the aperture from above. The probe 29' is separated from the enclosure which is metal by a dielectric spacer (not shown).

[0069] Figure 14 is a diagrammatic cross sectional view of a filter including two cavity resonators separated by an aperture and where the cross caps are each roughly 45 degrees out of alignment (from the arms of the crosses being aligned). Specifically one is axially rotated by to lie at 45+X degrees and the other is axially rotated to lie by 45+X degrees in the opposite direction so that the arms of the caps are 90+2X degrees out of alignment (from the arms of the crosses being aligned).

[0070] Some dimensions are as indicated in Table 1 except the height of the cavity is 55.4mm (rather than 55mm). Each cavity is 40mm in width and 40mm in length and has a height of 55.4 mm. The full-height aperture 28' between the two resonator posts with caps is 26.1mm wide. The other two 28"' full height apertures are 31.4mm wide.

[0071] Into each aperture protrudes a tuning screw of 4mm diameter and 24mm length. The cross shaped caps have arms of span (/1 as shown in Figure 3) of 31.2 mm and width (12 in Figure 3) of 9.2 mm. Walls between cavities are 4mm thick.

[0072] The results of capacitive coupling against rotation angle X are shown in Figure 16. Figure 16 shows graphs of coupling coefficient as a function of axial rotation angle for two example filters as shown in Figures 14 and 15, one with a probe length of 20mm and the other with a probe length of 24 mm.

[0073] From Figure 16, it can be seen that in this example small variations in the angle X due to mechanical tolerances or assembly level inaccuracies in the alignment of the resonators correspond to small levels of changes in the that positive (inductive) coupling. Looking at Figures 14 to 16, it is seen that (as in the previously described case for capacitive coupling) the inductive coupling has low sensitivity to a few degrees of misalignment, but nevertheless there is a small variation in inductive coupling as the rotation angle increases. This can be useful as it allows fine-tuning, post-fabrication, of the inductive coupling between the two resonators. This tuning may be used in combination with the tuning screw 29', or in a similar embodiment (not shown) without the presense of that tuning screw.

[0074] The examples above described with reference to Figures 2,3,5, and 8 have resonator posts with caps that have four arms so can be considered cross-shaped. However, examples are possible having one, two, three or more than four arms. For example, an example is shown in Figures 17 and 18 of a resonator post 144 with a cap 112 having a single arm 133. Figure 17 is a perspective view and Figure 18 is a side view of that resonator post and cap.

[0075] For example, a cap with three arms may be in the form of a triangle where an arm can be, for example, a segment of a triangle including an apex.

[0076] In some other examples, a lobe of an ellipsoid-shaped cap constitutes an arm.

[0077] In various example emboiments, arms can lie in a plane perpendicular to the longitudinal axis of the post or lie at some other angle from the perpendicular. For example the arms could be bent up, for example by say 30 degrees.

[0078] In the specific examples described with reference to Figures 2, 3, 5, 8 etc, the cap is produced by being machined, but in other embodiments it is produced by any of die-casting, laser cutting or some other known manufacturing process. The resonator post and cap may be manufactured separately then mechanically and electrically connected, or manufactured as a single piece.

[0079] The present invention may be embodied in other specific forms without departing from its essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

[0080] A person skilled in the art would readily recognize that steps of various above-described methods can be performed by programmed computers. Some embodiments relate to program storage devices, e.g., digital data storage media, which are machine or computer readable and encode machine-executable or computer-executable programs of instructions, wherein said instructions perform some or all of the steps of said above-described methods. The program storage devices may be, e.g., digital memories, magnetic storage media such as a magnetic disks and magnetic tapes, hard drives, or optically readable digital data storage media. Some embodiments involve computers programmed to perform said steps of the above-described methods.

Claims

1. A resonator comprising a resonant chamber, the resonant chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which
   the resonant chamber houses a resonator post which is grounded on the first wall so as to extend into the chamber;
   the resonator post having a cap at the end of the resonator post that is away from the first wall,
   the cap comprising at least one arm extending in a direction transverse to the longitudinal axis of the resonator post.

2. A resonator according to claim 1, in which the cap comprises four arms so as to take a cross-shape.

3. A resonator according to claim 1, in which the cap comprises one, two or three arms.

4. A resonator according to claim 1, in which the cap comprises more than four arms.

5. A radio frequency filter comprising two resonators according to any preceding claim in which in the wall between the resonant chambers there is a opening for electrical coupling.

6. A filter according to claim 5, in which the opening is a slot proximal to the caps allowing capacitive electrical coupling between the chambers.

7. A filter according to claim 5 or claim 6, in which one of the two resonators comprises an arm which is at least substantially aligned with a corresponding arm of the other of the two resonators.

8. A filter according to any of claims 5 to 7, in which the cap of at least one of the two resonators is rotatable around the longitudinal axis of its respective resonator post in order to tune the electrical coupling.

9. A filter according to any of claims 5 to 8, further comprising at least one further resonator according to any of claims 1 to 4.

10. A filter according to any of claims 5 to 8, further comprising two further resonators each according to any of claims 1 to 4.

11. A filter according to claim 10, in which the resonators take a configuration in which the two further resonators have respective resonant chambers interconnected by an opening and each resonant chamber of the further two resonators is connected to a respective one of the first two resonant chambers by a respective opening, the openings being apertures for inductive electrical coupling.

