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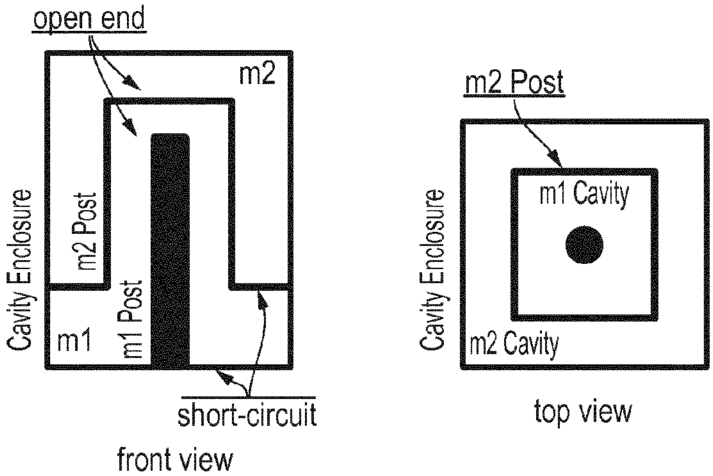

FIG. 2

(57) Abstract: Aspects and embodiments relate to a cavity resonator assembly and filters formed from such cavity resonator assemblies. One aspect provides a resonator assembly comprising: a first resonator cavity, a first resonant member, and a first signal feed; a second resonator cavity, a second resonant member, and a second signal feed. The first resonant member is located within the first resonator cavity, arranged to receive a signal from the first signal feed and configured to resonate within the first cavity at a first fundamental frequency. The second resonant member is located within the second resonator cavity, arranged to receive a signal from the second signal feed and configured to resonate within the second cavity at a second fundamental frequency. At least a portion of the second cavity is housed within the first resonant member, and the first resonator cavity surface from which the first resonant member extends is offset from a second resonator cavity surface from which the second resonant member extends. Aspects and embodiments may provide resonator assemblies which offer a reduction in size compared to a typical dual band resonant structure. That is to say, arrangements may be such that limited additional physical space is required for a dual resonant structure compared to a single resonant structure. Aspects and embodiments may provide for increased flexibility and scalability when building filters from resonant structures compared to conventional filtering solutions.

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A RESONATOR ASSEMBLY AND FILTER

FIELD OF THE INVENTION

The present invention relates to a cavity resonator assembly and filters formed from such cavity resonator assemblies.

BACKGROUND

Filters formed from coaxial cavity resonators are widely used in data transmission systems and, in particular, telecommunications systems. In particular, filters formed from cavity resonators are often used in base stations, radar systems, amplifier linearization systems, point-to-point radio and radio frequency (RF) signal cancellation systems.

Although filters tend to be chosen or designed depending on a particular application, there are often certain desirable characteristics common to all filter realisations. For example, the amount of insertion loss in the pass band of a filter ought to be as low as possible, whilst the attenuation in the stop band should be as high as possible. Furthermore, in some applications the frequency separation between the pass band and stop band (guard band) may need to be very small, which can require filters of high order to be deployed in order to achieve such a specific requirement. However, requirements for high order filters are typically followed by an increase in cost due to a greater number of components and an increase in the need for space which is often at a premium in telecommunications implementations such as those listed above.

One challenging task in filter design is that of reducing the size of the filters whilst retaining their operational characteristics, including electrical performance. It is desired to provide smaller filters which have performance characteristics that are comparable to much larger structures. With the arrival of small cells within telecommunication systems and the need to provide multiband solutions within a similar footprint to that of single band solutions, there is an increasing need to reduce the size of various telecommunication components including filters.

It is desired to provide a cavity assembly which can be used in a filter to address some of the issues currently being faced in filter design.

SUMMARY

Accordingly, a first aspect provides a resonator assembly comprising: a first resonator cavity, a first resonant member, and a first signal feed; a second resonator cavity, a second resonant member, and a second signal feed; the first resonant member being located within the first resonator cavity, arranged to receive a signal from the first signal feed and configured to resonate within the first cavity at a first fundamental frequency; the second resonant member being located within the second resonator cavity, arranged to receive a signal from the second signal feed and configured to resonate within the second cavity at a second fundamental frequency; wherein at least a portion of the second cavity is housed within the first resonant member, and wherein a first resonator cavity surface from which the first resonant member extends is offset from a second resonator cavity surface from which the second resonant member extends.

The first aspect recognises that in microwave filters and duplexers which use coaxial cavity technology, the basic building block is that of a coaxial resonator. The coaxial resonator can be thought of as a distributed transmission line with an element which has an associated physical length configured to provide a required electrical length to support a standing wave at a given frequency. That frequency becomes the frequency of operation for the resonator in a resulting filter. A conventional TEM combline/coaxial resonator assembly comprises: a metallic cavity enclosure, often having a circular or rectangular shaped cross-section. Located within that metallic cavity enclosure there is a resonant member. That resonant member typically takes the form of a cylindrical metallic post located at the centre of the circle or rectangle of the metallic cavity structure. The metallic post is typically grounded at one side and open-ended at the opposite side.

The first aspect recognises that it is possible to provide a resonant assembly which can allow for the provision of more than one cavity within a volume normally suited to a single cavity. The plurality of cavities may be configured such that the resonant assembly can support the same, or different, resonant frequency in each of the cavities. Such a resonant assembly may allow for creation of a coaxial cavity resonator operable to support two resonant modes. Such a resonant assembly may be deployed in compact dual mode filters. The first aspect recognises that it is possible to provide one resonant mode per pass band for emerging dual band wireless base station filter applications.

Arrangements in accordance with the first aspect may support two resonant modes within a reduced physical space, thereby allowing the resonator to be used to form compact dual mode filters. It will be appreciated that one possible use of the first aspect might be within dual band wireless base station filter applications. In such a scenario it is possible to construct a cavity assembly which is operable to provide resonant frequency bands which are in relatively close proximity, for example 1800/1900 MHz.

It has been recognised that it is possible to form a dual band filter within a space similar to that used for a single band. According to such an arrangement, each combline resonator may provide one resonant mode per pass band. Figure 1 illustrates schematically a physical configuration of a combline resonator which can be used to form a dual band filter within a space similar to that used for a single band. The structure shown schematically in Figure 1 comprises three metallic conductors. The metallic conductors comprise an inner metallic resonating element (in this case, an inner post); an intermediate conductor (in this case, an open cylinder of substantially square cross-section located around the inner post); and a cavity enclosure. The inner and intermediate conductors are short-circuited by the cavity enclosure at one of their ends and are open-ended at the other end. Their lengths are selected such that they are close to $\lambda/4$ for the desired resonant frequencies. The lengths of the inner post and intermediate conductor may be different in order to precisely control the resonant frequency of the two modes supported by the structures. The cross-section of such a resonator can be seen in Figure 1 and the structure illustrated operates to provide two asynchronous resonant modes which may be suited to realise compact microwave dual band filters. However, the first aspect recognises that an arrangement such as that shown in Figure 1 may lead to complex filter construction and that there may be problems with the operation of any filters formed from more than one such cavity.

