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(54) **Coaxial resonator filter**

(57) A resonant assembly is disclosed. The resonator assembly comprises: a resonator having a first conductive resonance post surrounded by a conductive enclosure defining a cavity, the first conductive resonance post being operable to filter a signal within a first frequency band, and a second conductive resonance post located within the cavity and orientated transversely with respect to the first conductive resonance post, the second conductive resonance post being operable to filter a signal within a second frequency band concurrently with the first conductive resonance post filtering the signal within the first frequency band. Through this approach, it is possible to provide a single device which implements more than one independent resonance or filtering at the same time within the same cavity volume, allowing significantly smaller cavity filters to be built, which avoids the need to provide separate devices, one for each frequency. This is particularly convenient in resonant assemblies used in RF front ends which will often be required to receive signals at two or more different frequencies.

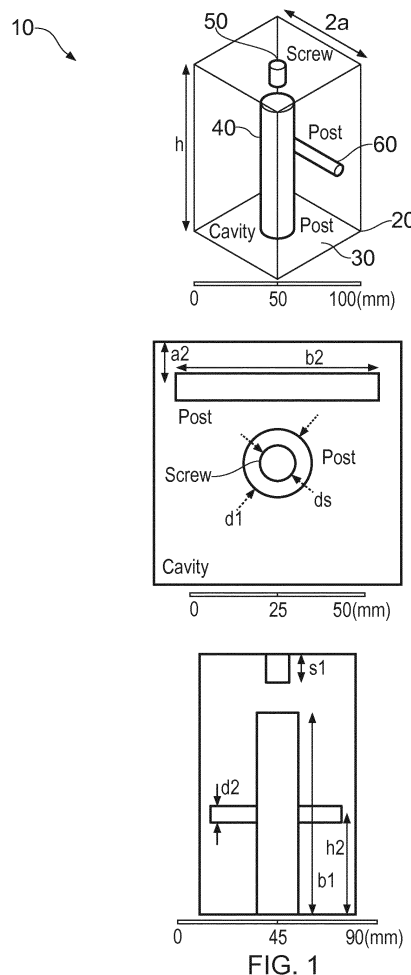


**FIG. 1**

**Description**FIELD OF THE INVENTION

5     **[0001]**   The present invention relates to a resonant assembly.

BACKGROUND

10    **[0002]**   Resonant devices are known. In low-frequency electronics, a resonant circuit contains a capacitor and a coil. The capacitor is used to store electrical energy and the coil stores magnetic energy. At resonance, energy stored in the resonant circuit is continuously converted between two states, swapping between capacitor and coil over time. At higher frequencies, transmission lines can resonate. A quarter-wavelength transmission line with one end grounded and the other end open can be seen as a combination of a capacitor and coil. Increasing the permittivity of the transmission line by using, for example, ceramic materials reduces the size of the resonant device. Resonant devices are often used in radio-frequency (RF) front ends. Each resonant device has its own characteristics, including its own resonance frequency. The resonance frequency is dependent on the characteristics of the device and, in particular, on the characteristics of the mixtures of various materials making up the device.

15    **[0003]**   It is desired to provide an improved resonant device.

20    SUMMARY

25    **[0004]**   According to a first aspect, there is provided a resonator assembly, comprising: a resonator having a first conductive resonance post surrounded by a conductive enclosure defining a cavity, the first conductive resonance post being operable to filter a signal within a first frequency band, and a second conductive resonance post located within the cavity and orientated transversely with respect to the first conductive resonance post, the second conductive resonance post being operable to filter a signal within a second frequency band concurrently with the first conductive resonance post filtering the signal within the first frequency band.

30    **[0005]**   The first aspect recognizes that conventional resonators such as, for example, a transverse electromagnetic (TEM) combine resonator consist of a metallic cavity enclosure (with a generally circular shaped or rectangular shaped cross section) with a cylindrically-shaped metallic post at the centre of the circular/rectangular cavity grounded at one side and open-circuit at the opposite side. Each of these resonators is dimensioned to provide a resonance at a particular desired frequency. However, the first aspect recognizes that it is possible to reuse the cavity in order to provide a resonator which resonates at more than one particular desired frequency so that more than one resonance can be achieved concurrently or simultaneously.

35    **[0006]**   Accordingly, a resonator assembly may be provided. The resonator assembly may comprise a resonator. The resonator may have a first conductive resonance post. The first conductive resonance post may be surrounded by a conductive enclosure which defines a cavity. The first conductive resonance post may filter a signal at a first frequency band. That is to say, the first conductive resonance post may resonate at a frequency within a first frequency band, thereby attenuating frequencies of the signal outside of the first frequency band. The resonator may also have a second conductive resonance post. The second conductive resonance post may be positioned or located within the cavity. The second conductive resonance post may filter a signal within a second frequency band. That is to say, the second conductive resonance post may resonate at a frequency within the second frequency band, thereby attenuating frequencies of the signal which fall outside of the second frequency band. The filtering of the signals within the first frequency band and the second frequency band may occur simultaneously or concurrently so that the filtering within the two frequency bands occurs at the same time using a single cavity. Through this approach, it is possible to provide a single device which implements more than one independent resonance or filtering at the same time within the same cavity volume, allowing significantly smaller cavity filters to be built, which avoids the need to provide separate devices, one for each frequency. This is particularly convenient in resonant assemblies used in RF front ends which will often be required to receive signals at two or more different frequency bands.

50    **[0007]**   In one embodiment, the second conductive resonance post is electrically isolated from the conductive enclosure. Hence, the second conductive resonance post fails to be electrically connected to the conductive enclosure.

55    **[0008]**   In one embodiment, the resonator assembly comprises an insulating mounting operable to retain the second conductive resonance post within the conductive enclosure. It will be appreciated that a variety of different mounting structures may be utilized to retain the conductive resonance ring element in place.

60    **[0009]**   In one embodiment, the second conductive resonance post has a length corresponding to a half-wavelength and/or less at a frequency within the second frequency band. Accordingly, the second conductive resonance post is dimensioned to have an effective electrical length of a half wavelength at a selected frequency within the second frequency band. This enables a stationary standing wave at the selected frequency to be established within the conductive enclosure

for the conductive resonance ring element. The length can be adjusted to less than a half wavelength by capacitively loading the conductive resonance post.

**[0010]** In one embodiment, the first conductive resonance post comprises an elongate member extending along a first axis and the second conductive resonance post comprises an elongate member extending along a second axis, wherein the second axis is orientated transversely to the first axis. Accordingly, the second conductive resonance post may be positioned or orientated transversely with respect to the elongate axis of the first conductive resonance post. It will be appreciated that the orientation may not need to be completely normal to the elongate axis but may also be orientated at non-normal angles.