12. A filter according to claim 11, in which the resonators each include resonator posts carrying caps, and the caps of the resonators separated by the slot are rotated to be at least substantially aligned and the caps of the resonators separated by apertures are rotated to be not aligned.

13. A filter according to claim 12, in which the caps are cross-shaped caps, and the caps of the resonators separated by apertures are positioned so that the resonators have respective arms at least substantially 45 degrees or 90 degrees out of alignment.

14. A filter according to any of claims 11 to 13, in which the apertures in the walls between resonant chambers are at least substantially the height of the walls between resonant chambers.

15. A method of radio frequency filtering comprising passing a signal for filtering through two resonators, each resonator comprising a resonant chamber, each resonant chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which
the resonant chamber houses a resonator post which is grounded on the first wall so as to extend into the chamber; the resonator post has a cap at its end that is away from the first wall; the cap having at least one arm extending in a direction transverse to the longitudinal axis of the resonator post; and
in which in the wall between resonant chambers there is an opening for electrical coupling.

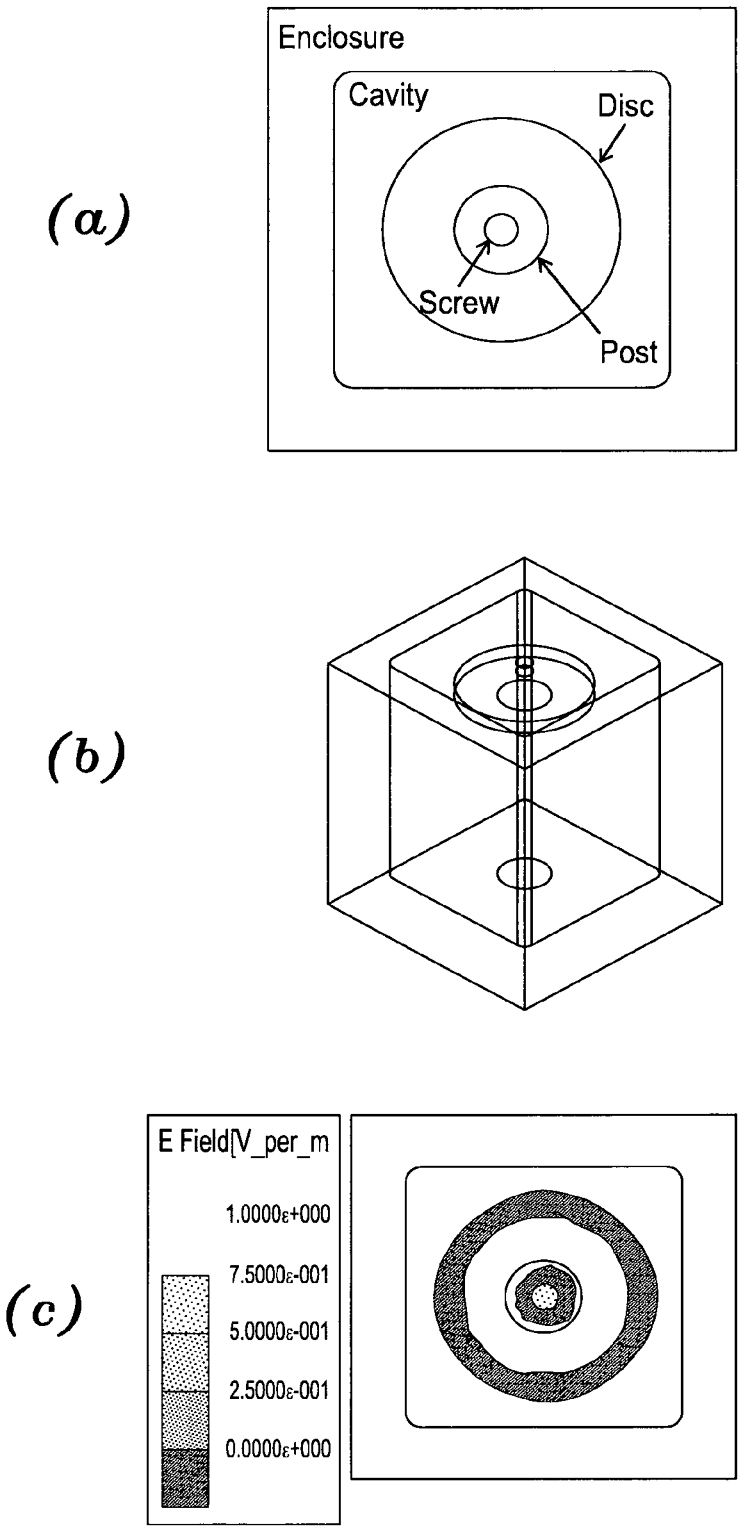

FIG. 1
PRIOR ART

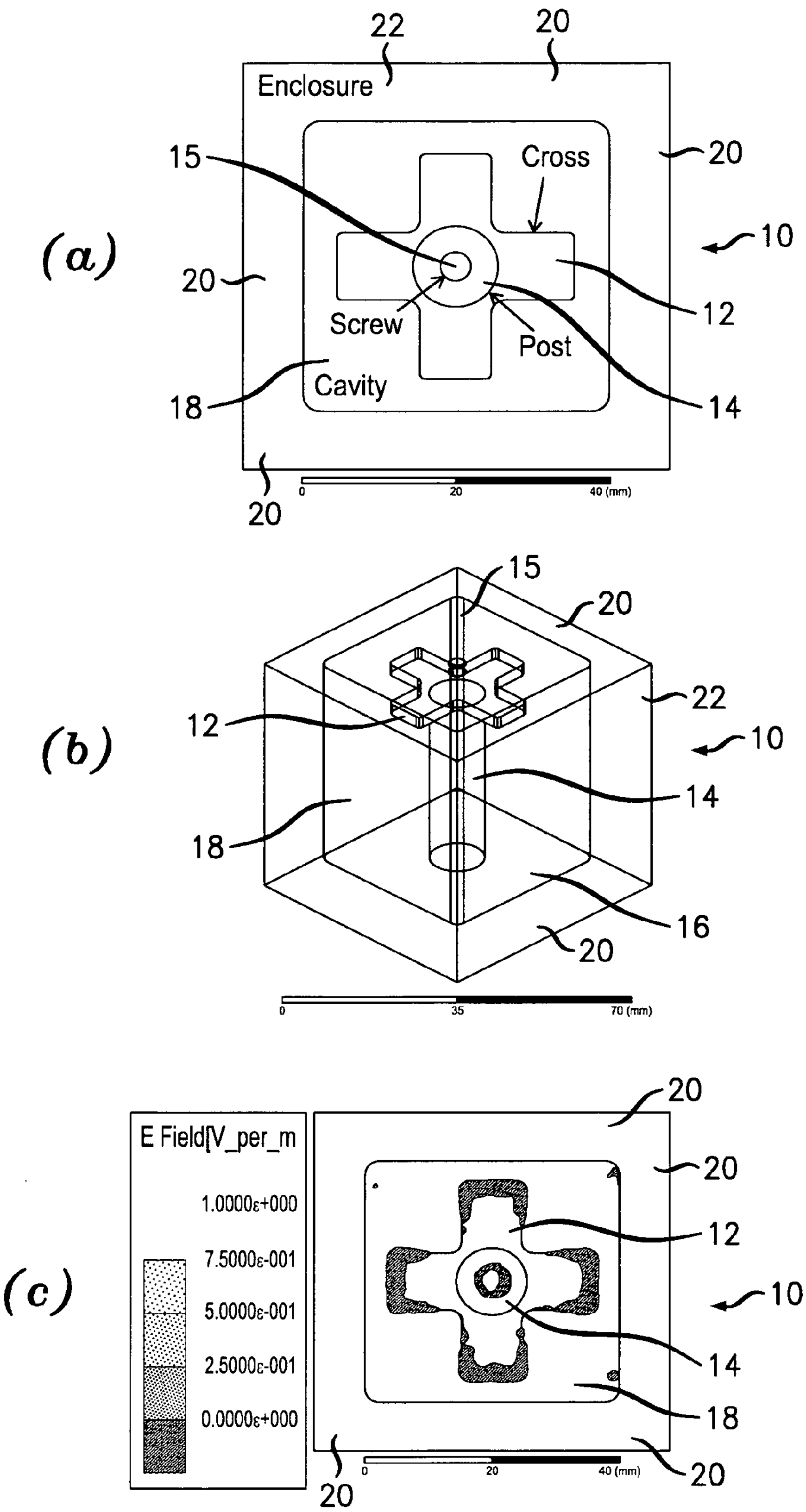
(a)
22
20
Enclosure
15
Cross
20
10
20
12
Screw
Post
18
Cavity
14
20
0
20
40 (mm)
(b)
15
20
22
12
10
14
18
16
20
0
35
70 (mm)
(c)
E Field[V_per_m
1.0000ε+000
7.5000ε-001
5.0000ε-001
2.5000ε-001
0.0000ε+000
20
20
12
10
14
18
20
20
0
20
40 (mm)

FIG. 2

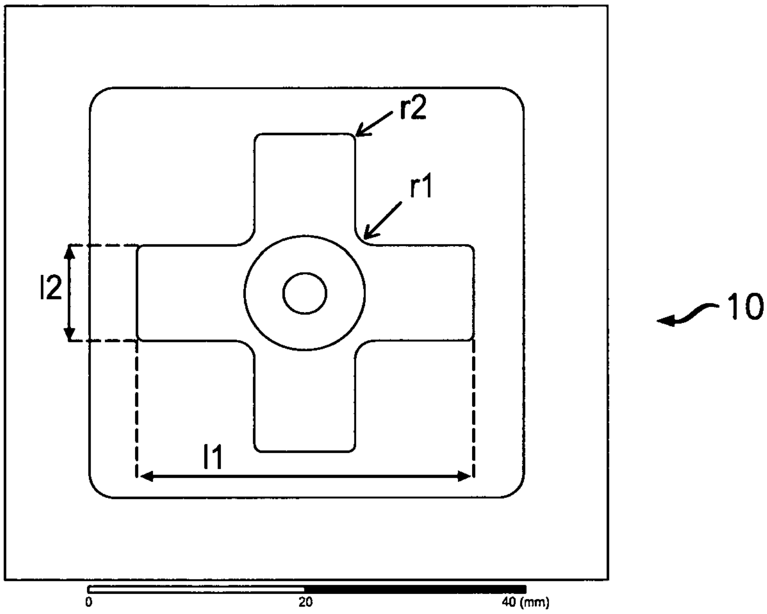
r2
r1
l2
10
l1
0
20
40 (mm)