The first aspect may provide a resonator assembly or resonant structure. That assembly or structure may comprise a first resonator cavity and a second resonator cavity. Each cavity may comprise a conductive metal enclosure or may comprise an enclosure including a metallic inner coating. That is to say it is the wall surfaces of a cavity which may be conductive. Each resonator cavity may contain therein a resonant member. That resonant member may take various forms and may, for example, comprise, for example, a post. That post may be substantially solid or may be hollow. The post may be of substantially regular cross-section along its length, or may, for example, comprise a head portion which has a greater cross-sectional area. Each resonator cavity may include a signal feed. That signal feed may comprise a conductive wire signal feed or an appropriate signal coupling which allows a signal to couple into the conductive cavity. The first resonant member maybe located within the first conductive resonator cavity, and may be arranged to receive a signal from a first signal feed and configured to resonate within the first cavity at a first fundamental frequency.

The second resonant member may be located within the second resonator cavity, arranged to receive a signal from a second signal feed and configured to resonate within the second cavity at a second fundamental frequency. At least a portion of said second cavity may be housed within the first resonant member. That is to say, the first resonant member may comprise a hollow member and the hollow inside of the first resonant member may form part of the second resonant cavity. The hollow inside of the first resonant member may form the majority of the second resonant cavity. The hollow inside of the first resonant member may form only part of the second resonant cavity. The first conductive resonator cavity surface from which the first resonant member extends is offset from a second conductive resonator cavity surface from which the second resonant member extends. That is to say, the first and second resonant member may be configured to have a different effective ground planes.

The first aspect recognises that by arranging one cavity within another cavity it may be possible to save space, and that with arrangements in which a part, rather than all, of the second cavity lies within the first resonant member and/or in which a first conductive resonator cavity surface from which the first resonant member extends is offset from a second conductive resonator cavity surface from which the second resonant member extends, it may be possible to allow the part of the second cavity which is outside the first resonant member to have greater cross sectional area, and/or a greater volume than the part of the cavity inside the first resonant member, thereby providing space for greater energy storage.

Furthermore, the first aspect recognises that by configuring the first and second resonant members such that are attached to different cavity base surface planes, such that those cavity bases are offset from each other may assist with provision of a volume for energy storage in the second resonator cavity. Configuring the first and second resonant members in such a way, so that they have offset cavity bases, may also ease coupling arrangements between first and/or second resonant cavities of adjacent resonant assemblies in accordance with the first aspect, thereby aiding filter construction and design.

According to one embodiment, the first and second cavities are configured to be substantially electrically and magnetically isolated from each other. Accordingly, operation of each cavity (first or second) may be substantially independent to operation of the other cavity. Accordingly, each cavity may be tuned independently. The independence of cavities may make a resonator assembly particularly suited to use as a duplexing unit in a frequency division duplexing system. That is to say, one resonant cavity may be used for transmission and another for reception. Furthermore, it will be appreciated that the high level of isolation between the two resonances may allow for a minimum sacrifice in overall Q-factor.

According to one embodiment, the second resonator cavity comprises a cavity having a non-uniform cross-sectional area along its length. According to one embodiment, the second resonator cavity is configured in a general form of an inverted mushroom, a stem of the mushroom forming the first resonant member. Accordingly, there may be provided an increased volume within which to store magnetic energy at resonance. Compared to known arrangements, some arrangements can allow for an improved physical configuration in relation to the coaxial resonating members in each cavity of the enclosure, the configuration allowing volume for magnetic energy storage and suppressing volume for electric energy storage, thus increasing in two ways the efficiency of the resonator and saving overall resonator assembly volume.

According to one embodiment, at least one of the first and second resonator cavities comprises: a tunable screw extending into the resonator cavity. It will be appreciated that provision of appropriate tuning screws in relation to the resonating members positioned in each cavity may allow for tuning of the appropriate resonating cavity. According to one embodiment, the second resonant member is formed from a tunable screw insert extending into the second conductive resonator cavity.

According to one embodiment, the first and second fundamental frequencies are different. According to one embodiment, the first and second fundamental frequencies are substantially identical. If the first and second frequencies are different, the cavities may be independently fed and a signal may be extracted from each cavity independently. If the first and second frequencies are the same, the cavities may be still be independently fed and a signal may be extracted from each cavity independently or the cavities may be still fed by a common signal feed, or the signal may be coupled between cavities. The two-cavity arrangement of the enclosure may offer for particularly flexible operation.

According to one embodiment, the first and second cavities are configured so that the second signal feed is configured to receive a signal from the first conductive resonator cavity. In some embodiment, capacitative coupling is provided between cavities. Accordingly, a capacitative probe may link the cavities. In some embodiments, inductive coupling is provided between cavities. Accordingly, one or more apertures may link the cavities. According to one embodiment, the first and second signal feeds may comprise a single signal feed. That is to say, both cavities may be fed by the same signal feed.

According to one embodiment, configuring the first or second resonant member to resonate within the cavity at the first or second fundamental frequency respectively comprises: selecting at least one physical dimension of the resonant member.

According to one embodiment, at least one of the first and second resonant member comprises a resonating post. The first resonator post may comprise a hollow metallic post. The second resonator post may comprise a solid metal post or screw.

A second aspect provides a filter comprising: a plurality of resonator assemblies, at least one of the resonator assemblies comprising a resonator assembly according to the first aspect, the filter comprising an input resonator assembly and an output resonator assembly arranged such that a signal received at the input resonator assembly passes through the plurality of resonator assemblies and is output at the output resonator assembly; an input feed line configured to transmit a signal to an input resonator member of the input resonator assembly such that the signal excites the input resonator member, the plurality of resonator assemblies being arranged such that the signal is transferred between the corresponding plurality of resonator members to an output resonator member of the output resonator assembly; an output feed line for receiving the signal from the output resonator member and outputting the signal.

According to one embodiment, the filter comprises at least two adjacent resonator assemblies comprising a resonator assembly according to the first aspect, and wherein the adjacent resonator assemblies are configured such that a signal can be passed between adjacent first conductive resonator cavities and a signal can be passed between adjacent second conductive resonator cavities. According to one embodiment, the filter comprises at least two adjacent resonator assemblies comprising a resonator assembly according to the first aspect, and wherein the adjacent resonator assemblies are configured such that a signal can be passed between adjacent first conductive resonator cavities or a signal can be passed between adjacent second conductive resonator cavities. Accordingly, since it will be understood that the two resonant cavities may be configured such that they support different resonant frequencies or the same resonant frequency and in either case it is possible to feed the relevant cavities independently or simultaneously. Various modes of filter operation therefore follow.

According to one embodiment, the filter is configured to form a filter of a duplexer.

According to one embodiment, the filter is at least one of: a radio frequency filter or a combline filter.

Further particular and preferred aspects are set out in the accompanying independent and dependent claims. Features of the dependent claims may be combined with features of the independent claims as appropriate, and in combinations other than those explicitly set out in the claims.