**[0011]** In one embodiment, the second axis is orientated orthogonally to the first axis.

**[0012]** In one embodiment, the first conductive resonance post upstands from a first face of the conductive enclosure, second and third faces of the conductive enclosure upstand from the first face and the second conductive resonance post extends between the second and third faces.

**[0013]** In one embodiment, the second conductive resonance post comprises at least a portion of a ring-shaped member extending across a plane, wherein the plane is orientated transversely to the first axis.

**[0014]** In one embodiment, the plane is orientated orthogonally to the first axis.

**[0015]** In one embodiment, the at least a portion of a ring-shaped member is located concentrically with the first conductive resonance post. Accordingly, the ring-shaped member may at least partially surround the first conductive resonance post. In one embodiment, the ring-shaped member is located coaxially with the first conductive resonance post.

**[0016]** In one embodiment, the ring-shaped member comprises one of an annulus, a torus and a polyhedron. Accordingly, the ring-shaped member may comprise a portion, sector or segment of an annulus, a torus or other ring-shaped polyhedron structure.

**[0017]** In one embodiment, the first conductive resonance post is electrically connected with the conductive enclosure.

**[0018]** In one embodiment, the first conductive resonance has a length corresponding to a quarter-wavelength and/or less at a frequency within the first frequency band. Accordingly, the first conductive resonance post is dimensioned to have an effective electrical length of a quarter wavelength at a selected frequency within the first frequency band. This enables a stationary standing wave at the selected frequency to be established within the conductive enclosure for the conductive resonance post. The length can be adjusted to less than a quarter wavelength by capacitively loading the conductive resonance post.

**[0019]** In one embodiment, the frequencies within the second frequency band are greater than frequencies within the first frequency band. Accordingly, the second frequency band encompasses frequencies which are higher than the frequencies in the first frequency band.

**[0020]** In one embodiment, harmonics of the frequencies within the first frequency band fail to coincide with the frequencies within the second frequency band. By preventing the harmonics of the different frequency bands from overlapping, coupling between the conductive resonance post and the conductive ring is reduced. This helps to improve isolation between the two filtered signals. For example, 700MHz and 2100 MHz are used, the harmonics of the 700 MHz can coincide with the usable second frequency band. Also, coupling between the first frequency band elements and the second frequency band elements can occur.

**[0021]** In one embodiment, the resonator assembly comprises at least one further conductive resonance post located within the cavity and orientated transversely with respect to the first conductive resonance post, the further conductive resonance posts being operable to filter a signal within a respective frequency band concurrently with the first conductive resonance post filtering the signal within the first frequency band. Accordingly, the additional conductive resonance posts may be provided, each of which may also filter signals concurrently within associated frequency bands. This enables yet more filtering to occur within the same resonator space.

**[0022]** In one embodiment, each further conductive resonance post is operable to filter a signal within one of the second frequency band and another frequency band concurrently with the first conductive resonance post filtering the signal within the first frequency band.

**[0023]** In one embodiment, the resonator assembly comprises a plurality of the resonators adjacently located and having shared portions of the conductive enclosure, and wherein the second conductive resonance post in each resonator is orientated towards the shared portions of the conductive enclosure. Accordingly, individual resonators may be positioned together to provide a resonant assembly having desired filtering characteristics.

**[0024]** In one embodiment, the shared portions of the conductive enclosure comprise at least one aperture to facilitate coupling between adjacent resonators.

**[0025]** In one embodiment, one of the plurality of resonators comprises a first signal feed operable to convey its signal to the first resonance post of that resonator and another of the plurality of resonators comprises a second signal feed operable to convey its signal to the second resonance post.

**[0026]** 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.

**[0027]** 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

**[0028]** Embodiments of the present invention will now be described further, with reference to the accompanying drawings, in which:

Figure 1 illustrates the arrangement of a resonator assembly according to one embodiment;  
 Figure 2 illustrates the arrangement of a resonator assembly according to one embodiment;  
 Figures 3A and 3B illustrate the electric field intensity distribution at resonance;  
 Figure 4 illustrates the arrangement of coupling feeding pins used to couple signals to or from the resonator assembly;  
 and  
 Figure 5 illustrates a filter.

## DESCRIPTION OF THE EMBODIMENTS

### Overview

**[0029]** Before discussing the embodiments in any more detail, first an overview will be provided. Embodiments provide a resonator assembly having one or more resonators or filters. Each of the resonators or filters is a dual-frequency resonator or filter which is able to concurrently or simultaneously filter signals within different frequency bands. For example, in a dual-frequency arrangement, the same or different signals may be provided to the resonator and the signals are filtered to exclude or reject all but a first frequency band which passes through, whilst the same or another signal is filtered simultaneously or concurrently to exclude or reject all but another frequency band which passes through.

**[0030]** The resonator comprises a conductive enclosure within which is provided with a first conductive resonance post which filters within the first frequency band as well as a second conductive resonant post which filters within a second frequency band. The first and second conductive resonance posts may have any suitable cross-section which need not be circular. Typically, the first conductive resonance post is dimensioned to have a length which matches a quarter of the wavelength of a frequency within the first frequency band such that a standing wave is established within the structure at the selected resonant frequency. The second conductive resonance post is typically positioned away from the first conductive resonance post and orientated in a direction so that the elongate axes of the first and second conductive resonance posts are generally orthogonal in order to re-use the same space within the conductive enclosure to perform the dual-frequency filtering, which provides for a smaller and more lightweight arrangement than would be required if two different resonator or filter assemblies were provided, one for each filtering function. Typically, the second conductive resonance post is dimensioned to have a length which matches half of the wavelength of a frequency within the second frequency band such that a standing wave is established within the structure at the selected resonant frequency. This length of the second conductive resonance post provides for an improved Q-factor of the device compared to other arrangements, which significantly reduces insertion losses resulting from use of the device.

**[0031]** Hence, embodiments utilize the physical space provided by a single cavity in the combline technology to include an additional metallic cylindrical post that operates in a half-wavelength resonance at a side of the rectangular cavity (this side can be any of four; the vertical position of the high frequency post can also vary). This is to introduce an additional electromagnetic resonance at a higher frequency.

**[0032]** In embodiments where the configuration of the resonator is symmetric, the opportunity for coupling between adjacent resonators is increased, which simplifies the construction of the device and provides increased opportunities for the location of tuning mechanisms which are used to calibrate the resonance characteristics of the conductive resonance structures and control the resultant filtering characteristics.

