(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 179 552 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
14.06.2017 Bulletin 2017/24

(51) Int Cl.:
H01P 1/202 *(2006.01)* ***H01P 1/205*** *(2006.01)*

(21) Application number: **15306969.5**

(22) Date of filing: **10.12.2015**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD

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Remarks:
Amended claims in accordance with Rule 137(2) EPC.

(54) A RESONATOR ASSEMBLY, A RADIO FREQUENCY FILTER AND A METHOD OF RADIO-FREQUENCY FILTERING

(57) A resonator assembly is provided comprising a resonant chamber, each chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which the resonator chamber houses two or more resonators, each resonator comprising a first cylinder grounded on one of the first and second walls and extending into the chamber, and a second cylinder which is coaxial with the first cylinder and grounded on the other of the first and second walls and extending into the chamber; a first set of the resonators having their respective first cylinders grounded on the first wall and their respective second cylinders grounded on the second wall; a second set of the resonators having their respective first cylinders grounded on the second wall and their respective second cylinders grounded on the first wall; wherein each resonator of the first set is for magnetic field coupling in proximity with at least one resonator of the second set.

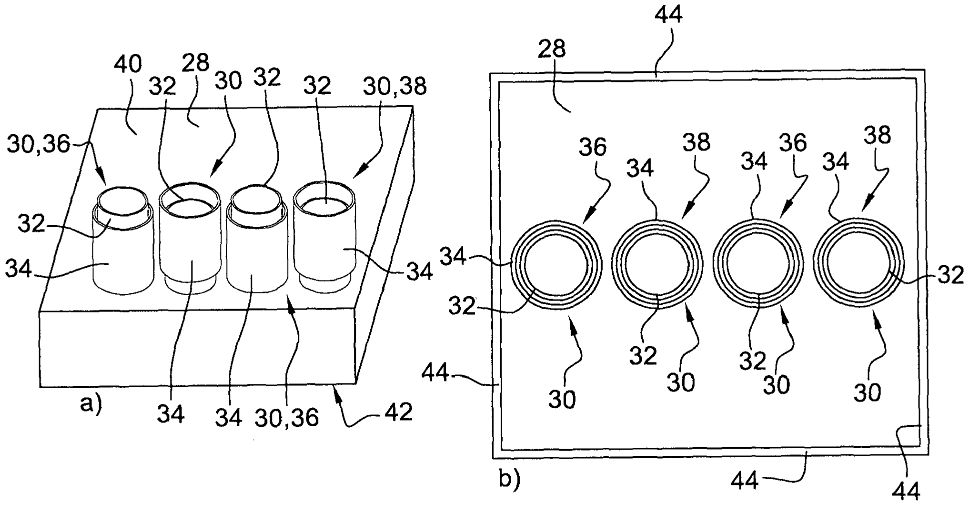

Fig. 5

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Description

Field of the Invention

[0001] The present invention relates to a resonator assembly for telecommunications, in particular for radio-frequency filters, and to a method of radio frequency filtering.

Description of the Related Art

[0002] Filters are widely used in telecommunications. Applications include base stations for wireless cellular communications, radar systems, amplifier linearization systems, point-to-point radio, and RF signal cancellation systems, to name just a few. Although a specific filter is chosen or designed dependent on the particular application, it is generally desirable for a filter to have low insertion loss in the pass-band and high attenuation in the stop-band. Furthermore, in some applications, the frequency separation (known as the guard-band) between stop-band and pass-band needs to be small, so a filter of a high order is required. Of course as the order of a filter increases, so does its complexity in terms of the number of components the filter requires and hence the filter's size. Furthermore, although increasing the order of a filter increases stop-band attenuation, insertion loss in the pass-band is also thereby increased (see for example the book by J.S. Hong and M.J. Lancaster entitled "Microstrip Filters for RF/Microwave Applications", John Wiley & Sons, ISBN: 0-471-38877-7, 2001).

[0003] One of the challenging tasks in filter design is how to reduce their size ('miniaturization') but retain good electrical performance. One of the main parameters governing a filter's sensitivity and insertion loss is the so-called quality factor ("Q-Factor" or "Q") of the elements making up the filter. The Q-factor is defined as the ratio of energy stored in the element to the time-averaged power loss. For lumped elements that are used especially at low radiofrequencies in filter design, Q is typically in the range of about 60 to 100. For cavity-type resonators, Q is higher and can be as high as several thousands.

[0004] Although lumped components enable significant miniaturization their low Q prohibits their use in applications where high rejection and or selectivity are required.

[0005] On the other hand, cavity resonators offer sufficient Q but their relatively large size prevents their use in many applications.

[0006] The miniaturization problem is especially pressing with the advent of small cell base stations, where the volume of the base station should be minimal, since it is important the base station be as inconspicuous as possible (as opposed to an eyesore). As regards larger more powerful base stations, there is a trend in macrocell base stations towards multiband solutions within a similar mechanical housing to that of previous single-band solutions, so filter miniaturization without sacrificing system performance is becoming important for macrocell base stations too.

[0007] Several known solutions exist. For lower performance requirements, ceramic mono-block filters with external metallization are used. They offer significant size reduction but have a relatively low Q of a few 100's (up to 500), which is too low for many applications. Additionally, the small size of the filters prevents their use in high-power applications, due to relatively high insertion losses and rather limited power-handling capabilities.

[0008] Another type of known filters is filters with ceramic resonators. Like mono-block filters, they also offer significant size reductions. Furthermore, these filters offer power-handling capabilities that are much higher than those of mono-block filters. However, cost is the main prohibiting factor for wider deployment of these filters.

[0009] Yet another type of known filters is filters made up of resonant cavity chambers that include resonators. These often have multiple resonant cavity chambers connected together in a series so are often know as comb-line filters. In high-power applications, such as those found in mobile cellular communication base stations, there is no real practical alternative to these filters. However it is believed that the relatively large size of cavity filters is the principle factor which limits their widespread use.

Summary

[0010] The reader is referred to the appended independent claims. Some preferred features are laid out in the dependent claims.

[0011] An example of the present invention is a resonator assembly comprising a resonant chamber, each chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which
the resonator chamber houses two or more resonators,
each resonator comprising a first cylinder grounded on one of the first and second walls and extending into the chamber, and a second cylinder which is coaxial with the first cylinder and grounded on the other of the first and second walls and extending into the chamber;
a first set of the resonators having their respective first cylinders grounded on the first wall and their respective second

cylinders grounded on the second wall;
a second set of the resonators having their respective first cylinders grounded on the second wall and their respective second cylinders grounded on the first wall;
wherein each resonator of the first set is for magnetic field coupling in proximity with at least one resonator of the second set.

[0012] Some embodiments provide low -profile miniaturised coaxial distributed resonators, being distributed in the sense that the resonator comprises both a first cylinder and a second cylinder.

[0013] Some embodiments provide size reduction as compared to the known approaches and provide an increase of the Q-factor for the same cavity size.