FIG. 3

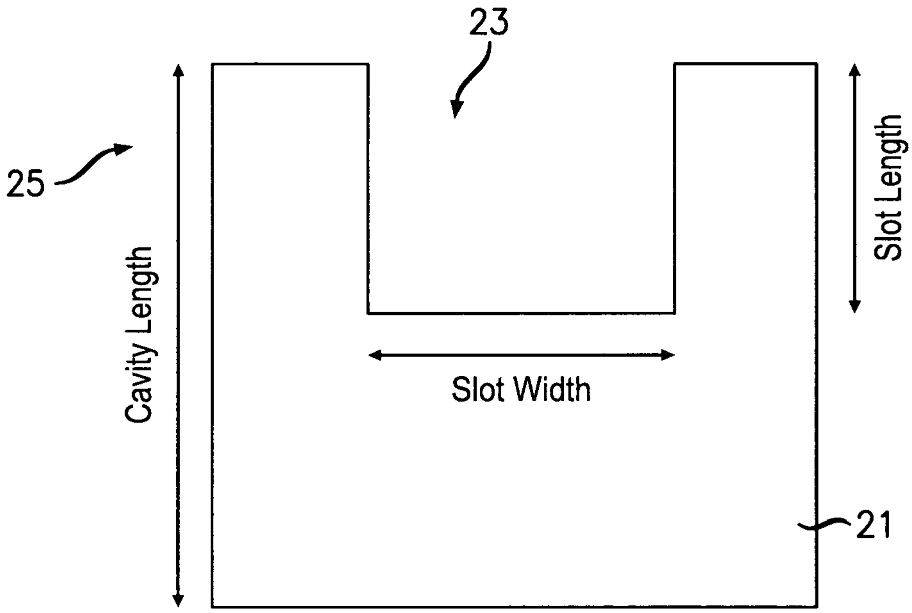
23
25
Cavity Length
Slot Length
Slot Width
21