### Resonator Configuration

**[0033]** Figure 1 illustrates the arrangement of a resonator, generally 10, according to one embodiment. An enclosure 20 is provided which defines a cavity 30. In this example, the enclosure 20 is a cuboid having six faces. However, it will be appreciated that the enclosure 20 may have any suitable configuration and may be a non-cuboid. The enclosure 20 is made of a conductive material, such as a metal, or may be made of another material which is then coated with a conductive material.

**[0034]** A first conductive resonance post 40 is provided which extends into the cavity 30 from a face of the conductive enclosure 20. The first conductive resonance post 40 is electrically connected to the conductive enclosure 20. The first conductive resonance post 40 is dimensioned to have a length b1 which corresponds with a quarter wavelength of a

frequency within the frequency band to be filtered and may have any suitable cross-section. In other words, the length  $b_1$  is selected to have an effective electrical length which corresponds to a quarter of the wavelength of a frequency within the frequency band to be filtered. A tuning screw 50 is provided which is coaxially located, aligned with an elongate access of the first conductive resonance post 40, and retained by and protruding from a face of the conductive enclosure 20. Rotation of the tuning screw 50 adjusts its length  $LS_1$  within the cavity 30, which provides for fine-tuning of the resonance frequency of the first conductive resonance post 40.

**[0035]** A second conductive resonance post 60 is provided which is placed proximate the first conductive post 40. The second conductive resonance post 60 again may be metallic or coated with a conductive coating. The second conductive resonance post 60 is dimensioned to have a length  $b_2$  which matches a half of the wavelength of a frequency within a second frequency band. Typically, the second frequency band encompasses frequencies which are higher than those of the first frequency band. In a similar manner to the first conductive resonance post 40, a tuning screw is provided (not shown) which is used to provide fine adjustment of the resonance frequency of the second conductive resonance post 60.

**[0036]** It will be appreciated that the second conductive resonance post 60 and the first conductive resonance post 40 may also be formed from dielectric high permittivity material.

**[0037]** A mounting (not shown) is provided in order to retain the second conductive resonance post 60 in place. This is typically achieved by a non-conductive pin, post or clip which mounts the second conductive resonance post 60 using either or both of a face of the conductive enclosure 20 or the conductive post 40. The second conductive resonance post 60 may be mounted on plastic and the plastic may be retained as mentioned above. For example, the plastic support could be as long as the side wall of the cavity, so that it can be mounted against the internal cavity walls. Another example is that two plastic parts are mounted against the two opposing sides of the inner cavity walls and the post is mounted within the two plastic holders.

**[0038]** Typical dimensions (in mm) of the resonator 10 are:  $2a=72$ ,  $h=120$ ,  $b_1=93$ ,  $d_1=20.4$ ,  $ls_1=13$ ,  $ds=d_1/2$ ,  $h_2=b_1/2$ ,  $d_2=7.7$ ,  $b_2=60$ .

**[0039]** Figure 2 illustrates the arrangement of a resonator, generally 10a, according to one embodiment. In this arrangement, the second conductive resonance post 60a is shown as a segment of a torus (or shaped around a circle) dimensioned to resonate at a half wavelength but it will be appreciated that other configurations are possible, such as a segment of a ring of fixed thickness (an annular ring), or even a square, rectangular, hexagonal or other (typically regular) polyhedral ring may be provided. The plane within which the second conductive resonance post 60a is orientated to be generally orthogonal to the elongate axis of the first conductive resonance post 40. This is particularly useful where the length of the second conductive resonance post 40 exceeds the width of the cavity.

**[0040]** Hence, these arrangements utilise the physical space provided by the single rectangular cavity 30 of a coaxially cavity resonator to include an additional metallic post which operates at a half-wavelength resonance at the middle of the rectangular cavity 30. It will be appreciated that the vertical position of the second conductive resonance post can be varied. Providing the second conductive resonance post introduces an additional electromagnetic resonance at a higher frequency.

**[0041]** In embodiments, additional second conductive resonance posts may be provided, each of which is positioned near the first conductive post 40. Those additional second conductive resonance posts may be dimensioned identically or differently to the second conductive resonance posts mentioned above. This enables additional frequencies to be filtered (where the second conductive resonance posts are dimensioned differently) or multiple signals to be simultaneously filtered at the same frequency (where the second conductive resonance posts are identical). Again, appropriate apertures and feeds will be provided in order to achieve a filter having the desired characteristics.

#### Operation

**[0042]** The structural arrangement of the resonator 10 undergoes two electromagnetic resonances simultaneously at two distinct frequency bands. The first conductive resonance post 40 resonates at a lower frequency band ( $f_1$ ) and the second conductive resonance post 60 resonates at a higher frequency band ( $f_2$ ). The combination of the first conductive resonance post 40 and the second conductive resonance post 60 means that the first conductive resonance post 40 and the second conductive resonance post 60 resonate at slightly different frequencies than if they were alone within the cavity 30. However, this slight change in frequency can be accommodated by the dimensioning of these structures and by the tuning screws.

**[0043]** This basic structure, therefore, is able to receive one or more signals to be filtered concurrently. For example, a signal may be provided which is coupled to the first conductive resonance post 40 which then filters that signal to reject those frequencies which are outside of its resonant frequency or its harmonics. Likewise, the same or one or more different signals may be provided to the second conductive resonance post 60 which again rejects those frequencies which are outside of its resonant frequency or its harmonics.

**[0044]** Figures 3A and 3B illustrate the electric field intensity distribution at resonance at the lower frequency (shown in Figure 3A) and at the higher frequency (Figure 3B).

### Operational Performance

**[0045]** An Eigenmode analysis tool was used to calculate the resonant frequency and Q-factor of the resonator 10. Ohmic losses are included in these simulations; aluminium was simulated for the cavity walls and copper for the first conductive resonance post 40 and the second conductive resonance post 60. The dimensions of the simulated structures are those mentioned above. Tables 1 and 2 show the results.