[0014] Some embodiments minimize the physical size and profile of cavity resonators/ filters (that can offer the high Q) so provide a low-profile suitable for use, for example, in small cell base stations.

[0015] Some embodiments address two significant problems of cavity filters, i.e. the filter cavity size and the frequency-tunable range of the filter. Some embodiments simultaneously provides for (A) reduced physical dimensions of cavity filters and (B) an extended frequency-tunable range of cavity filters. Both qualities are valued in industrial applications.

[0016] Regarding (A), filters are typically the bulkiest and heaviest subsystems in mobile cellular base stations, rivaled only by power-amplifier heatsinks. Therefore filter miniaturization is always desired.

[0017] Regarding (B), a typical envisioned application scenario includes a mobile cellular operator, who has a definite plan to transition his services to a different frequency band sometime in the future, procuring cavity filters for his base stations. If the operator purchases conventional filters, the operator will have to purchase a second set of filters when he decides to transition to the new frequency band. In contrast, some embodiments altogether eliminate the need to purchase the second set of filters, by providing for simple retuning of filters. In another application scenario, network providers and manufacturers of mobile cellular base stations tend to stockpile cavity filters, rather than procure them in a built-to-order fashion. Retunability of stockpiled filters without the need to open the filter up is valued.

[0018] Some embodiments enhances performance and provides a suitable, practical means to reduce the size without compromising frequency tunability and performance.

[0019] Some embodiments exploit unique electromagnetic characteristics that arise when combline resonators are appropriately placed in the vicinity of each other.

[0020] Preferably in each resonator the first cylinder is an inner cylinder and the second cylinder is an outer cylinder lying coaxially such that along part of their lengths the first cylinder and the second cylinder overlap.

[0021] Preferably the resonators are disposed in a line.

[0022] Preferably resonators are disposed in a grid configuration. Preferably, the grid configuration is a rectangle or square or circle. Preferably, along a row or column of the grid, between two resonators of one of the first set and the second set, a resonator is provided of the other of the first set and the second set.

[0023] Preferably the resonators alternate along a line, column or row such that one has its inner cylinder grounded on the top wall and outer cylinder grounded on the bottom wall and the next along the line, column or row has its inner cylinder grounded on the bottom wall and outer cylinder grounded on the top wall.

[0024] Preferably the line, column or row is at least partially curved or circular.

[0025] Preferably the resonators of the first set are in an inter-digitated configuration with the resonators of the second set.

[0026] Preferably a tuning screw is provided through one of the first wall and second wall having an adjustable insertion length into the cavity. Preferably the tuning screw is disposed through a central position on said one of the first wall and second wall.

[0027] Preferably for each resonator a corresponding resonator post is provided grounded on one of the first wall and the second wall and extending along the central longitudinal axis of the respective first and second cylinders.

[0028] Preferably each resonator post is of adjustable insertion length into the cavity.

[0029] Examples of the present invention also relates to corresponding filter and method of filtering.

[0030] An example of the present invention relates to a radio frequency filter comprising at least one resonator assembly as indicated above.

[0031] An example of the present invention relates to a method of radio frequency filtering comprising passing a signal for filtering through at least one resonator assembly, each resonator assembly comprising a resonant chamber, each chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which
the resonator chamber houses two or more resonators;
each resonator comprising a first cylinder grounded on one of the first and second walls and extending into the chamber and a second cylinder which is coaxial with the first cylinder and grounded on the other of the first and second walls and extending into the chamber;
a first set of the resonators having their respective first cylinders grounded on the first wall and their respective second cylinders grounded on the second wall;
a second set of the resonators having their respective first cylinders grounded on the second wall and their respective

second cylinders grounded on the first wall;
wherein each resonator of the first set is for magnetic field coupling in proximity with at least one resonator of the second set.

Brief Description of the Drawings

[0032] Embodiments of the present invention will now be described by way of example and with reference to the drawings, in which:

Figure 1 is a diagram illustrating a known resonant chamber including stepped -impedance resonator (PRIOR ART),
Figure 2 is a diagram illustrating (a) perspective view and (b) cross-sectional view of a resonant chamber in which multiple (in this case nine) resonators are disposed in a grid configuration (ALTERNATIVE PROPOSAL)
Figure 3 is a diagram illustrating (a) perspective view and (b) cross-sectional view of a resonant chamber in which there is a single distributed resonator consisting of an inner cylinder and an outer cylinder (ALTERNATIVE PROPOSAL)
Figure 4 is the equivalent circuit of the single distributed resonator shown in Figure 3 (ALTERNATIVE PROPOSAL),
Figure 5 is a diagram illustrating a perspective view and cross-sectional view of an example resonant chamber according to a first embodiment of the present invention including four distributed resonators arranged in a line,
Figure 6 is a diagram illustrating a generalised equivalent circuit for multiple distributed resonators in a resonant chamber, one example of which is shown in Figure 5,
Figure 7 is a diagram illustrating a perspective view and cross-sectional view of an example resonant chamber according to a second embodiment of the present invention including four distributed resonators arranged in a grid, which is sometimes referred to as in a folded fashion, including a main tuning screw between the four distributed resonators,
Figure 8 is a diagram illustrating a perspective view and cross-sectional view of an example resonant chamber according to a third embodiment of the present invention including nine distributed resonators arranged in grid, sometimes referred to as in a folded fashion,
Figure 9 is a diagram illustrating a perspective view and cross-sectional view of an example resonant chamber according to a fourth embodiment of the present invention including nine distributed resonators arranged in a circular folded fashion, and
Figure 10 is a diagram illustrating a filter made up of three resonant chambers each including nine distributed resonators arranged in a grid.

Detailed Description

[0033] When considering the known system shown in Figure 1, the inventors realised that the known approach to seeing to reduce size of resonant cavities used in combline filters is to add a capacitive cap 2 to a resonator 4 within the resonant cavity chamber 6. This increase the diameter of the resonator's top end 8 so as to provide a greater electrical loading and hence reduce the frequency of operation. Unfortunately, however this approach reduces the Q factor.
[0034] Moving away from the known approach, the inventors considered an alternative proposal which is shown in Figure 2, in which multiple resonators 10, each of which is a rod, are arranged so as to extend along parallel axes from the top 12 or bottom 14 of the resonant cavity chamber 16.
[0035] This is a "so-called" folded arrangement of nine individual resonators, where each element is standard 90 degree long rod. Considering this resonator configuration, the inventors realised that a useful question is whether better performing resonators can be provided that give a greater level of miniaturization.
[0036] More specifically, the inventors realised that the effect of multiple resonators is further enhanced when the multiple resonators are arranged in a folded (i.e. grid) configuration, as shown in Fig. 2, for example as compared to along a line (be it straight or circular). Incidentally, considering the alternative proposal shown in Figure 2, the inventors realised when arranging the rod resonators in a linear or curvilinear fashion, the resonator effect is stronger when the number of resonators is kept small.
[0037] The inventors considered another alternative proposal which is shown in Figure 3.
[0038] In this alternative approach, within a resonant chamber 18 a distributed resonator 18 is provided consisting of an inner cylinder 20 and an outer cylinder 22. The two cylinders 20,22 are concentric, and at least a portion of the inner cylinder 20 lies within the outer cylinder 22. One of the cylinders 20,22 extends from the top wall 24 of the chamber 18 into the chamber, the other of the cylinders 22,20 extends from the bottom wall 26 of the chamber 18 into the chamber. The equivalent circuit is shown in Figure 4 for this arrangement shown in Figure 3.
[0039] The inventors realised that making each resonator a distributed resonator of a lower order (2 in the example shown in Figure 3, in other words for example consisting of two cylinders), the inventors realised an enhanced minia-

turisation effect is obtained without deterioration of the Q factor.