Where an apparatus feature is described as being operable to provide a function, it will be appreciated that this includes an apparatus feature which provides that function or which is adapted or configured to provide that function.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will now be described further, with reference to the accompanying drawings, in which:

Figure 1 illustrates schematically, in side and plan view, layout of an existing dual-resonance coaxial cavity resonator; including quarter wavelength resonating elements;

Figure 2 illustrates schematically, in side and plan view, a layout of a coaxial cavity resonator configured to support two resonances: fundamental resonant mode 1 and fundamental resonant mode 2;

Figure 3 illustrates schematically, in side and plan view, an alternative layout of a coaxial cavity resonator configured to support two resonances: fundamental resonant mode 1 and fundamental resonant mode 2;

Figures 4a and 4b illustrate the distribution of electric field (magnitude) across a vertical plane of one possible resonator volume, for resonant, fundamental modes one and two respectively;

Figures 4c and 4d illustrate the distribution of magnetic field (magnitude) across a vertical plane of one possible resonator volume, for resonant, fundamental modes one and two respectively;

Figures 5a and 5b illustrate schematically, in side and plan view, layout configurations which allow for possible coupling between modes of a coaxial cavity resonator;
Figure 5a shows capacitive coupling in which the layout includes an aperture to support coupling between the two modes;
Figure 5b shows inductive coupling in which the layout includes a wire to support coupling between the two mode;
Figures 6a and 6b illustrate schematically, in side and plan view, layout configurations which allow for possible coupling between modes of a coaxial cavity resonator;
Figure 6a shows capacitive coupling in which the layout includes a probe to support coupling between the two modes;
Figure 6b shows inductive coupling in which the layout includes at least one aperture to support coupling between the two modes;
Figure 7a illustrates the distribution of electric field (magnitude) across a vertical plane of one possible resonator volume;
Figure 7b illustrates the distribution of magnetic field (magnitude) across a vertical plane of one possible resonator volume;
Figure 8 illustrates schematically components of a possible resonant post which allows for post-fabrication tuning of one mode of a coaxial cavity filter;
Figures 9a to c illustrate schematically various assembly coupling arrangements in which resonator arrangements can be used to achieve increased efficiency in cross-couplings in the coaxial cavity filter technology; and
Figure 10 illustrate schematically, in plan view, a layout of a coaxial cavity filter which achieves extended physical proximity as required to perform cross couplings.

DESCRIPTION OF THE EMBODIMENTS

Before discussing the embodiments in any more detail, first an overview will be provided.

Figure 2 illustrates schematically one possible layout of a resonator assembly configured to support two resonances in accordance with one arrangement. As can be seen from the schematic side view and plan view shown in Figure 2 of one possible arrangement, a resonator enclosure is provided. The resonator enclosure shown is configured such that within a cavity enclosure there is provided two cavities. A first cavity m1 is provided and supports operation of a first resonating element, m1, placed within a first cavity m1. There is also provided a second resonant mode supported by a second cavity m2 and associated resonating element, the m2 post, shown in Figure 2. As can be seen in Figure 2, within a space comparable to that of a traditional cavity enclosure, there exists two cavities: a cavity for supporting resonant mode 1 and a cavity for supporting resonant mode 2. In the arrangement shown, the outer shell of the cavity provided for resonant mode 1 forms the resonating element associated with resonant mode 2. The common wall is configured to play two roles within the enclosure; first, forming a cavity enclosure for the resonant mode 1 and, second, providing a resonant element for the resonant mode 2. In a configuration such as that shown schematically in Figure 2, the isolation between the two modes/ resonances is infinite since they are totally isolated by a magnetic wall. The shaded areas within Figure 2 each schematically represent a cavity, one provided for each mode, m1 and m2.

As can be seen schematically in Figure 2, arrangements may be such that two short-circuit planes are provided and two open-end regions are provided for each resonating member. That is to say, there are two ground planes, one for each mode supported within the overall resonant enclosure. One difference between the arrangement shown schematically in Figure 2 and that of some known arrangements, for example, that of Figure 1, is that the resonant member m1 has its own short circuit or ground plane. Provision of two separate ground planes allows for increased isolation between modes and, in the particular spatial physical arrangement shown in Figure 2, there is provided an increased volume within which to store magnetic energy at resonance, thus allowing the m1 resonant mode to couple magnetically. Compared to known arrangements, an arrangement such as that shown schematically in Figure 2 can allow for an improved physical configuration in relation to the coaxial resonating members in each cavity of the enclosure, that improved configuration allowing volume for magnetic energy storage and suppressing volume for electric energy storage, thus increasing in two ways the efficiency of the resonator and saving overall volume. An arrangement such as that shown schematically in Figure 2 may also result in reduced complexity when achieving coupling between resonator enclosures and coupling between the two resonant cavities m1 and m2 when compared to the resonator enclosure shown in Figure 2.

It will be appreciated that the high level of isolation between the two resonances in an arrangement such as that shown in Figure 2 may allow for a minimum sacrifice in overall Q-factor. The physical configuration shown schematically in Figure 2 can result in reduced design complexity in relation to filters formed from such enclosures. In particular, for example, in an arrangement such as that shown in Figure 2, tuning of the two resonances may be effected substantially independently. Furthermore, post-fabrication tuning ability may significantly reduce overall design complexity, consequently leading to improved costs and time-to-market improvements and thereby improved overall efficiency. Further benefits may occur in relation to filters formed from a plurality of enclosures such as that shown in Figure2, since the physical arrangement of the cavities (if operating at the same fundamental frequency) shown in Figure 2 may allow for planning and improved arrangement of physical components to allow for transmission zeros within a signal which can be of importance when implementing efficient signal filters.

Figure 3 illustrates schematically an alternative arrangement of a coaxial cavity resonator assembly which is configured to support two resonances. The embodiment shown in Figure 3 includes a resonating member in cavity m1 which extends downwardly from the inside of the resonating member provided in cavity m2. It will be appreciated that provision of appropriate tuning screws in relation to the resonating members positioned in each cavity may allow for tuning of the appropriate resonating cavity.

Figures 4a through to 4d illustrate schematically electric and magnetic field distributions within an arrangement such as that shown in Figure 2. Figure 4a and Figure 4b show the distribution of the electric field (magnitude) on a vertical plane across the resonator volume for resonant fundamental modes m1 and m2 respectively. Figures 4c and 4d show the corresponding distribution of a magnetic field (magnitude) for modes m1 and m2 respectively. It can be seen from Figure 4 that the structural configuration of an arrangement such as that shown in Figure 2 is such that the resulting resonator assembly can support two resonant modes. The two modes, as they appear in Figure 4, are electrically isolated. Figures 4c and 4d show the corresponding distribution of magnetic field (magnitude) in relation to modes m1 and m2 supported within the cavity. The lighter shades of grey represent a higher intensity.

Arrangements such as those shown schematically in Figures 2 and 3 can be implemented using current mass-market low cost fabrication techniques. Although the complexity of a resonator assembly and any resulting filter assemblies may be slightly increased compared to standard coaxial technology, some of the benefits offered by such an arrangement may compensate for such increased complexity. Post-fabrication tuning of assemblies and filters including resonator assemblies such as those shown schematically in Figures 2 and 3 is unlikely to add additional complexity to those devices.

A resonator assembly such as that shown schematically in Figure 2 or Figure 3 may be constructed to operate in various ways. In particular, it will be understood that the two resonant cavities may be configured such that they support different resonant frequencies or the same resonant frequency. In either case it is possible to feed the relevant cavities independently or simultaneously. Various modes of operation are described in more detail below.

Dual Resonance – Filters and Diplexers

According to some arrangements, a dual resonance coaxial cavity resonator is provided. Such a structure may be configured to support two modes at different frequencies or within different frequency bands: m1f1; m2f2. Some configuration can be used to support dual band filters and diplexers. In relation to, for example, the arrangements shown schematically in Figures 2 and 3, the two modes supported, m1f1 and m2f2, are supported in the isolated cavities m1 and m2 respectively. The two frequencies of the resonant cavities need not coincide and may be interchangeable. That is to say, f1 may be higher or lower in frequency than f2.