**Table 1 - Resonant properties of resonators according to embodiments and conventional resonators**

| Resonator                                                                            | Mode 1      |           | Mode 2      |           |
|--------------------------------------------------------------------------------------|-------------|-----------|-------------|-----------|
|                                                                                      | $f_o$ (MHz) | $Qu$ (Al) | $f_o$ (MHz) | $Qu$ (Al) |
| Case 0 - Standalone resonators for each mode                                         | 695.2       | 5590      | 2004.6      | 9894      |
| Case 1- Resonator with second conductive resonance post located at top of cavity     | 689.3       | 5596      | 1802.6      | 6020      |
| Case 2 - Resonator with second conductive resonance post located at middle of cavity | 693.3       | 5440      | 1765.0      | 6130      |
| Case 3 - Resonator with second conductive resonance post located at bottom of cavity | 699.2       | 5343      | 1937.1      | 5253      |

**Table 2 - Resonant properties of resonators according to embodiments**

| Resonator       | Mode 1 - Standalone |           | Mode 2 - Dual Frequency |           |
|-----------------|---------------------|-----------|-------------------------|-----------|
|                 | $f_o$ (MHz)         | $Qu$ (Al) | $f_o$ (MHz)             | $Qu$ (Al) |
| Case 1- Top     | 1795.3              | 6000      | 1802.6                  | 6020      |
| Case 2 - Middle | 1752.24             | 6209      | 1765.0                  | 6130      |
| Case 3 - Bottom | 1915.77             | 5221      | 1937.1                  | 5253      |

**[0046]** Table 1 and Table 2: Resonant properties for the first 2 eigenmodes of the standalone low-band cavity, and combined low plus high-band cavity. Table 2 summarizes the resonant properties of the dual-frequency cavity when the position of the high frequency post is varied. In other words, case 0 summarizes the resonant properties for a conventional resonant device having a single conductive resonance post dimensioned to resonate at around 700MHz (mode 1) and another conventional resonant device having a single conductive resonance post dimensioned to resonate at around 2GHz (mode 2), whereas cases 1 - 3 summarize the resonant properties for a resonant device of embodiments having a first conductive resonance post dimensioned to resonate at around 700MHz (mode 1) simultaneously with a second conductive resonance post dimensioned to resonate at around 2GHz.

**[0047]** The results demonstrate that two resonant modes can be supported with these arrangements that closely correspond to the resonant modes of the individual standalone resonator modes of the low-band and high-band resonators. This is demonstrated in Figure 3 where the EM electric field intensity distribution for the two frequencies is shown. Tables 1 and 2 summarize the resonant performance of the standalone low-band coaxial cavity resonator, and dual-frequency resonator according to embodiments. The Q-factor of the low-frequency resonance is slightly decreased (by 2.7 %). The high-frequency resonance Q-factor is increased significantly (6000 is reported). This is due to the greater electrical size of the host cavity and the larger area that energy is stored as compared to previous arrangements. It is to be noted that the first harmonic resonance frequency of the standalone low-band resonator is not significantly affected by the inclusion of the high-band metallic post, thus does not create problems to the high-band resonance of the dual frequency coaxial cavity resonator.

**[0048]** One limitation of this arrangement is that the ratio of the low and high frequencies cannot be close to unity (i.e., the two frequencies cannot be very similar) since under those circumstances the resonance of the two structures will begin to interact and cannot be decoupled as required for the distinct filtering functions to be achieved.

### Signal Feed

**[0049]** Figure 4 illustrates the arrangement of coupling feeding pins used to couple signals to or from the first conductive resonance post 40 and the second conductive resonance post 60. As can be seen in Figure 4A, a capacitive coupling 70 is provided to couple the signal to the first conductive resonance post 40. Likewise, a capacitive coupling 80 is provided to couple the signal to the second conductive resonance post 60. As shown in Figure 4B, in an alternative configuration,

a direct coupling 90 is provided to couple the signal to the first conductive resonance post 40.

### High Order Filter

**[0050]** In order to produce a high order filter with the required filtering characteristics, a plurality of resonators may be arranged together, as shown in Figure 5. As can be seen, four resonators are provided which are arranged adjacent to each other. A first resonator 10B comprises an arrangement similar to that described above, with a first conductive resonance post 40 together with a second conductive resonance post 60. A capacitive feed 70 couples with the first conductive resonance post 40, whilst a capacitive feed 80 couples with the second conductive resonance post 60. A tuning screw (not shown) is provided to control the resonant frequency of the first conductive resonance post 40, whilst a tuning screw 110 is provided for controlling the resonant frequency of the second conductive resonance post 60.

**[0051]** Another resonator 10B' is provided which has a mirror configuration to that of resonator 10B.

**[0052]** Interposed between resonators 10B and 10B' are two resonators 10C. These are of identical configuration to the resonators 10A and 10A', but without the couplings 70 and 80.

**[0053]** Apertures (not shown) are formed in the walls of the conductive enclosure to facilitate electromagnetic coupling between adjacent resonators.

**[0054]** In operation, a signal can be provided to one of the two capacitive feeds 80 and a filtered signal is provided by the other. The signal couples from the capacitive feed 80 into the adjacent second conductive resonance post 60 and this induces resonance in the second conductive resonance post 60 of the adjacent resonator 10C, which induces resonance in the second conductive resonance post 60 of the adjacent resonator 10C, which induces resonance in the second conductive resonance post 60 of the adjacent resonator 1BA' and a filtered signal is provided out of the capacitive feed 80.

**[0055]** Likewise, a signal may be provided via the capacitive feed 70 to the first conductive resonance post 40 and a filtered signal is provided by the other capacitive feed 70.

**[0056]** It will be appreciated that the filter may be bi-directional, in that the signal may be fed into either coupling and the filtered signal obtained from the other coupling. This arrangement enables simultaneous filtering at two frequency bands to be achieved either on the same or different signals.

**[0057]** In more complex arrangements, it is possible to provide the couplings for the different frequencies in the cavity of different resonators helps to improve the isolation or decoupling between the resonators.

**[0058]** Hence, it can be seen that these arrangements enable two electromagnetic resonances to be achieved concurrently at distinct frequencies in a single physical volume within a single metallic enclosure using coaxial cavity filter technology. In embodiments, two EM resonances are created at distinct frequencies,  $f_1$  (low frequency) and  $f_2$  (high frequency) that largely correspond to the centre metallic quarter-wavelength post and half-wavelength metallic post, respectively. The centre metallic post within the rectangular metallic cavity with the high frequency metallic post is resonating at a frequency  $f_1$  (slightly different than the standalone centre metallic post within the cavity), whereas the metallic post for high frequency within the cavity with the metallic post at the centre is resonating at a higher desired frequency  $f_2$  ( $f_2 > f_1$ ). Due to the distinct and separated in spectrum resonances at  $f_1$  and  $f_2$  for a dual-resonance cavity, the high frequency metallic post physical size is a fraction of the centre's metallic post size.

**[0059]** Hence, it can be seen that these arrangements provide for a reduced physical size compared to providing two sets of filters, one for each frequency, since the two distinct resonant frequencies can co-exist within the same resonator at the expense of slightly higher manufacturing costs and design complexity. Arrangements support very high Q-factor filtering at the high frequency, which helps to minimise insertion losses. This arrangement provides for cost reduction compared to the cost of the design and fabrication of two separate filters. Also, size reduction is achieved since no additional physical space is required for a second filter. Instead, the two filters can be incorporated into the space already used for the low frequency filtering.