[0040] The inventors realised that the alternative approaches shown in Figure 2 and Figure 3 could be usefully combined.

Linear Configuration Example

[0041] As shown in Figure 5, within a resonant chamber 28 four resonators 30 are provided. Each of these resonators is a distributed resonator, distributed in the sense that each consists of two elements, namely an inner cylinder 32 and an outer cylinder 34. The inner cylinder 32 and outer cylinder 34 are coaxial and hollow.

[0042] The four distributed resonators are disposed along a notional line within the chamber 28 (so can be consider to be in a linear configuration) and are disposed along the line so as be alternating between a first configuration 36 and second configuration 38. In the first configuration 36 the inner cylinder extends from the top wall 40 of the chamber 26 and the outer cylinder extends from the bottom wall 42 of the chamber 28. In the second configuration 38 the inner cylinder 32 extends from the bottom wall 42 of the chamber 26 and the outer cylinder 34 extends from the top wall 40 of the chamber 28. The resonant chamber 28 of course also includes side walls 44, and a cavity defined by the top wall 40, bottom wall 42 and side walls 44 within which the resonators 30 are disposed.

[0043] In some other embodiments (not shown) a different number of distributed resonators is provided in the resonant chamber.

[0044] The equivalent circuit of the resonant chamber shown in Figure 5 is shown in a generalised form in Figure 6. Figure 6 is the equivalent circuit for the resonant chamber having *n* distributed resonators where *n* is three or more. (In the Figure 5 example *n* is 4).

[0045] The inventors realised that it was possible to replace the rod resonators shown in Figure 2 with multiple distributed resonators, one of which is shown in Figure 3.

[0046] The resultant composite resonator (made of the multiple distributed resonators) can be denoted as $R_{n,m}$ where n stand for the number of cylinders in each individual distributed resonator and m stands for the number of distributed resonators in the chamber. Using this notation, the composite resonator shown in Figure 5 is $R_{2,4}$.

[0047] As shown in Figure 5 and Figure 6, not only are the individual resonators are distributed resonators, but multiple distributed resonators 30 are provided. In particular, as shown in Figure 5, the individual distributed resonator 30 is of second order, i.e. the individual distributed resonator consists of two resonator elements 32,34 coupled together, namely the inner cylinder 32 and the outer cylinder 34.

Folded Configuration (Grid)

[0048] It was realised that a greater level of miniaturisation is achievable by providing the distributed resonators in a folded form as shown in Figure 7.

[0049] As shown in Figure 7, four distributed resonators are provided in a grid configuration, the grid being a square in this example. In other embodiments the grid may be rectangular, substantially circular, substantially oval, or hexagonal, and so on. Considering the grid as made up of distributed resonators 30' laid out in rows and columns, the distributed resonators are disposed such that along a row or columns between two distributed resonators 36' in the first configuration, a distributed resonator 38' of the second configuration is disposed. Here we mean, as we did in the Figure 5 example, that in the first configuration 36' the inner cylinder extends from the top wall 40' of the chamber 28' and the outer cylinder extends from the bottom wall 42' of the chamber 28'. In the second configuration 38' the inner cylinder 32' extends from the bottom wall 42' of the chamber 26' and the outer cylinder 34' extends from the top wall 40' of the chamber 28'. The resonant chamber 28' of course also includes side walls 44', and a cavity defined by the top wall 40', bottom wall 42' and side walls 44' within which the resonators 30 are disposed.

[0050] The distributed resonator of the first configuration 36' includes a coaxial tuning screw 46 extending from the bottom wall 42' of the chamber 28' into the chamber 28'. The distributed resonator of the second configuration 38' includes a coaxial tuning screw 48 extending from the top wall 40' of the chamber 28'in to the chamber 28'. The is also a main tuning screw 50 disposed in a central position on the bottom wall 42' to lie between the distributed resonators 30' coaxially with the distributed resonators 30'.

Comparison of Properties

[0051] In Table 1 the resonant frequencies, f_0, of the two resonant chambers shown in respective Figures 5 and 7 are presented for comparison. In all cases, the cavity size is identical, 40 x 40 x 12 mm^3, and the distributed resonators of second order, operating at a frequency of 1113 MHz, are the same. The reported resonant-frequency values were obtained by utilizing the full-wave analysis software tool of CST Studio Suite 2013 by CST AG. www.cst.com/Products/CSTS2.

Table 1: Comparison of resonant frequencies of distributed resonators of Figs. 3,5,7.

Resonator type	Resonant frequency, f_0 [MHz]	Q-factor
Single distributed resonator (Fig 3) (ALTERNATIVE PROPOSAL) for comparison	1113	2608
Single cylindrical resonator post (not shown) (PRIOR ART) for comparison	3261	5772
4 resonator elements linear (Fig. 5)	879	1332
4 resonator elements folded (Fig. 7) with Omm tuning screw 46,48,50 insertion (equivalent to no tuning screw being present)	740	2054

[0052] As evident from Table 1, the use of closely-coupled distributed resonators leads to a significant reduction of the operating frequency compared to the operating frequency of a single resonator. This, conversely, means that, for the same resonant frequency, closely-coupled distributed resonators yield filters with substantially reduced volumes and very low profiles. For example, the proposed four distributed resonators in folded configuration of Fig. 5 operating at 740 MHz have a height of only 12 mm or the equivalent electrical length of 10.66 degrees. This level of profile reduction is substantial. The profile of the resonant chamber with distributed resonators is of the same order as a conventional TM resonator.

[0053] Furthermore, it is relevant to mention the possibility of tuning of the resonant chambers of Figures 5 and 7. Due to the fact that each of the individual resonators is a distributed resonator, it is possible to include an extra resonator element inside each of the individual resonator elements, as shown in Fig. 7. These extra resonator elements are the tuning screws 46,48 meaning that, in this example, each individual distributed resonator 30' has its own tuning screw 46,48, which would induce a change in the frequency of operation of the individual distributed resonator element. Further, one more screw 50 is included to the resonator structure of Fig. 7, suitably positioned in the middle of the cavity. The addition of individual tuning screws 46,48,50 , effectively, makes the resonator of Fig. 5 a folded $R_{3,4}$ configuration (rather than a folded $R_{2,4}$ configuration where the tuning screws were not present).