FIG. 4

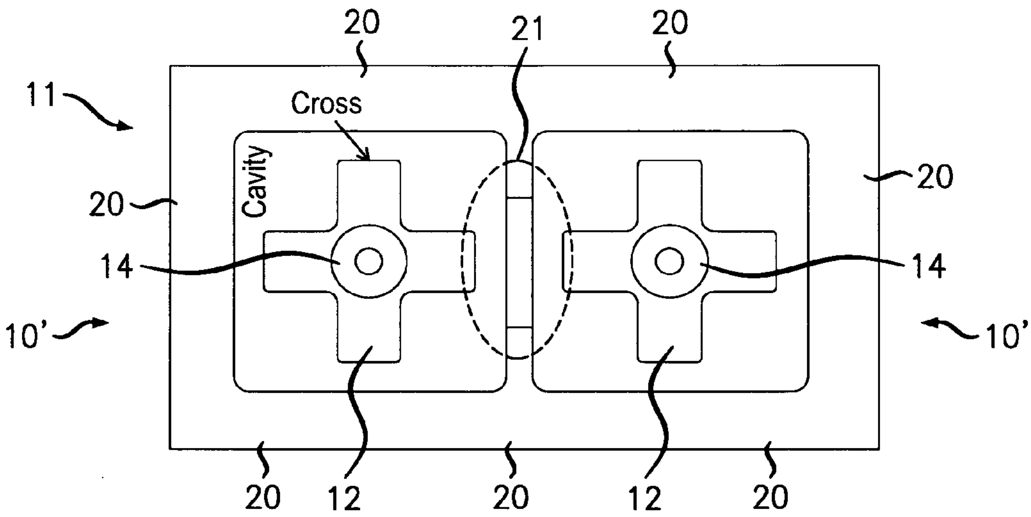

FIG. 5

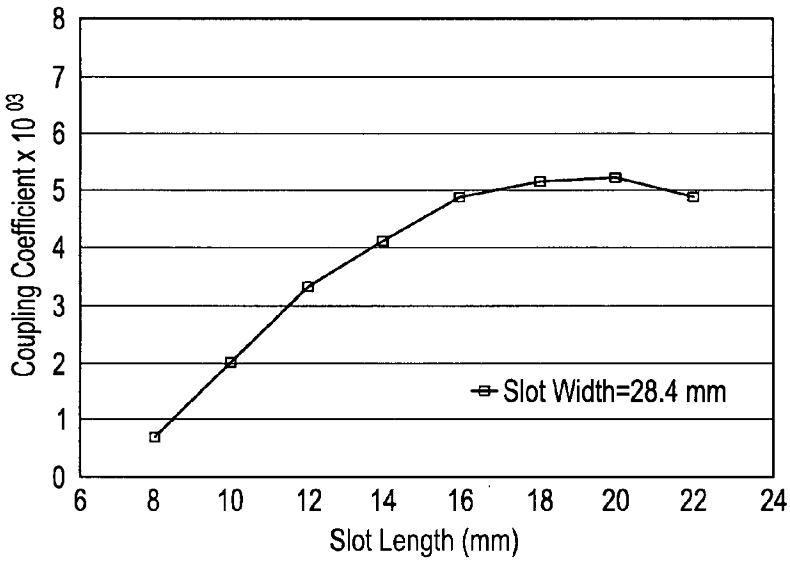

FIG. 6

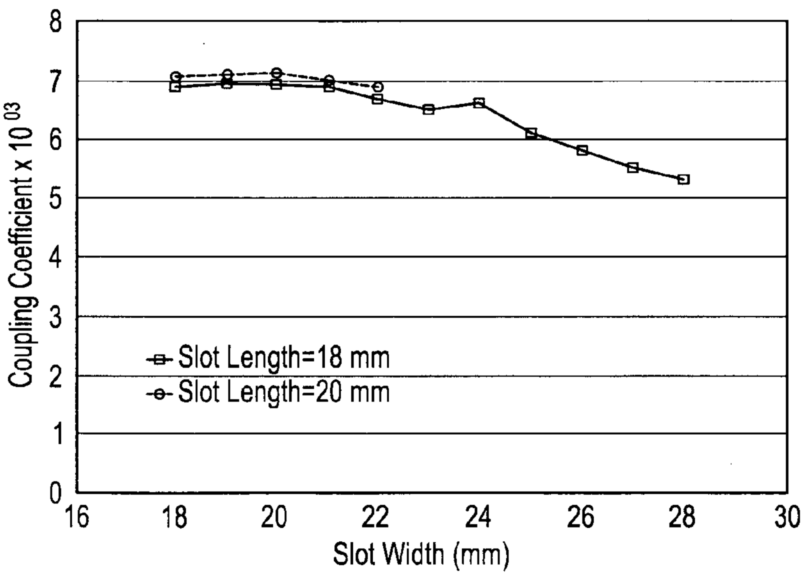

FIG. 7

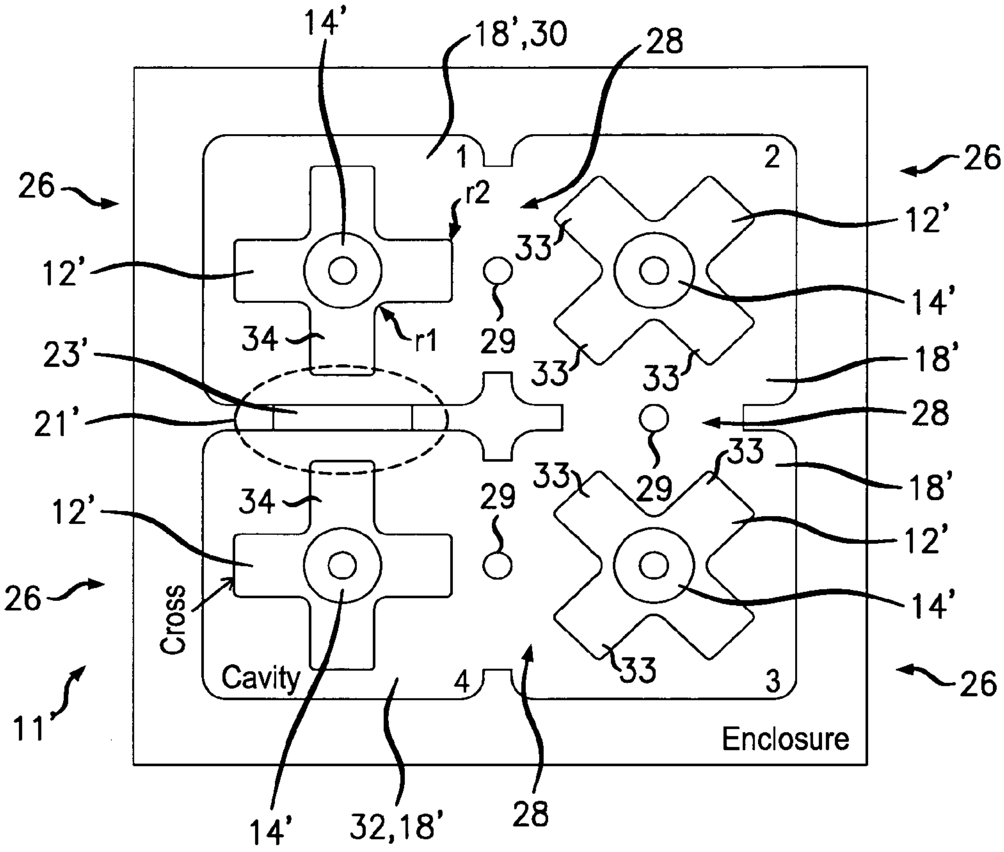

FIG. 8