**[0060]** Further, these arrangement provide the following benefits and advantages:

1. Cost reduction. The additional cost of design and fabrication (in same or other implementation technology, e.g., microstrip) for two separate high frequency filters as compared to the proposed solution is significantly higher.
2. Size reduction. No additional physical space is required for the second high frequency filter (f2). It can be incorporated in the low band resonant structure (at f1) without any additional physical space requirement.
3. High Q-factor (at f2) with no additional physical space. The additional physical space of the combined resonant structure allows for increase in the quality factor at the high frequency regime (f2). This can allow for high performance filtering; required for narrow-band filter wireless telecommunication applications. The quality factors of the high frequency resonant structures are higher (represent lower ohmic losses) as compared with the standalone high filtering quality factors in the conventional filtering solution.
4. In the conventional coaxial cavity technology, to achieve the two filtering functions two distinct physical cavities are required. A cavity is required to support the high frequency, f2. This cavity is conventional in the same technology

substantially smaller than the cavity at  $f_1$ . Thus, and due to the fact that additional physical space is inherent to the new resonant structure (as compared to the conventional case) at the high frequency, increase in the high power handling capabilities for terrestrial communication systems can be pursued.

**[0061]** Advantages as compared to an arrangement of dual quarter wavelength conductive resonant posts within the same cavity:

1. Increased Q-factor and thus minimized ohmic loss for the high frequency filtering (as high as 40 %). This is due to the fact that equal amount of electromagnetic energy is stored in larger physical area (volume).
2. Symmetric topology. This can support topologies (physical structural configuration of the resonant cavities) for high order filters due to the fact that it is feasible to couple simultaneously on all sides of the cavity as opposed to prior art (i.e., grounded post at the corner of the rectangular cavity).
3. Enhanced coupling capability. It allows to couple simultaneously from all sides of a single cavity to the neighbouring cavities. Does not require additional coupling elements (e.g., coupling wires).
4. It involves tuning screws that are easier to realize since the metallic post is exposed simultaneously to all of the neighbouring cavities.
5. Enhanced flexibility of achieving independent control of coupling for the two distinct filtering functions when we utilize a dual-slot de-coupling iris.
6. It is easier to physically realize this dual-frequency resonance in a circular cavity. This is due to the fact that the high frequency post in the former case is placed at a corner of the rectangular cavity. There is physical space limitation when the cavity is of circular cross section.
7. Improved power handling. This is due to the fact that the energy stored at  $f_2$  in the new structure is stored at a greater physical volume thus minimizing the risks for high power discharge phenomena.

**[0062]** 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.

**[0063]** 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.

**[0064]** 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.

**[0065]** 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:

5 a resonator having a first conductive resonance post surrounded by a conductive enclosure defining a cavity, said first conductive resonance post being operable to filter a signal within a first frequency band, and a second conductive resonance post located within said cavity and orientated transversely with respect to said first conductive resonance post, said second conductive resonance post being operable to filter a signal within a second frequency band concurrently with said first conductive resonance post filtering said signal within said first frequency band.

2. The resonator assembly of claim 1, wherein said second conductive resonance post is electrically isolated from said conductive enclosure.

15 3. The resonator assembly of claim 1 or 2, wherein said second conductive resonance post has a length corresponding to no more than a half-wavelength at a frequency within said second frequency band.

4. The resonator assembly of any preceding claim, wherein said first conductive resonance post comprises an elongate member extending along a first axis and said second conductive resonance post comprises an elongate member extending along a second axis, wherein said second axis is orientated transversely to said first axis.

5. The resonator assembly of any preceding claim, wherein said second conductive resonance post comprises at least a portion of a ring-shaped member extending across a plane, wherein said plane is orientated transversely to said first axis.

6. The resonator assembly of claim 5, wherein said ring-shaped member comprises one of an annulus, a torus and a polyhedron.

7. The resonator assembly of any preceding claim, wherein said first conductive resonance post is electrically connected with said conductive enclosure.

8. The resonator assembly of any preceding claim, wherein said first conductive resonance has a length corresponding to a quarter-wavelength and/or less at a frequency within said first frequency band. The length can be adjusted to less than a quarter wavelength by capacitively loading the conductive resonance post.

9. The resonator assembly of any preceding claim, wherein said frequencies within said second frequency band are greater than frequencies within said first frequency band.

10. The resonator assembly of any preceding claim, wherein harmonics of said frequencies within said first frequency band fail to coincide with said frequencies within said second frequency band.

11. The resonator assembly of any preceding claim, comprising at least one further conductive resonance post located within said cavity and orientated transversely with respect to said first conductive resonance post, said further conductive resonance posts being operable to filter a signal within a respective frequency band concurrently with said first conductive resonance post filtering said signal within said first frequency band.

12. The resonator assembly of claim 11, wherein each further conductive resonance post is operable to filter a signal within one of said second frequency band and another frequency band concurrently with said first conductive resonance post filtering said signal within said first frequency band.

13. The resonator assembly of any preceding claim, comprising a plurality of said resonators adjacently located and having shared portions of said conductive enclosure, and wherein said second conductive resonance post in each resonator is orientated towards said shared portions of said conductive enclosure.

14. The resonator assembly of claim 13, wherein said shared portions of said conductive enclosure comprise at least one aperture to facilitate coupling between adjacent resonators.

15. The resonator assembly of claim 13 or 14, wherein one of said plurality of resonators comprises a first signal feed

operable to convey its signal to said first resonance post of that resonator and another of said plurality of resonators comprises a second signal feed operable to convey its signal to said second resonance post.

5 **Amended claims in accordance with Rule 137(2) EPC.**

1. A resonator assembly, comprising:

10 a resonator (10; 10B; 10B'; 10C') having a first conductive resonance post (40) surrounded by a conductive enclosure (20) defining a cavity (30), said first conductive resonance post being operable to filter a signal within a first frequency band, and a second conductive resonance post (60; 60A) located within said cavity and orientated transversely with respect to said first conductive resonance post, said second conductive resonance post being operable to filter a signal within a second frequency band concurrently with said first conductive resonance post filtering said signal within said first frequency band, wherein harmonics of said frequencies within said first frequency band fail to coincide with said frequencies within said second frequency band.

2. The resonator assembly of claim 1, wherein said second conductive resonance post is electrically isolated from said conductive enclosure.

20 3. The resonator assembly of claim 1 or 2, wherein said second conductive resonance post has a length corresponding to no more than a half-wavelength at a frequency within said second frequency band.