[0054] As an example, the tuning performance of the resonant chamber of Fig. 7 is presented in Table 2, for the case without any screw intrusion and the case when the tuning screws 46,48,50 penetrate the 12 mm tall cavity by 11 mm. This 11mm penetration leaves 1 mm gap between the open end top of the tuning screws 46,48,50 and the cavity 28', which given the size of cavity, is acceptable.

Table 2: Tuning performance of resonator structure of Fig. 7 with no screw intrusion and with a maximum allowable screw intrusion.

	f_0 ($R_{3,4}$ resonators), Fig. 7 [MHz]	Q-factor
Screw intrusion (0 mm)	740	2054
Screw intrusion (11 mm)	640	1843
Frequency tunability [%]	14.4	N/A

[0055] As evident from Table2, the proposed structures for resonant chambers including distributed resonators not only offer a substantial reduction in the frequency of operation, but they also lend themselves to frequency tunability. For example, the folded arrangement of 4 distributed resonators (Fig. 7) has a frequency tunability of over 14%, which compares favourably with known standard coaxial resonators, having a typical frequency tunability of about 5%.

[0056] It is worth mentioning that the results of Tables 1 and 2 are examples and in other examples higher values of Q-factors and frequency tunability may be possible.

Some Other Examples

[0057] It is possible to extend the concept of the proposed multiple distributed resonator to greater numbers of individual distributed resonators, such as 9, as shown in Fig. 8. In Figure 8 the distributed resonators may be considered to be in a grid configuration.

[0058] Various gird configurations are possible, square, rectangular, circular, other regular shape, or irregular shape. In these the distributed resonators alternative along a line, column or row such that such that the one has its inner cylinder grounded on the top wall and outer cylinder grounded on the bottom wall and the next along the line, column or row has its inner cylinder grounded on the bottom wall and outer cylinder grounded on the top wall.

[0059] Other numbers of distributed resonators are possible, for example, 2, 3, 4, 5, and so on.

[0060] Other examples of the proposed approach of a resonant cavity with distributed resonators in a folded configuration approach include arrangements where the distributed resonators are not arranged in a rectangular grid, but can be arranged in a circular fashion, for example, where a distributed resonator may be coupled to one or more other distributed resonators. An example is shown in Figure 9.

Folded configuration (circular)

[0061] As shown in Figure 9 a resonator assembly is shown which we can refer to by the short-hand $R_{2,9}$ where 2 is the number of elements making up a single distributed resonator (in this case an inner cylinder and outer cylinder) and 9 denotes the number of distributed resonators.

[0062] In this assembly eight distributed resonators 30' are disposed along a notional circular line, such that such that the one has its inner cylinder grounded on the top wall and outer cylinder grounded on the bottom wall and the next along the line has its inner cylinder grounded on the bottom wall and outer cylinder grounded on the top wall. There is also a central distributed resonator 52 having the same structure as the others.

[0063] For the purpose of arranging the individual resonator elements in this way, the number of individual distributed resonator 30', 52 is kept to be 9, (as was the case in the Figure 8 example).

Note on Matrix order

[0064] The order of the resonator matrix in Fig. 8 is equal to $\sqrt{9}=3$ since we have 3 rows and three columns and hence 3 * 3 = 9. In other words, the order of the resonator matrix is, in general, equal to:

$$\text{Matrix order} = \sqrt{\text{number of individual resonator elements}}$$

[0065] For the case of the Figure 9 example which has a circular arrangement of nine individual distributed resonators, the equivalent order of the resonator matrix is 3. It is however, possible to arrange the individual resonator elements in a circular fashion, but in the way such that the square root of the individual resonator elements is not a positive and integer number, but a rational number. An example would be if the number of individual resonator elements arranged in a circular fashion is eight, which would make the effective order of the resonator matrix to be $\sqrt{8}=2.83$.

Some further examples

[0066] The present invention may be embodied in other specific forms without departing from its essential characteristics. For example a filter may be provided made up of at least one or multiple (e.g. two or more) resonator assemblies as described above. The multiple resonator assemblies may be connected together with appropriate connectors for coupling between the assemblies, for example so as to constitute a combline filter. One example is shown in Figure 10.

[0067] As shown in Figure 10, three resonator assemblies are provided each consisting of a respective resonant chamber 28' in each of which there are nine distributed resonators 30" disposed in a grid configuration (as described above with respect to Figure 8). The three resonant chambers 28' are coupled in a row 27 to form a filter 29. As the filter 29 has three resonant assemblies, it may be referred to as a three-pole filter. Between adjacent resonant chambers 28' a respective coupling wall 31 is provided, so the filter 29 has two coupling walls 31. Each of the coupling walls 31 is of partial height (as opposed to full height) so as to allow electromagnetic coupling between the adjacent resonant chambers 28'. Input/output signal feeding mechanisms 33 are provided into the first resonant chamber 28a and last resonant chamber 28c in the row 27. In this example, the input/output signal feeding mechanisms 33 are feeding tubes, but other types of input/output signal feeding mechanisms are possible.

[0068] The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

[0069] A person skilled in the art would readily recognize that steps of various above-described methods can be performed by programmed computers. Some embodiments relate to program storage devices, e.g., digital data storage media, which are machine or computer readable and encode machine-executable or computer-executable programs of instructions, wherein said instructions perform some or all of the steps of said above-described methods. The program storage devices may be, e.g., digital memories, magnetic storage media such as a magnetic disks and magnetic tapes, hard drives, or optically readable digital data storage media. Some embodiments involve computers programmed to perform said steps of the above-described methods.

Claims

1. A resonator assembly comprising a resonant chamber, each chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which
the resonator chamber houses two or more resonators,
each resonator comprising a first cylinder grounded on one of the first and second walls and extending into the chamber, and a second cylinder which is coaxial with the first cylinder and grounded on the other of the first and second walls and extending into the chamber;
a first set of the resonators having their respective first cylinders grounded on the first wall and their respective second cylinders grounded on the second wall;
a second set of the resonators having their respective first cylinders grounded on the second wall and their respective second cylinders grounded on the first wall;
wherein each resonator of the first set is for magnetic field coupling in proximity with at least one resonator of the second set.

2. A resonator assembly according to claim 1, in which in each resonator the first cylinder is an inner cylinder and the second cylinder is an outer cylinder lying coaxially such that along part of their lengths the first cylinder and the second cylinder overlap.

3. A resonator assembly according to claim 1 or claim 2, in which the resonators are disposed in a line.

4. A resonator assembly according to claim 1 or claim 2, in which the resonators are disposed in a grid configuration.

5. A resonator assembly according to claim 4, in which the grid configuration is a rectangle or square or circle.

6. A resonator assembly according to clam 4 or 5, in which along a row or column of the grid between two resonators of one of the first set and the second set a resonator is provided of the other of the first set and the second set.