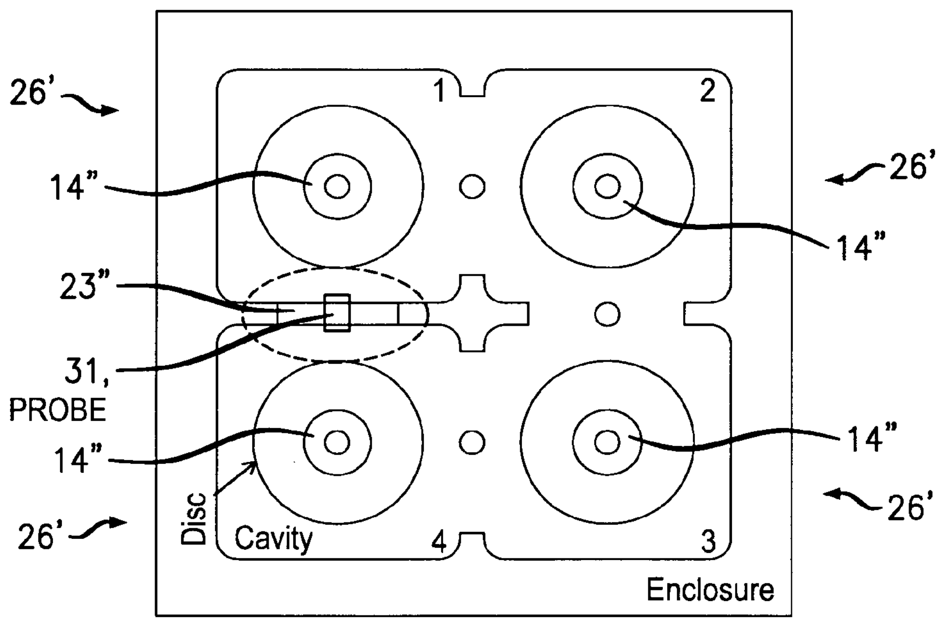

FIG. 9

ALTERNATIVE PROPOSAL FOR COMPARISON

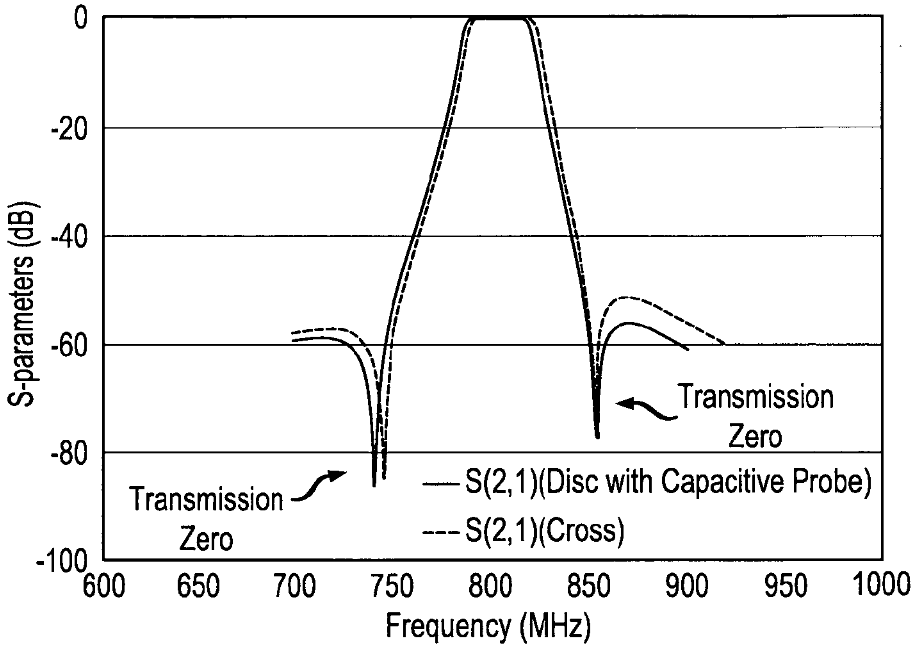

FIG. 10
COMPARISON

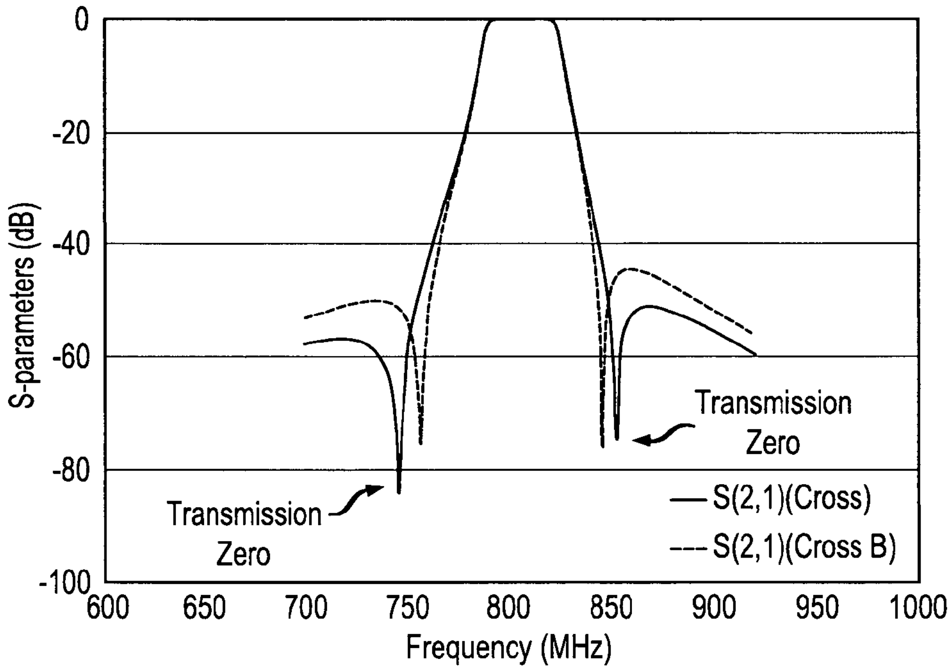

FIG. 11

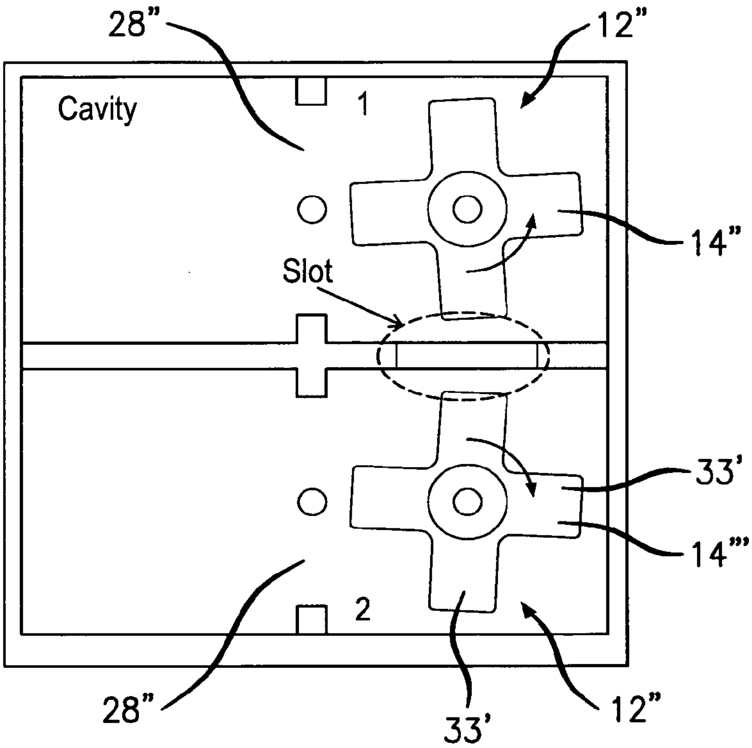