4. The resonator assembly of any preceding claim, wherein said first conductive resonance post comprises an elongate member extending along a first axis and said second conductive resonance post comprises an elongate member extending along a second axis, wherein said second axis is orientated transversely to said first axis.

5. The resonator assembly of any preceding claim, wherein said second conductive resonance post comprises at least a portion of a ring-shaped member (60A) extending across a plane, wherein said plane is orientated transversely to said first axis.

6. The resonator assembly of claim 5, wherein said ring-shaped member comprises one of an annulus, a torus and a polyhedron.

7. The resonator assembly of any preceding claim, wherein said first conductive resonance post is electrically connected with said conductive enclosure.

8. The resonator assembly of any preceding claim, wherein said first conductive resonance has a length corresponding to a quarter-wavelength and/or less at a frequency within said first frequency band.

9. The resonator assembly of any preceding claim, wherein said frequencies within said second frequency band are greater than frequencies within said first frequency band.

10. The resonator assembly of any preceding claim, comprising at least one further conductive resonance post located within said cavity and orientated transversely with respect to said first conductive resonance post, said further conductive resonance posts being operable to filter a signal within a respective frequency band concurrently with said first conductive resonance post filtering said signal within said first frequency band.

11. The resonator assembly of claim 10, wherein each further conductive resonance post is operable to filter a signal within one of said second frequency band and another frequency band concurrently with said first conductive resonance post filtering said signal within said first frequency band.

12. The resonator assembly of any preceding claim, comprising a plurality of said resonators adjacently located and having shared portions of said conductive enclosure, and wherein said second conductive resonance post in each resonator is orientated towards said shared portions of said conductive enclosure.

13. The resonator assembly of claim 12, wherein said shared portions of said conductive enclosure comprise at least one aperture to facilitate coupling between adjacent resonators.

- 14.** The resonator assembly of claim 12 or 13, wherein one of said plurality of resonators comprises a first signal feed operable to convey its signal to said first resonance post of that resonator and another of said plurality of resonators comprises a second signal feed operable to convey its signal to said second resonance post.

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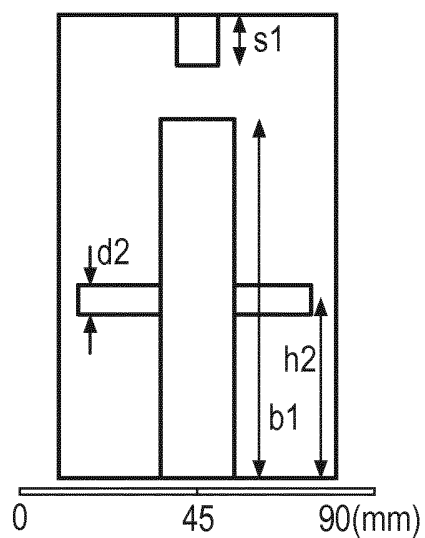
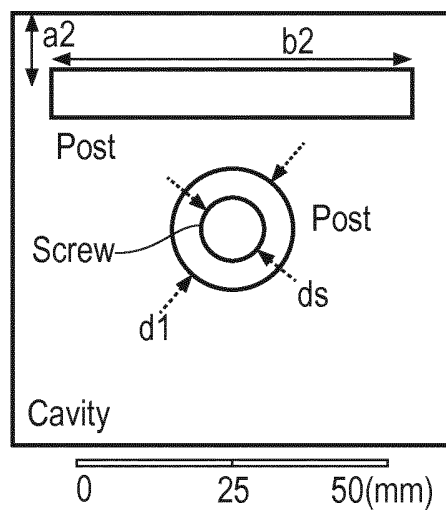
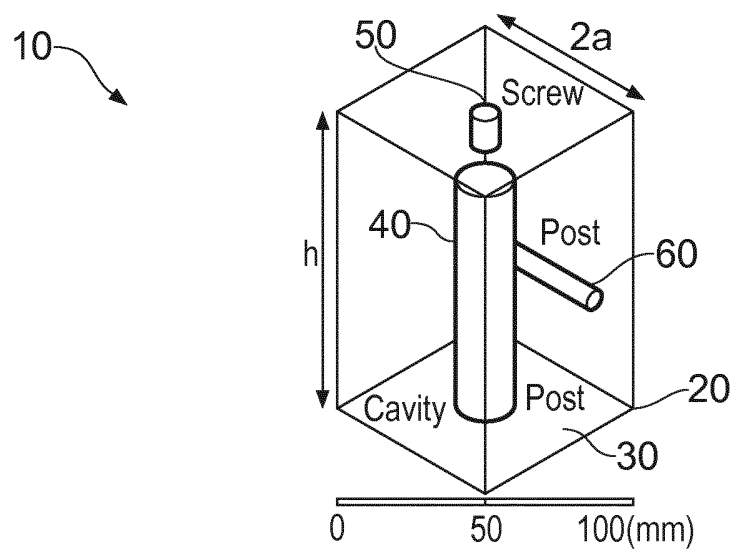


FIG. 1

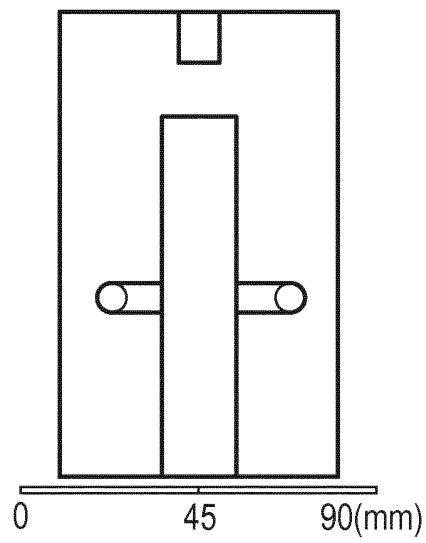
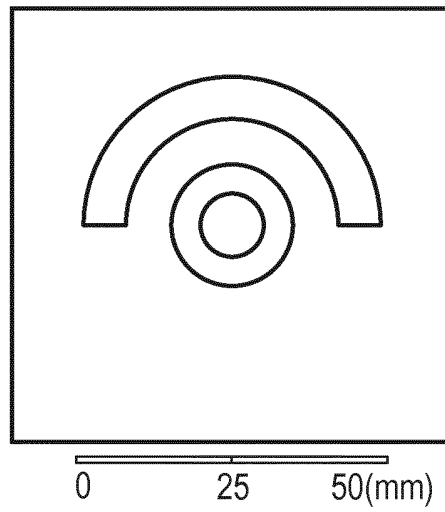
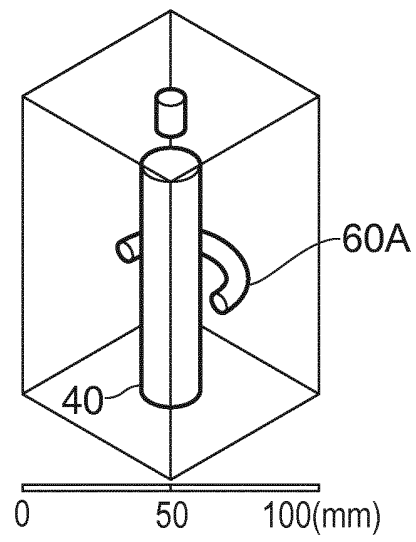