7. A resonator assembly according to any of claims 3 to 6, in which the resonators alternative along a line, column or row such that one has its inner cylinder grounded on the top wall and outer cylinder grounded on the bottom wall and the next along the line, column or row has its inner cylinder grounded on the bottom wall and outer cylinder grounded on the top wall.

8. A resonator according to claim 7, in which the line, column or row is curved or circular.

9. A resonator assembly according to any preceding claim in which the resonators of the first set are in an inter-digitated configuration with the resonators of the second set.

10. A resonator assembly according to any preceding claim, in which a tuning screw is provided through one of the first wall and second wall having an adjustable insertion length into the cavity.

11. A resonator assembly according to claim 10, in which the tuning screw is disposed through a central position on said one of the first wall and second wall.

12. A resonator assembly according to any preceding claim, in which for each resonator a corresponding resonator post is provided grounded on one of the first wall and the second wall and extending along the central longitudinal axis of the respective first and second cylinders.

13. A resonator assembly according to claim 12, in which each resonator post is of adjustable insertion length into the cavity.

14. A radio frequency filter comprising at least one resonator assembly according to any preceding claim.

15. A method of radio frequency filtering comprising passing a signal for filtering through at least one resonator assembly, each resonator assembly comprising a resonant chamber, each chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which
the resonator chamber houses two or more resonators;
each resonator comprising a first cylinder grounded on one of the first and second walls and extending into the chamber and a second cylinder which is coaxial with the first cylinder and grounded on the other of the first and second walls and extending into the chamber;
a first set of the resonators having their respective first cylinders grounded on the first wall and their respective second cylinders grounded on the second wall;
a second set of the resonators having their respective first cylinders grounded on the second wall and their respective second cylinders grounded on the first wall;
wherein each resonator of the first set is for magnetic field coupling in proximity with at least one resonator of the second set.

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

1. A resonator assembly comprising a resonant chamber (28), each chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which

the resonator chamber houses at least one resonator;
each resonator (30) comprising a first cylinder (32) grounded on one (40) of the first and second (42) walls (40,42) and extending into the chamber, and a second cylinder (34) which is coaxial with the first cylinder and grounded on the other (42) of the first and second walls (40,42) and extending into the chamber;
<u>**characterised in that**</u>
the resonator chamber houses two or more resonators (30),
a first set (36) of the resonators having their respective first cylinders (32) grounded on the first wall (40) and their respective second cylinders (34) grounded on the second wall (42);
a second set (38) of the resonators having their respective first cylinders (32) grounded on the second wall (42) and their respective second cylinders (34) grounded on the first wall (40);
wherein each resonator of the first set (36) is for magnetic field coupling in proximity with at least one resonator of the second set (38); and
in which in each resonator (30) the first cylinder (32) is an inner cylinder and the second cylinder (34) is an outer cylinder lying coaxially such that along part of their lengths the first cylinder (32) and the second cylinder (34) overlap; and
in which the resonators (36) of the first set are in an inter-digitated configuration with the resonators (38) of the second set.

2. A resonator assembly according to claim 1, in which the resonators are disposed in a line (Fig 5: 36,38,36,38).

3. A resonator assembly according to claim 1, in which the resonators are disposed in a configuration (Fig 7,Fig 8,Fig 9) comprising rows and columns.

4. A resonator assembly according to claim 3, in which the configuration is a rectangle or square (Fig 7,Fig 8) or circle (Fig 9).

5. A resonator assembly according to clam 3 or 4, in which along a row or column between two resonators of one (36,38) of the first set (36) and the second set (38) a resonator is provided of the other (38,36) of the first set (36) and the second set (38).

6. A resonator assembly according to any of claims 2 to 5, in which the resonators alternative along a line, column or row such that one has its inner cylinder grounded on the top wall and outer cylinder grounded on the bottom wall and the next along the line, column or row has its inner cylinder grounded on the bottom wall and outer cylinder grounded on the top wall.

7. A resonator according to claim 6, in which the line, column or row is curved or circular.

8. A resonator assembly according to any preceding claim, in which a tuning screw (46,48,50) is provided through one of the first wall and second wall having an adjustable insertion length into the cavity (28).

9. A resonator assembly according to claim 8, in which the tuning screw (Fig7:30) is disposed through a central position on said one of the first wall and second wall.

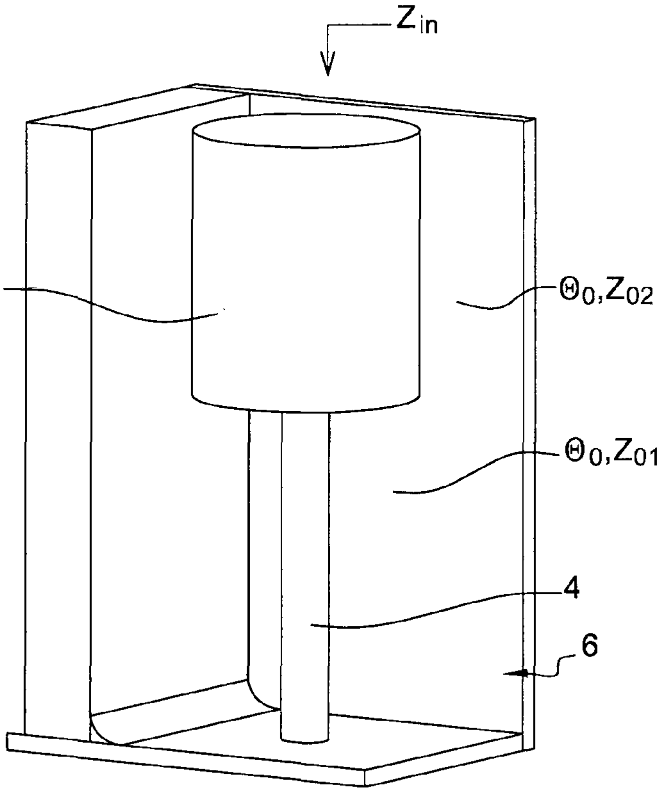
10. A resonator assembly according to any preceding claim, in which for each resonator (36,38) a corresponding resonator post (46,48) is provided grounded on one of the first wall and the second wall and extending along the central longitudinal axis of the respective first and second cylinders.

11. A resonator assembly according to claim 10, in which each resonator post (46,48) is a tuning screw of adjustable insertion length into the cavity.