Dual Resonance – Duplexing

According to some configurations, a dual resonance coaxial cavity resonator is provided in a resonator enclosure such as that shown schematically in Figures 2 and 3. According to such a configuration, a structure is operable to support two modes of resonance at different frequencies, m1f1Tx1 and m2f2Rx1, where m1 stands for mode 1, f1 stands for frequency band 1 and Tx1 indicates the filter functionality in relation to a transmission mode. The structure of Figures 2 and 3 are particularly suited to such functionality due to the high level of isolation provided between the two resonant cavities. It will be understood that in relation to configurations such as those shown in Figures 2 and 3, the resonance at m1/ m2 (m1f1, m2f2) may be such that the resonator enclosure can be used as a duplexing unit in a frequency division duplexing system. That is to say, one resonant cavity may be used for transmission and another for reception. It will further be understood that the previous configurations can be combined in order to provide a dual band duplexer.

Dual Mode

According to such a configuration, each of the two cavities m1, m2 provided in an arrangement such as that shown in Figures 2 and 3 may occur concurrently at the same frequency or within the same frequency band. According to such a configuration, it may be required that the two cavities provided within the enclosure, and the two

fundamental resonances, are coupled. That is to say, cavities m1 and m2 are no longer independent and are, instead, coupled.
Figures 5 and 6 illustrate schematically various configurations according to which coupling between cavities m1 and m2 of a coaxial cavity resonator such as those shown in Figures 2 and 3 may be achieved.

Figure 7 illustrates field distributions of such coupled modes.

Figure 5a illustrates schematically one configuration according to which capacitive coupling may be achieved. In the arrangement shown in Figure 5a, an aperture is included in the m2 post which supports coupling between the two modes m1f and m2f. According to the configuration shown in Figure 5b, inductive coupling is used and the configuration of the cavities m1 and m2 are such that an inductive wire is provided. In such arrangements, m1f is the mode 1 frequency of resonance and m2f is the mode 2 frequency of resonance and, in the examples shown, they are the same frequency f.

Figure 6a and Figure 6b illustrate schematically possible configurations for achieving coupling between modes of a coaxial cavity resonating assembly such as that shown in Figures 2 and 3. Figure 6a illustrates a configuration according to which capacitative coupling is provided between cavities m1 and m2. A probe is provided to support coupling between the two modes m1f and m2f. Figure 6b illustrates schematically inductive coupling. The configuration shown in Figure 6b illustrates an arrangement in which one or more apertures are used to achieve such inductive coupling. Again, in the arrangement shown, the resonant frequency in m1 is the same as the resonant frequency of cavity m2.

Figure 7a illustrates, for a particular configuration of a two-pole coaxial cavity filter, the magnitude of the electric field within the cavities. Figure 7b illustrates schematically for the same resonant assembly the dual-mode magnetic field magnitude.

Dual Mode – Transmission Zeros

It has been recognised that when configured to operate in a dual mode, a resonator assembly such as that shown in Figure 2 and Figure 3 may be particularly suited to achieving transmission zeros in relation to cross couplings. Figure 9 illustrates schematically coupling arrangements which allow increased flexibility in the way in which cross couplings can be achieved within a coaxial cavity filter arrangement comprising a plurality of resonator assemblies such as those shown in Figures 2 and 3.

Figure 8 illustrates schematically one mechanism by which post-fabrication tuning within a resonator such as those shown in Figures 2 and 3 may be achieved. According to such an arrangement, a hollow resonating member in the form of a post is provided. That resonator post is fixed to the metallic cavity wall by solder being screwed in or pressed in. A tuning screw is provided which extends along the axis of the hollow resonator post. The tip of the tuning screw may extend beyond or through the end of the hollow resonator post. At the tip of the hollow resonator post or tuning screw, a high electric field with low current is achieved. Adjustment of the tuning screw within the hollow resonator post to project further from the hollow resonator post may allow for tuning of the resonating member within a resonant cavity. It will be appreciated that, tuning of a resonant assembly may be required post fabrication. Provision of tuning screws allows that post fabrication tuning to occur in an efficient manner. Use of tuning screws may relax manufacturing tolerance requirements.

Figure 9 illustrates schematically various example coupling diagrams which demonstrate the flexibility and scalability of a resonator assembly such as that shown in Figures 2 and 3 if used in a manner where cavities m1 and m2 support the same resonant frequency. In particular, it will be appreciated that such coupling diagrams demonstrate that a resonator assembly such as that shown in Figures 2 and 3 may be used in filters formed from multiple such assemblies to achieve increased efficiency in cross couplings.

Figure 9a shows a typical coupling diagram for a 4 pole filter. In this coupling diagram each pole, 1 to 4 can have coupling only between neighbouring poles. Physical representations are similar to an inline filter which prohibits physical proximity of non-neighbouring resonators. In real life coaxial cavity filters, the coupling diagram is changed from that of Figure 9a to a “folded” coupling diagram. A physical representation of such a filter is one in which cavities are placed across from each other in a so-called “folded” configuration. In this way, physical proximity of non-adjacent cavities can be achieved. Such a folded configuration allows for the introduction of transmission zeros (TZs) in a filter response by implementing cross-couplings, which create several paths for a filtered signal. Such a folded configuration has limitations in relation to the number of nonadjacent resonators which can be arranged to be in physical proximity to allow for the required the cross-couplings.

Figure 9b illustrates schematically an arrangement in which poles 2 and 3 of Figure 9a with are replaced with a single pole: pole 2&3. This is possible since now poles 2&3 can take the physical form of a resonator enclosure such as that shown schematically in Figure 2. This allows poles 1 and pole 4 to be brought into close proximity in a real physical configuration. The physical configuration of resonator assemblies is shown schematically in Figure 10.

Figure 9 shows alternative configurations which may be possible due to the configuration of a resonator enclosure such as the ones shown in Figures 2 and 3. Figure 9 refers to configurations which employ one resonator enclosure such as that shown in Figure 2, and shows the potential benefits of employing all or a number of the resonators in a filter to be of the form of the enclosure shown in Figure 2.

Aspects and embodiments may provide for a reduction in size compared to a typical dual band resonant structure. That is to say, arrangements are such that limited additional physical space is required for a second resonant structure compared to a single resonant structure. Aspects and embodiments may provide for increased flexibility and scalability when building filters from resonant structures compared to conventional filtering solutions. Furthermore, aspects and embodiments may provide for improved out-of-band performance compared to conventional solutions.

A person of skill in the art would readily recognize that steps of various above-described methods can be performed by programmed computers. Herein, some embodiments are also intended to cover 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. The embodiments are also intended to cover computers programmed to perform said steps of the above-described methods.

The functions of the various elements shown in the Figures, including any functional blocks labelled as “processors” or “logic”, may be provided through the use of dedicated hardware as well as hardware capable of executing software in association with appropriate software. When provided by a processor, the functions may be provided by a single dedicated processor, by a single shared processor, or by a plurality of individual processors, some of which may be shared. Moreover, explicit use of the term "processor" or "controller" or "logic" should not be construed to refer exclusively to hardware capable of executing software, and may implicitly include, without limitation, digital signal processor (DSP) hardware, network processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA), read only memory (ROM) for storing software, random access memory (RAM), and non-volatile storage. Other hardware, conventional and/ or custom, may also be included. Similarly, any switches shown in the Figures are conceptual only. Their function may be carried out through the operation of program logic, through dedicated logic, through the interaction of program control and dedicated logic, or even manually, the particular technique being selectable by the implementer as more specifically understood from the context.