FIG. 2

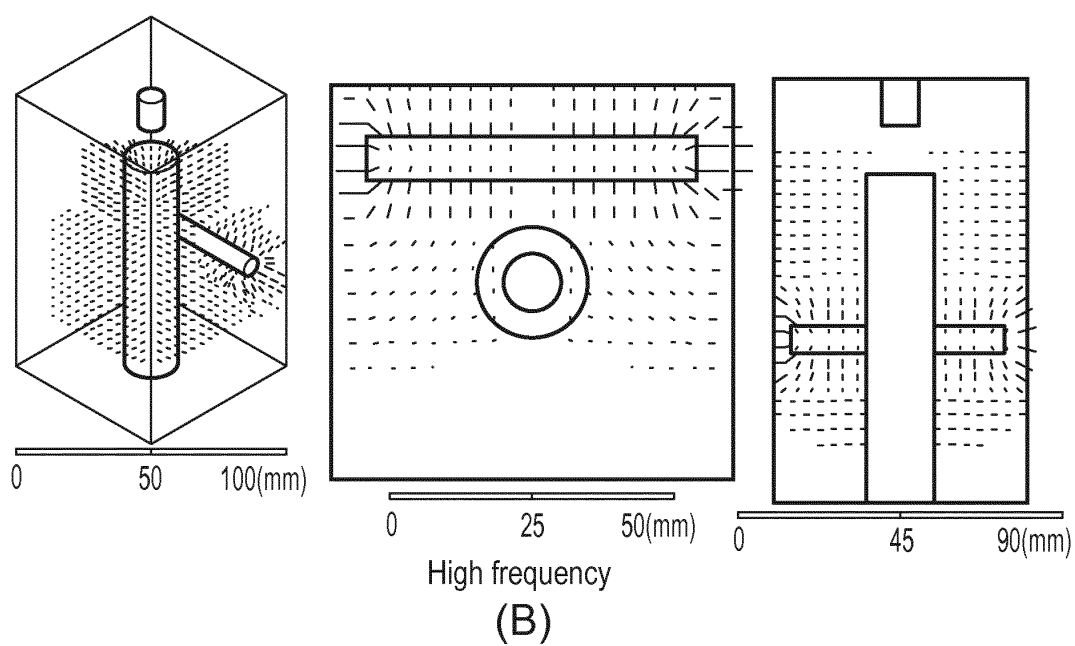
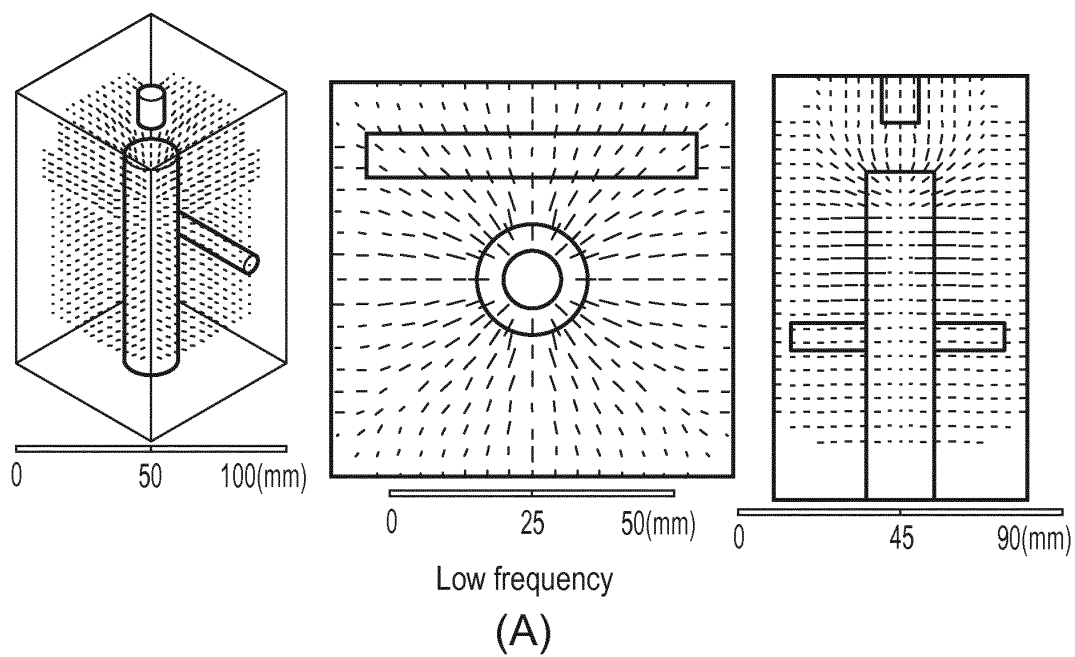
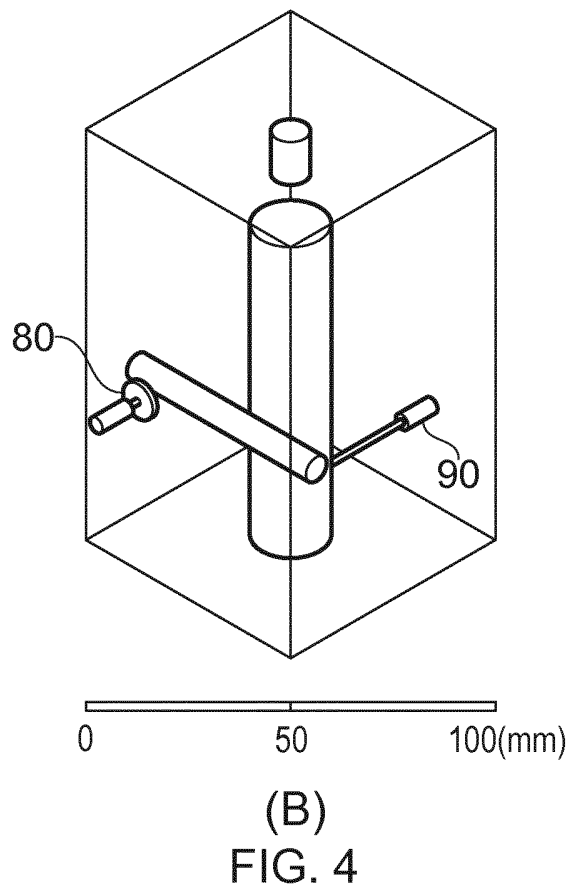
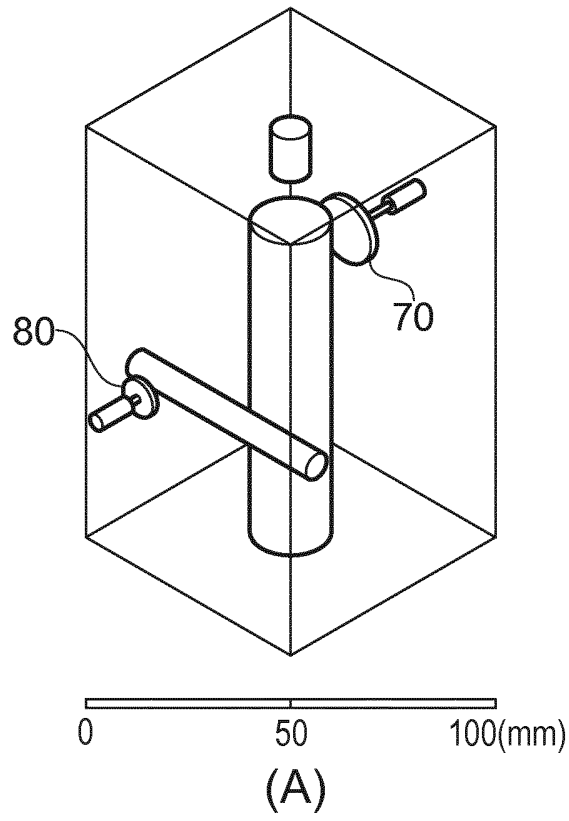