12. A radio frequency filter comprising at least one resonator assembly according to any preceding claim.

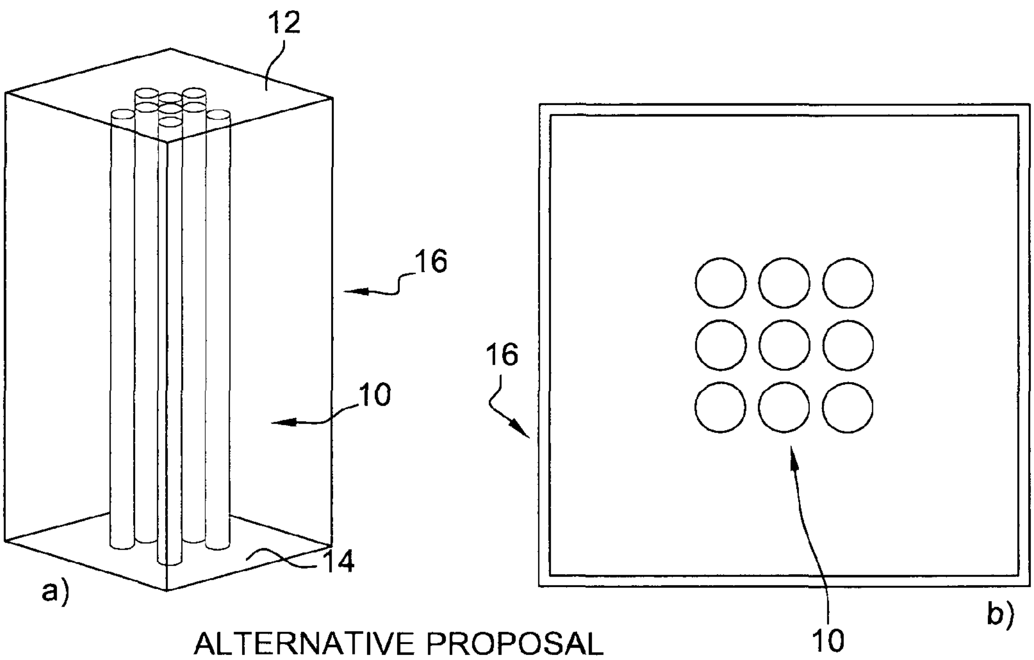
13. A method of radio frequency filtering comprising passing a signal for filtering through at least one resonator assembly, each resonator assembly comprising a resonant chamber, each chamber comprising a first wall, a second wall opposite the first wall, and side walls; in which

the resonator chamber houses at least one resonator;
each resonator comprising a first cylinder grounded on one of the first and second walls and extending into the chamber and a second cylinder which is coaxial with the first cylinder and grounded on the other of the first and second walls and extending into the chamber;
characterised in that
the resonator chamber houses two or more resonators;
a first set of the resonators having their respective first cylinders grounded on the first wall and their respective second cylinders grounded on the second wall;
a second set of the resonators having their respective first cylinders grounded on the second wall and their respective second cylinders grounded on the first wall;
wherein each resonator of the first set is for magnetic field coupling in proximity with at least one resonator of the second set; and
in which in each resonator (30) the first cylinder (32) is an inner cylinder and the second cylinder (34) is an outer cylinder lying coaxially such that along part of their lengths the first cylinder (32) and the second cylinder (34) overlap; and
in which the resonators (36) of the first set are in an inter-digitated configuration with the resonators (38) of the second set.