It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in computer readable medium and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

The description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass equivalents thereof.

CLAIMS

1. A resonator assembly comprising: a first resonator cavity, a first resonant member, and a first signal feed; a second resonator cavity, a second resonant member, and a second signal feed;
said first resonant member being located within said first resonator cavity, arranged to receive a signal from said first signal feed and configured to resonate within said first cavity at a first fundamental frequency;
said second resonant member being located within said second resonator cavity, arranged to receive a signal from said second signal feed and configured to resonate within said second cavity at a second fundamental frequency;
wherein at least a portion of said second cavity is housed within said first resonant member, and wherein a first resonator cavity surface from which said first resonant member extends is offset from a second resonator cavity surface from which said second resonant member extends.

2. A resonator assembly according to claim 1, wherein said first and second cavities are configured to be substantially electrically and magnetically isolated from each other.

3. A resonator assembly according to claim 1 or claim 2, wherein said second resonator cavity comprises a cavity having a non-uniform cross-sectional area along its length.

4. A resonator assembly according to claim 3, wherein said second resonator cavity is configured in a general form of an inverted mushroom, a stem of said mushroom forming said first resonant member.

5. A resonator assembly according to any preceding claim, wherein at least one of said first and second resonator cavities comprises: a tunable screw extending into said resonator cavity.

6. A resonator assembly according to claim 5, wherein said second resonant member is formed from a tunable screw insert extending into said second resonator cavity.

7. A resonator assembly according to any preceding claim, wherein said first and second fundamental frequencies are different.

8. A resonator assembly according to any one of claims 1 to 6, wherein said first and second fundamental frequencies are substantially identical.

9. A resonator assembly according to claim 8, wherein said first and second cavities are configured so that said second signal feed is configured to receive a signal from said first resonator cavity.

10. A resonator assembly according to any preceding claim, wherein configuring said first or second resonant member to resonate within said cavity at said first or second fundamental frequency respectively comprises: selecting at least one physical dimension of said resonant member.

11. A resonator assembly according to any preceding claim, wherein at least one of said first and said second resonant member comprises a resonating post.

12. A filter comprising: a plurality of resonator assemblies, at least one of said resonator assemblies comprising a resonator assembly according to any preceding claim, said filter comprising an input resonator assembly and an output resonator assembly arranged such that a signal received at said input resonator assembly passes through said plurality of resonator assemblies and is output at said output resonator assembly;
an input feed line configured to transmit a signal to an input resonator member of said input resonator assembly such that said signal excites said input resonator member, said plurality of resonator assemblies being arranged such that said signal is transferred between said corresponding plurality of resonator members to an output resonator member of said output resonator assembly;
an output feed line for receiving said signal from said output resonator member and outputting said signal.

13. A filter according to claim 12, comprising: at least two adjacent resonator assemblies comprising a resonator assembly according to any one of claims 1 to 11, and wherein said adjacent resonator assemblies are configured such that a signal can be passed between adjacent first resonator cavities and a signal can be passed between adjacent second resonator cavities.

14. A filter according to claim 12, comprising at least two adjacent resonator assemblies comprising a resonator assembly according to any one of claims 1 to 11, and wherein said adjacent resonator assemblies are configured such that a signal can be passed between adjacent first resonator cavities or a signal can be passed between adjacent second resonator cavities.