28"
12"
Cavity
1
14"
Slot
33'
14"'
2
28"
33'
12"

FIG. 12

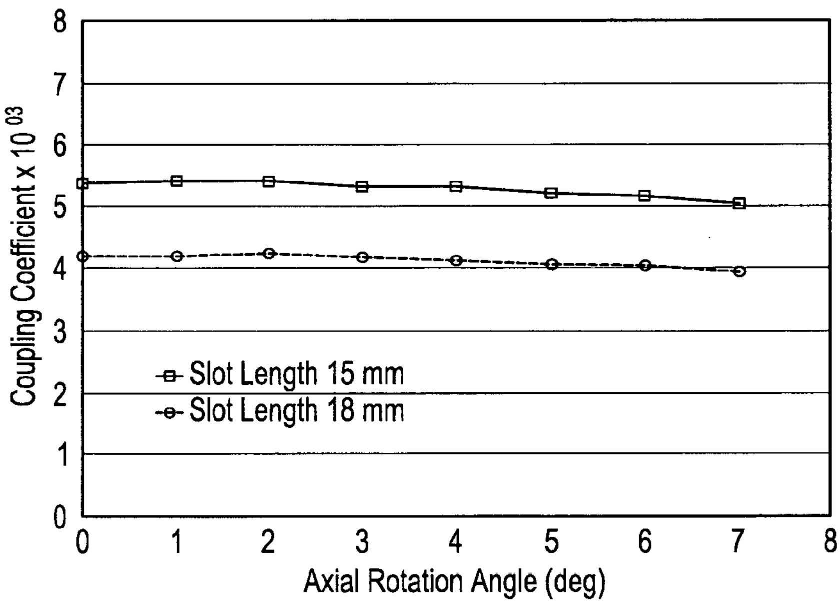
Coupling Coefficient x 10 03
Slot Length 15 mm
Slot Length 18 mm
Axial Rotation Angle (deg)
0
1
2
3
4
5
6
7
8