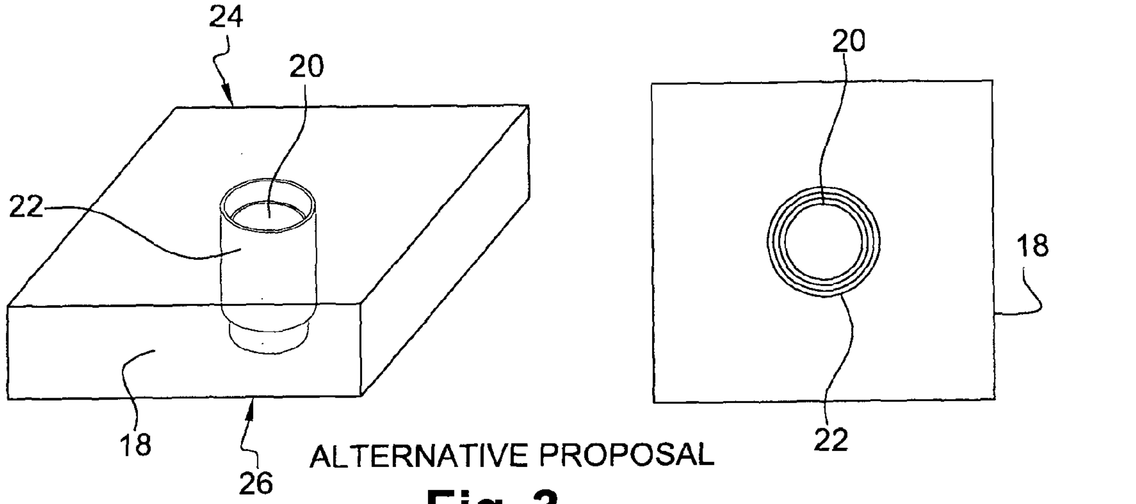
PRIOR ART

Fig. 1 : Stepped-impedance resonator



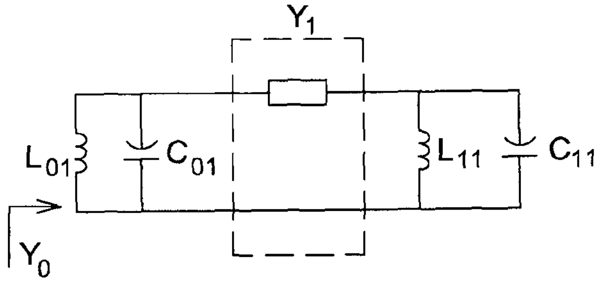
ALTERNATIVE PROPOSAL

Fig. 2 : A rectangular folded grid of nine resonators



ALTERNATIVE PROPOSAL

Fig. 3



ALTERNATIVE PROPOSAL

Fig. 4

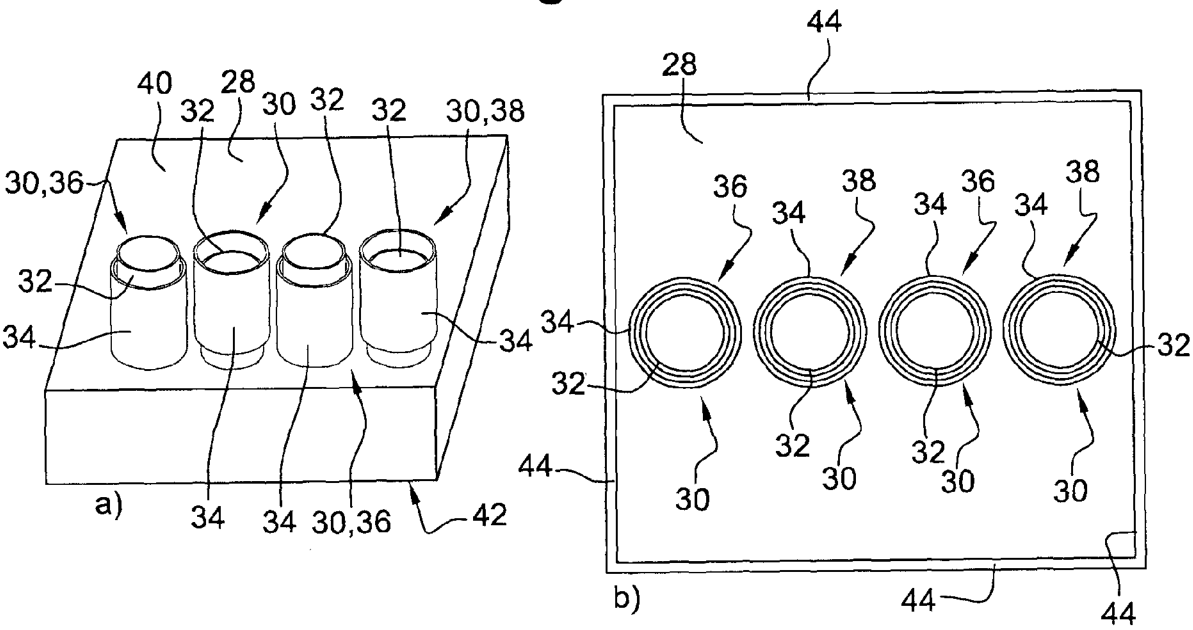


Fig. 5

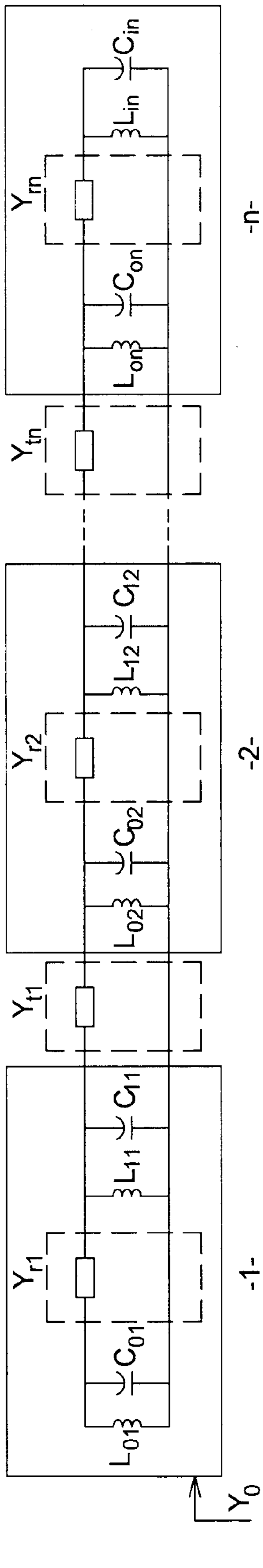

Y0
L01
C01
Yr1
L11
C11
Yt1
L02
C02
Yr2
L12
C12
Ytn
Lon
Con
Yrn
Lin
Cin
-1-
-2-
-n-

Fig. 6

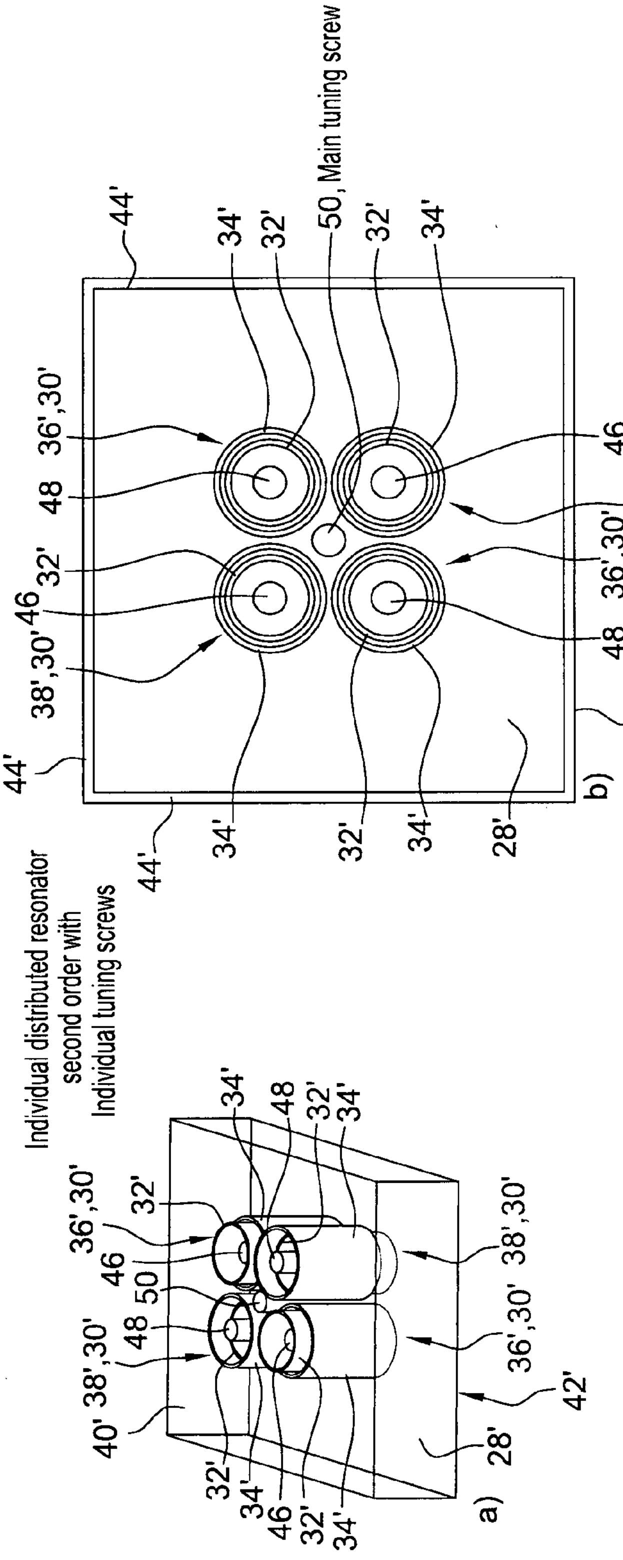
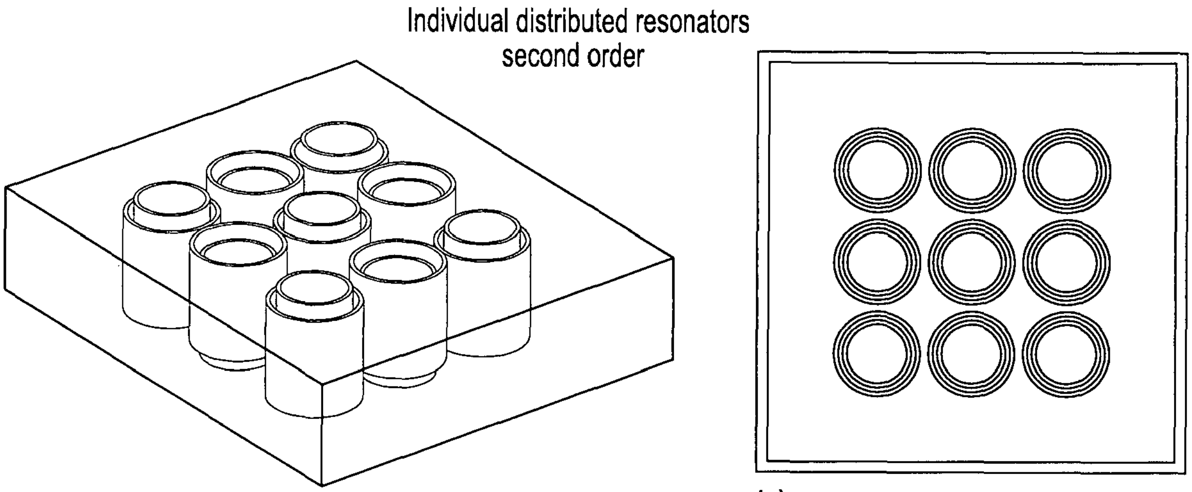
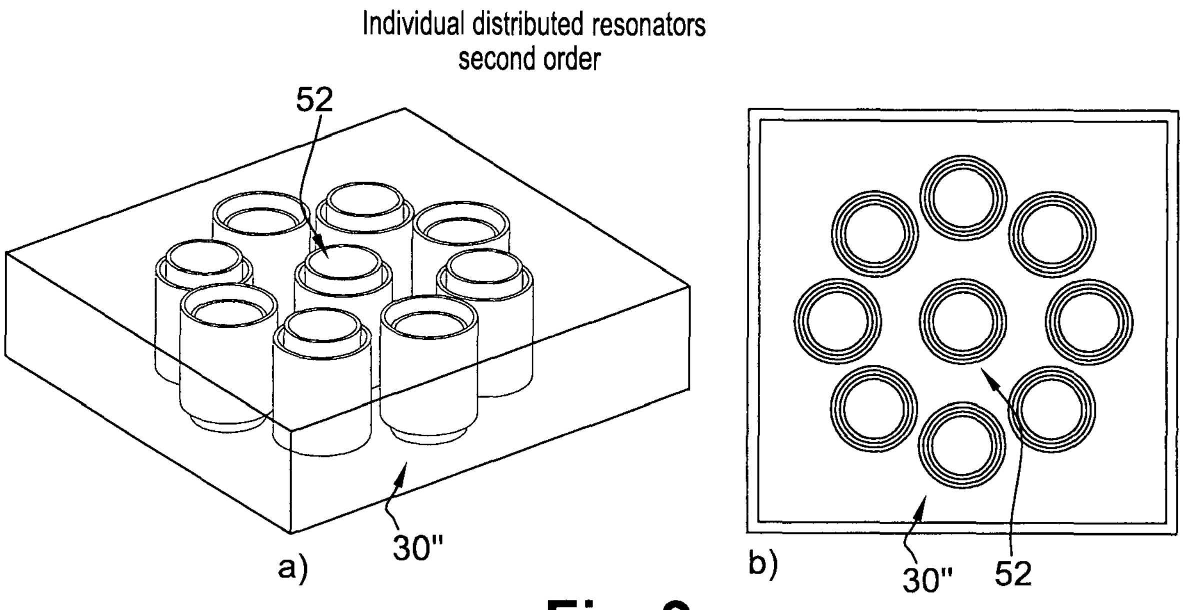