15. A filter according to any one of claims 12 to 14, configured to form a filter of a duplexer.

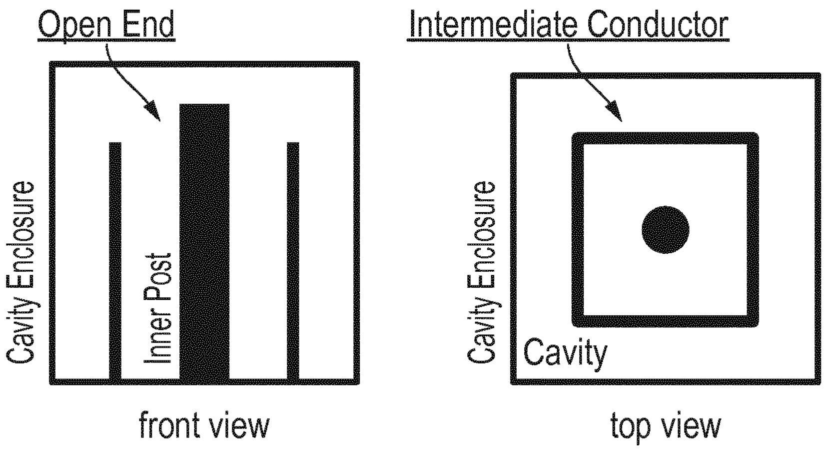


FIG. 1

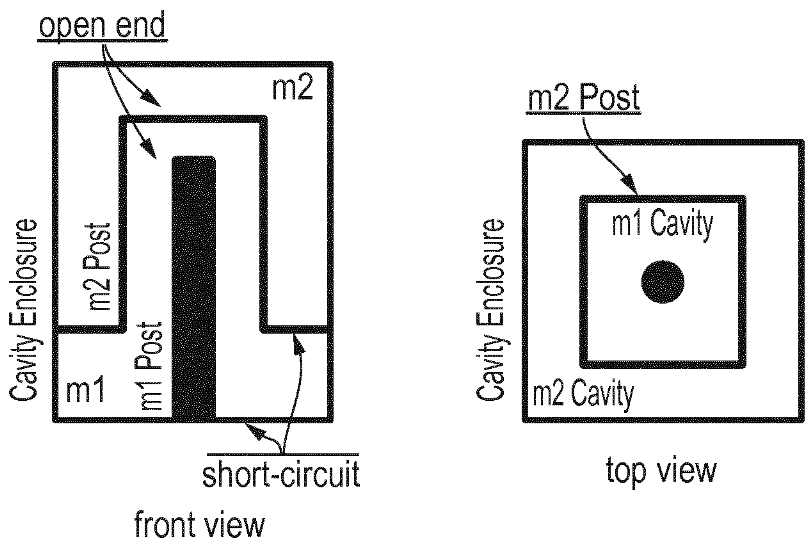


FIG. 2

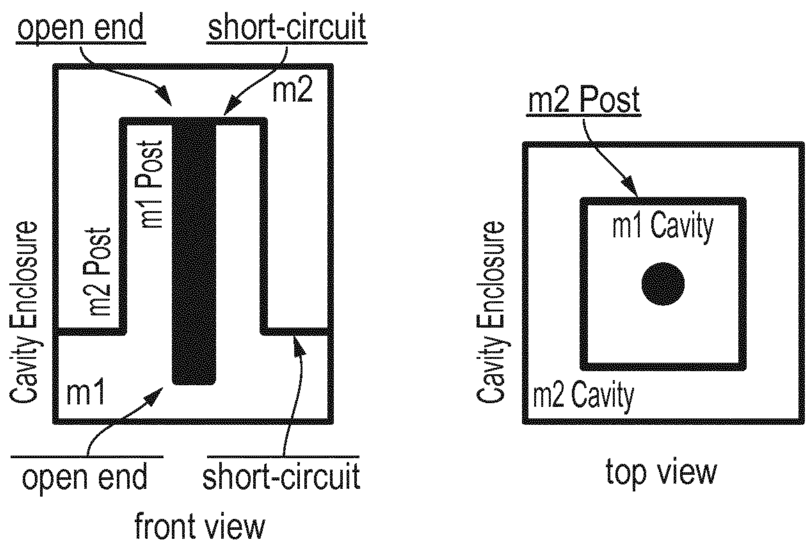
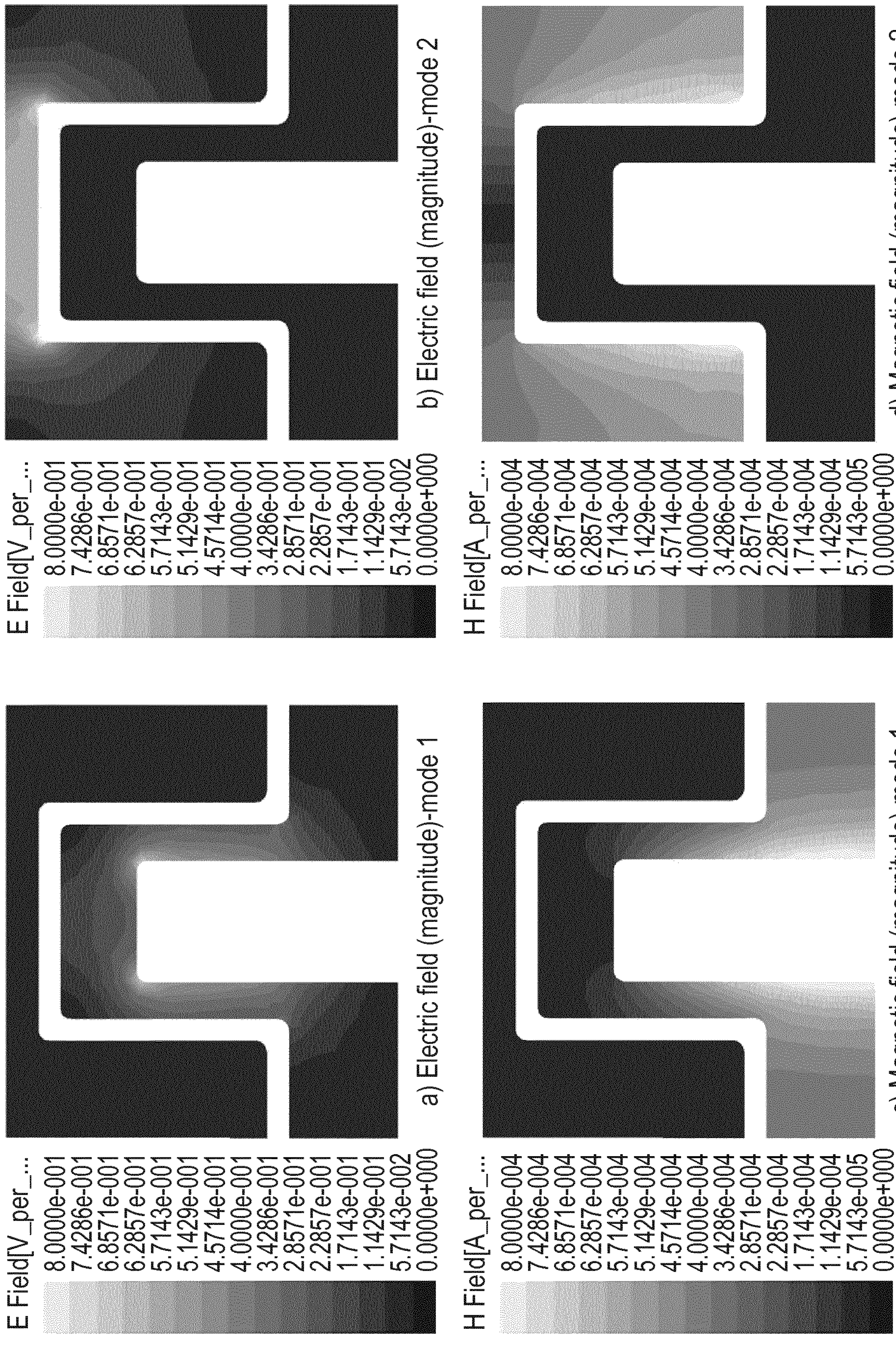