FIG. 13

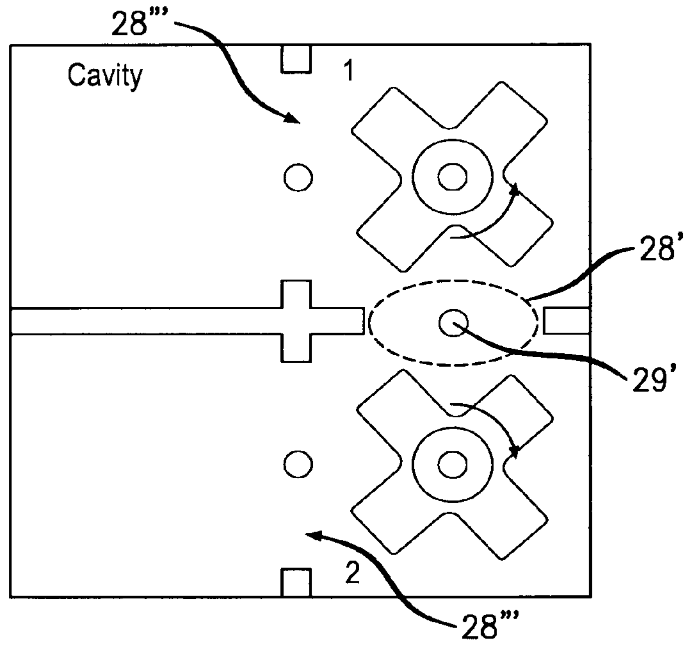

FIG. 14

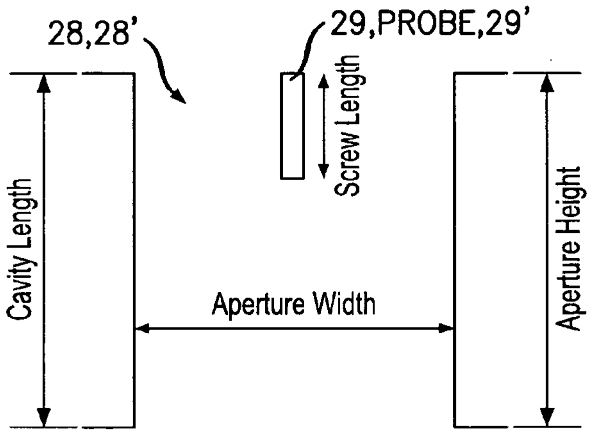

FIG. 15

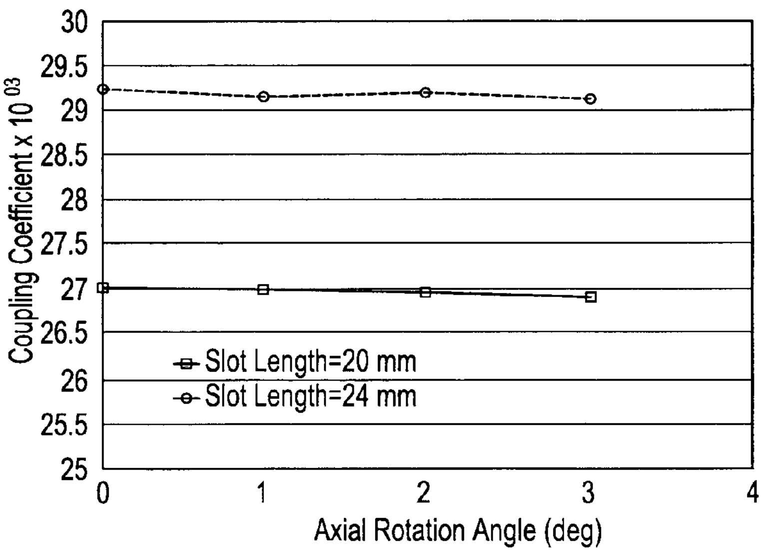

FIG. 16

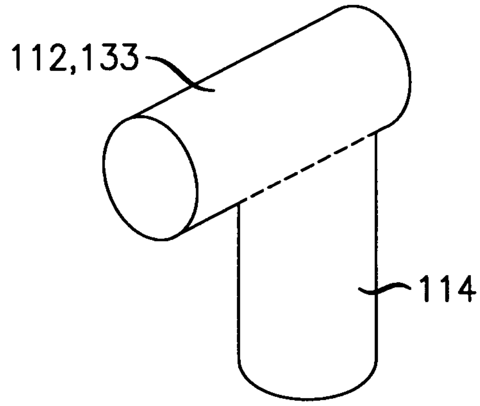

FIG. 17

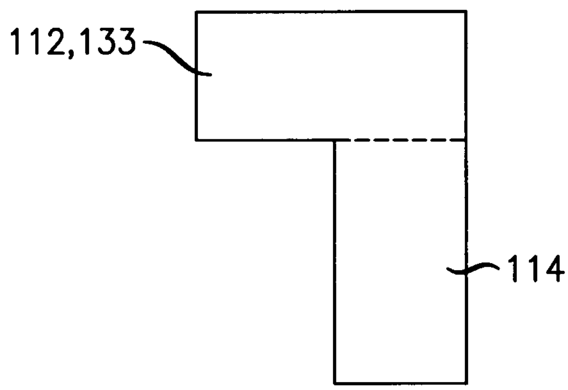

FIG. 18

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European Patent Office
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EUROPEAN SEARCH REPORT

Application Number
EP 14 29 0385

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 00/13256 A2 (ALLGON AB [SE]; RAETY TUOMO [FI]; KANERVO ANTTI [FI]) 9 March 2000 (2000-03-09) * figures 2,4-6 * * page 9, line 9 - page 10, line 30 * * page 11, line 17 - page 14, line 5 * -----	1-10,15	INV. H01P1/205 H01P7/04
X	US 2008/157899 A1 (WEITZENBERGER WILHELM [DE]) 3 July 2008 (2008-07-03) * figures 2,3 * * paragraph [0033] - paragraph [0035] * * paragraph [0040] - paragraph [0043] * -----	1,3, 5-11,14, 15	
X	WO 99/30383 A2 (LK PRODUCTS OY [FI]; VISTBACKA TAPANI [FI]; NIIRANEN ERKKI [FI]; ALA K) 17 June 1999 (1999-06-17) * figures 2,3 * * page 6, line 6 - line 14 * * page 6, line 30 - page 9, line 10 * -----	1-7, 9-11,15	
			TECHNICAL FIELDS SEARCHED (IPC)
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A	US 2013/009728 A1 (PUOSKARI JUKKA [FI] ET AL) 10 January 2013 (2013-01-10) * figure 1 * -----	1-15	

1

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	25 June 2015	Niemeijer, Reint

CATEGORY OF CITED DOCUMENTS

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25-06-2015

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