Individual distributed resonator second order with Individual tuning screws
a)
b)
50, Main tuning screw
28'
30'
32'
34'
36',30'
38',30'
40'
42'
44'
46
48
50

Fig. 7



a) b)

Fig. 8



a) b)

Fig. 9

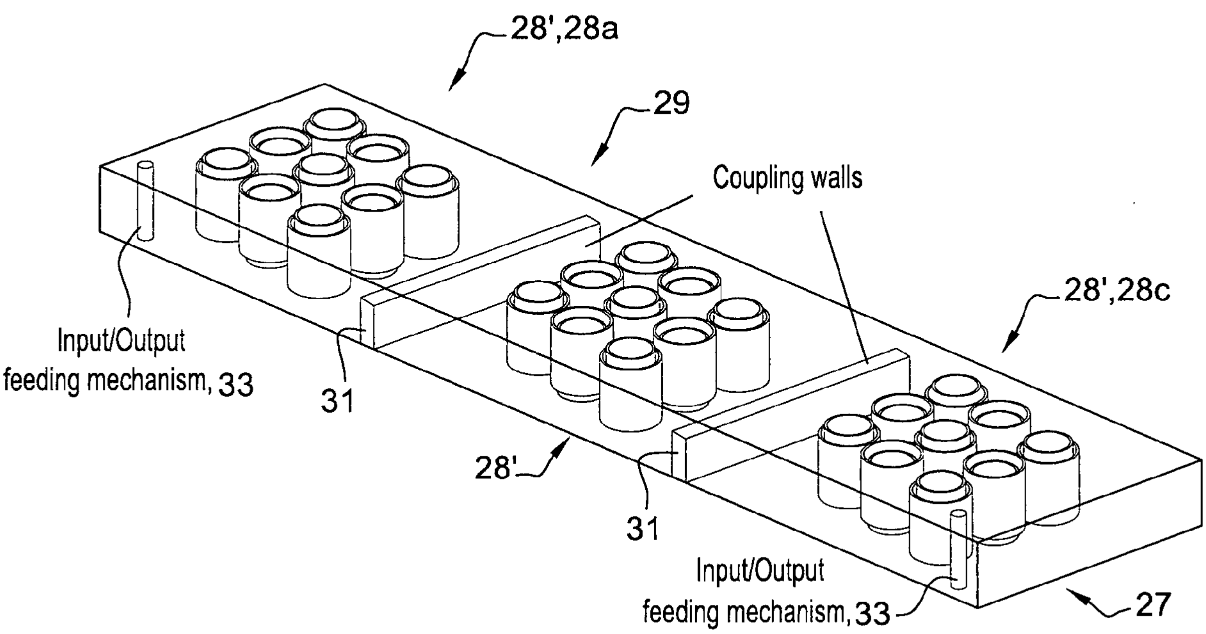

28',28a
29
Coupling walls
28',28c
Input/Output
feeding mechanism, 33
31
28'
31
Input/Output
feeding mechanism, 33
27

Fig. 10

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EUROPEAN SEARCH REPORT

Application Number
EP 15 30 6969

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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X Y	US 2013/271243 A1 (HAUNBERGER THOMAS [DE] ET AL) 17 October 2013 (2013-10-17) * paragraph [0039] - paragraph [0046]; figures 1,2 *	1,10,11 2,3,7-9, 12,14	
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	17 June 2016	Pastor Jiménez, J

CATEGORY OF CITED DOCUMENTS

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EUROPEAN SEARCH REPORT

Application Number
EP 15 30 6969

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1 The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
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