FIG. 3



a) Electric field (magnitude)-mode 1

b) Electric field (magnitude)-mode 2

c) Magnetic field (magnitude)-mode 1

d) Magnetic field (magnitude)-mode 2

FIG. 4

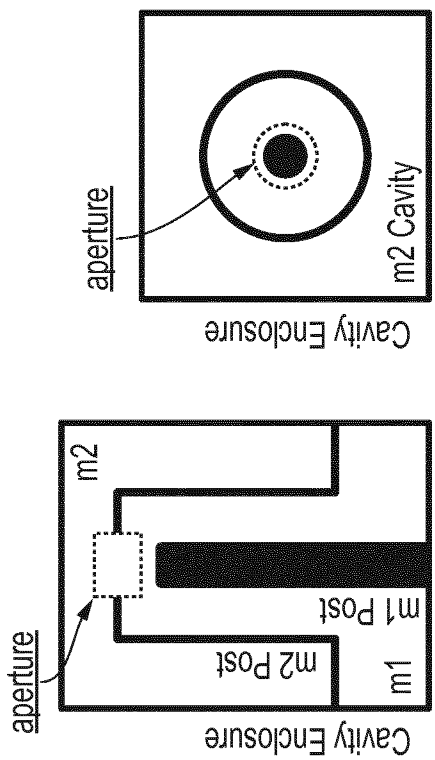


FIG. 5a

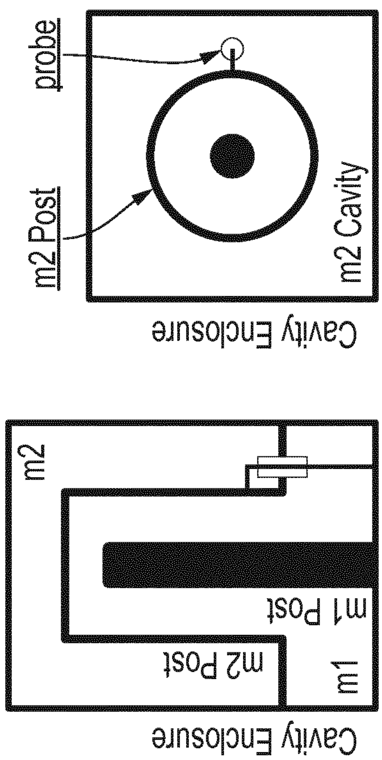


FIG. 5b

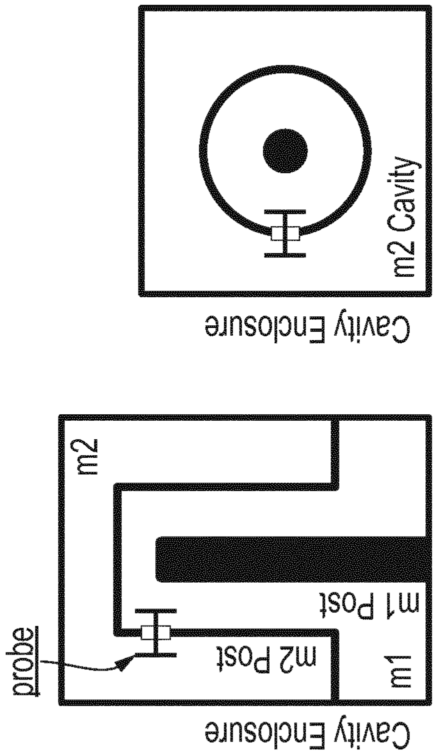


FIG. 6a

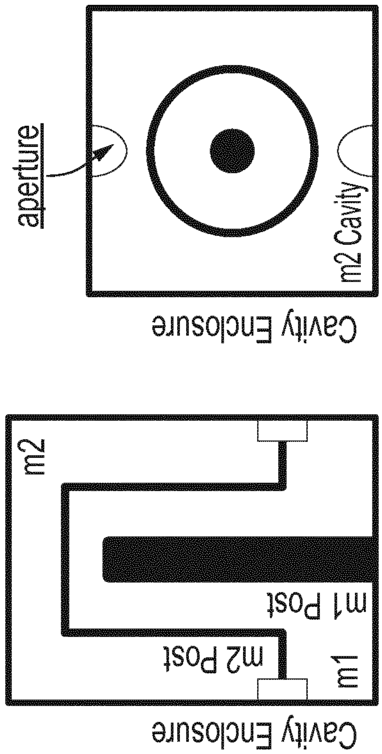


FIG. 6b

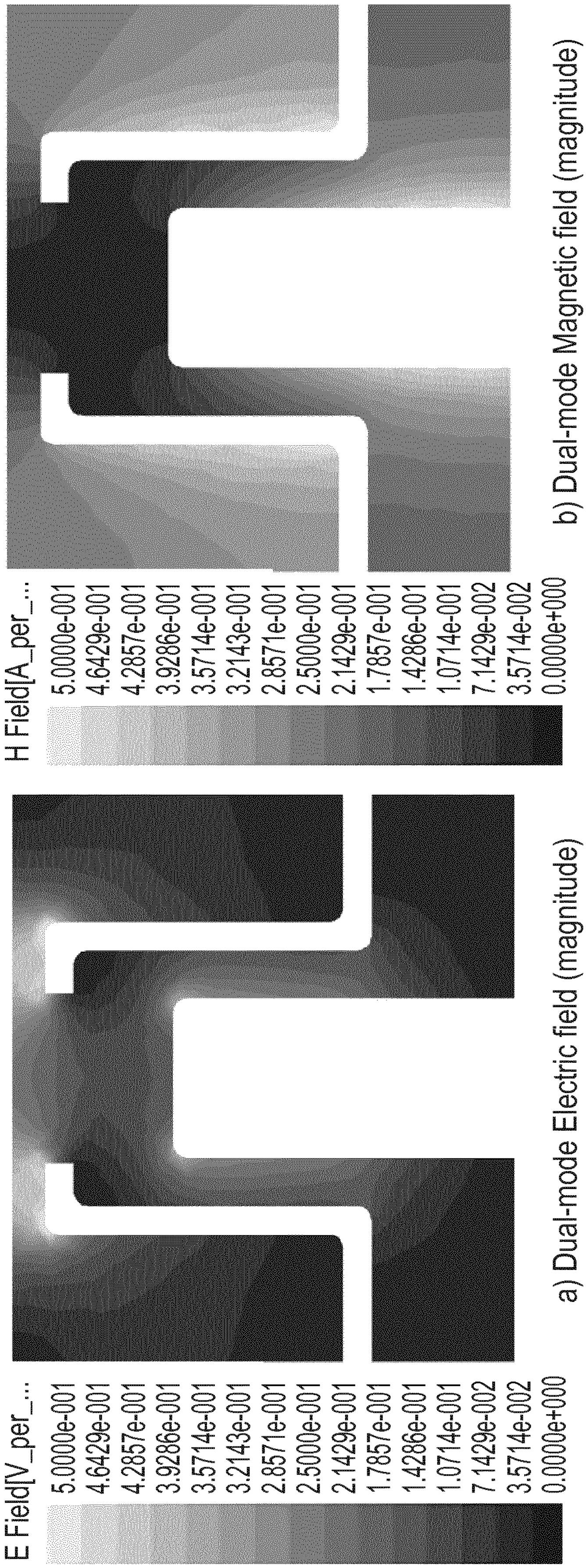

H Field[A_per_...
5.0000e-001
4.6429e-001
4.2857e-001
3.9286e-001
3.5714e-001
3.2143e-001
2.8571e-001
2.5000e-001
2.1429e-001
1.7857e-001
1.4286e-001
1.0714e-001
7.1429e-002
3.5714e-002
0.0000e+000
b) Dual-mode Magnetic field (magnitude)
E Field[V_per_...
5.0000e-001
4.6429e-001
4.2857e-001
3.9286e-001
3.5714e-001
3.2143e-001
2.8571e-001
2.5000e-001
2.1429e-001
1.7857e-001
1.4286e-001
1.0714e-001
7.1429e-002
3.5714e-002
0.0000e+000
a) Dual-mode Electric field (magnitude)