FIG. 3



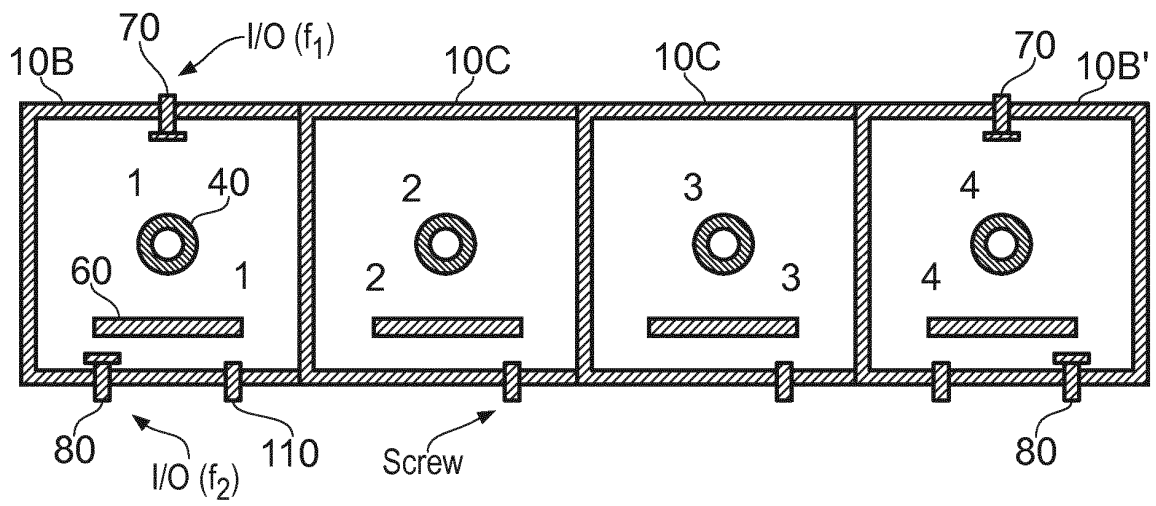


FIG. 5



## EUROPEAN SEARCH REPORT

Application Number  
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| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                   |                                                |                                         |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|-----------------------------------------|
| Category                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Citation of document with indication, where appropriate, of relevant passages                                                                                                     | Relevant to claim                              | CLASSIFICATION OF THE APPLICATION (IPC) |
| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | WO 2009/067056 A1 (ERICSSON TELEFON AB L M [SE]; LINDELL PATRIK [SE])<br>28 May 2009 (2009-05-28)                                                                                 | 1-4,7-15                                       | INV.<br>H01P1/205<br>H01P7/04           |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | * page 5, line 8 - page 7, line 3; figure 1 *                                                                                                                                     | 5,6                                            |                                         |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | -----<br>US 7 327 210 B2 (BLAIR BILL [US] ET AL)<br>5 February 2008 (2008-02-05)<br>* column 3, line 26 - column 4, line 17; figure 2 *                                           | 5,6                                            |                                         |
| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | -----<br>WO 2010/033057 A1 (ERICSSON TELEFON AB L M [SE]; MEDELIUS HANNES [SE]; SCHOEN LENNART [SE]) 25 March 2010 (2010-03-25)<br>* page 5, line 9 - page 6, line 10; figure 1 * | 1                                              |                                         |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | -----<br>WO 2009/056813 A1 (RADIO DESIGN LTD [GB]; SLEIGH PHILIP DAVID [GB]; PHILLIPS ELIZABETH FR) 7 May 2009 (2009-05-07)<br>* page 15, line 7 - page 16, line 13; figure 3b *  | 1-15                                           |                                         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                   |                                                | TECHNICAL FIELDS SEARCHED (IPC)         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                   |                                                | H01P                                    |
| The present search report has been drawn up for all claims                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                   |                                                |                                         |
| Place of search<br>Munich                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                   | Date of completion of the search<br>6 May 2014 | Examiner<br>La Casta Muñoa, S           |
| CATEGORY OF CITED DOCUMENTS<br>X : particularly relevant if taken alone<br>Y : particularly relevant if combined with another document of the same category<br>A : technological background<br>O : non-written disclosure<br>P : intermediate document<br>T : theory or principle underlying the invention<br>E : earlier patent document, but published on, or after the filing date<br>D : document cited in the application<br>L : document cited for other reasons<br>& : member of the same patent family, corresponding document |                                                                                                                                                                                   |                                                |                                         |

EPO FORM 1503 03.82 (P04C01)

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ON EUROPEAN PATENT APPLICATION NO.**

EP 14 30 5033

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The members are as contained in the European Patent Office EDP file on  
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06-05-2014

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