FIG. 7

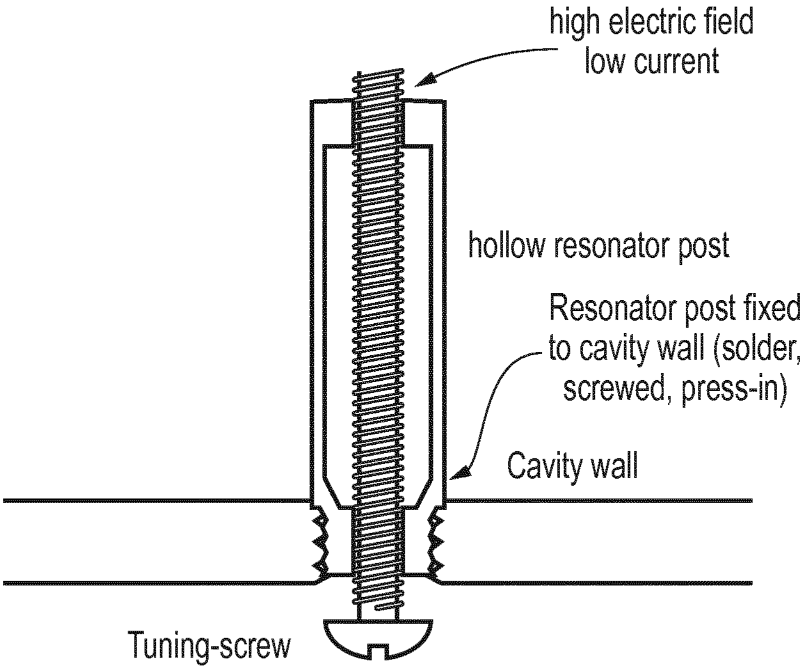


FIG. 8

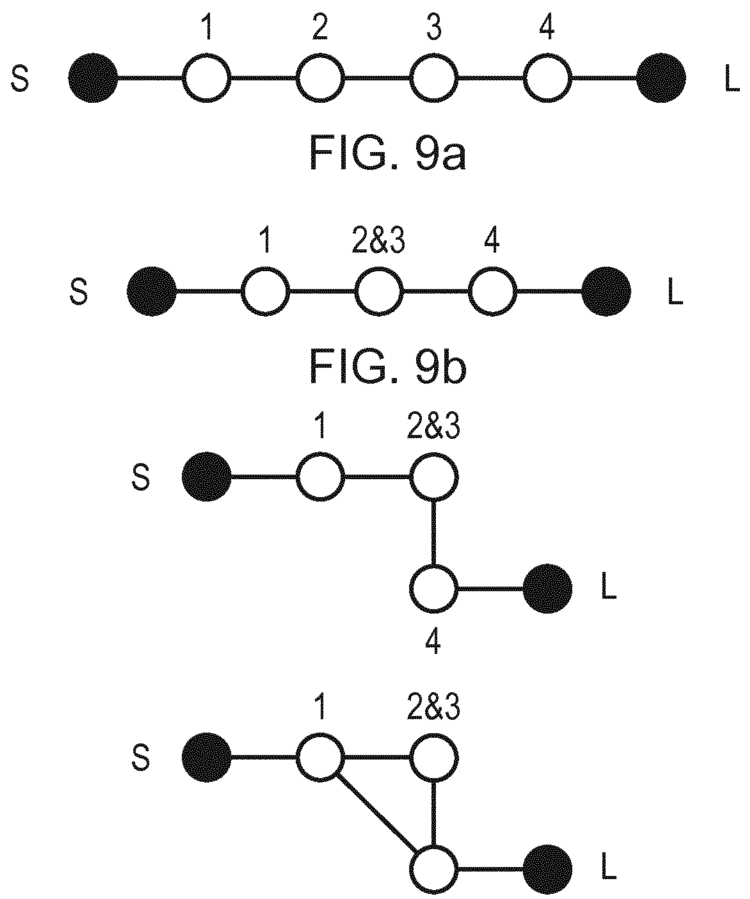


FIG. 9a

FIG. 9b

FIG. 9c

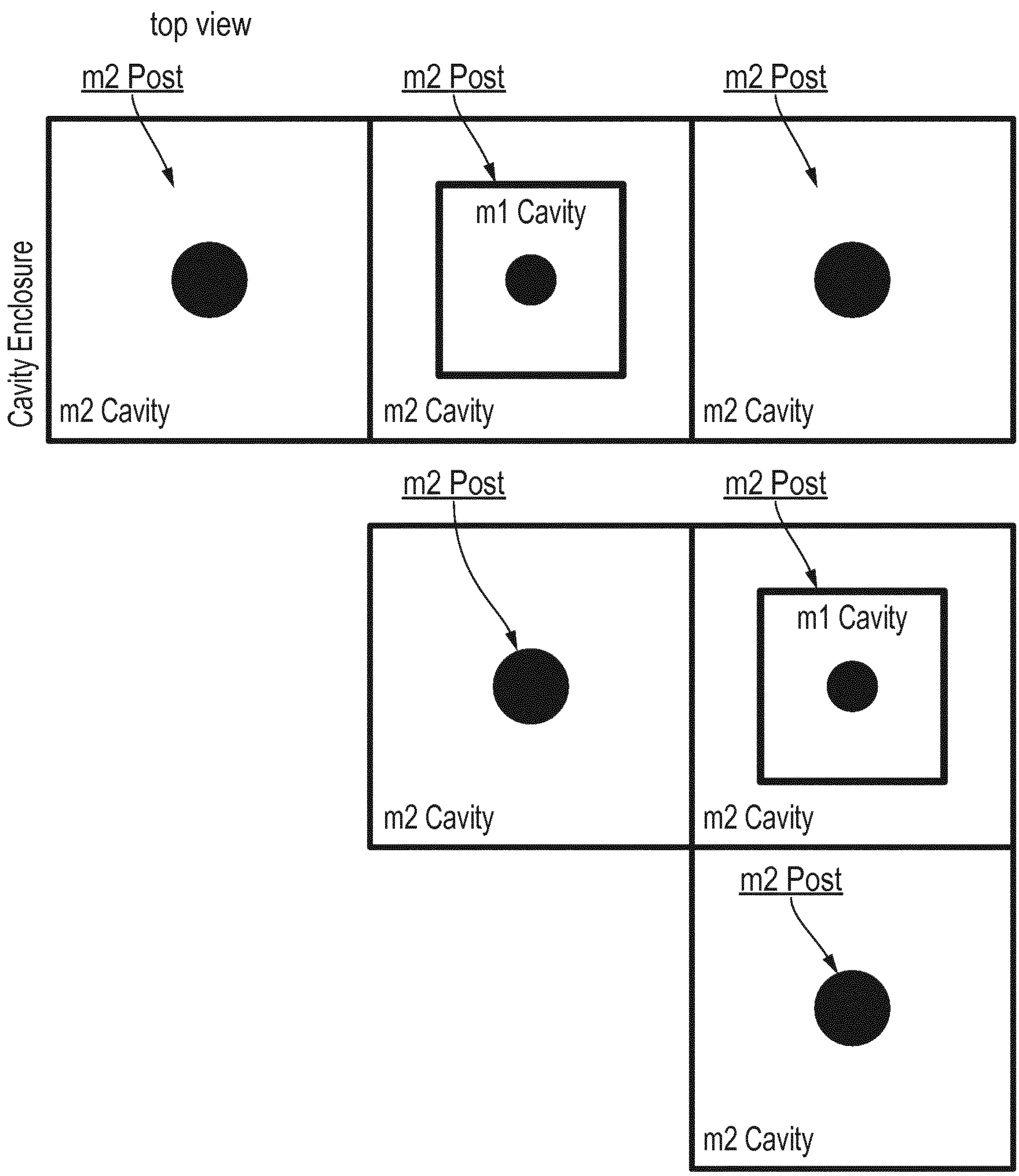

top view
m2 Post
m2 Post
m2 Post
Cavity Enclosure
m1 Cavity
m2 Cavity
m2 Cavity
m2 Cavity
m2 Post
m2 Post
m1 Cavity
m2 Cavity
m2 Cavity
m2 Post
m2 Cavity

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/057711

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01P1/205 H01P1/213 H01P7/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MUSONDA EVARISTO ET AL: "Microwave Bandpass Filters Using Re-Entrant Resonators", IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 63, no. 3, 1 March 2015 (2015-03-01), pages 954-964, XP011574138, ISSN: 0018-9480, DOI: 10.1109/TMTT.2015.2389216 [retrieved on 2015-03-03]	1-5,7, 9-15
Y	paragraph [II.A]; figure 8 paragraph [IV.B]; figure 23 -----	6
Y	US 2014/132372 A1 (WIEHLER ERIC [US] ET AL) 15 May 2014 (2014-05-15) paragraph [0042]; figures 11A-D ----- -/--	6

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 June 2016	22/06/2016

Name and mailing address of the ISA/	Authorized officer
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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 576 456 A1 (CGR MEV [FR]) 25 July 1986 (1986-07-25) page 4 - page 5; figure 1 -----	1,3,4, 8-11
A	JORGE A RUIZ-CRUZ ET AL: "Triple-Conductor Combline Resonators for Dual-Band Filters With Enhanced Guard-Band Selectivity", IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 60, no. 12, 1 December 2012 (2012-12-01), pages 3969-3979, XP011484729, ISSN: 0018-9480, DOI: 10.1109/TMTT.2012.2223482 the whole document -----	1-15
A	US 2014/347148 A1 (RUIZ-CRUZ JORGE A [ES] ET AL) 27 November 2014 (2014-11-27) paragraph [0034] - paragraph [0040]; figures 4-8 paragraph [0042] - paragraph [0044]; figures 10,11 paragraph [0048] -----	1-15

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/057711

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 2014132372	A1	15-05-2014	NONE	
FR 2576456	A1	25-07-1986	NONE	
US 2014347148	A1	27-11-2014	NONE	