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

Resonator, Funkfrequenzfilter und Filterverfahren

Résonateur, filtre de fréquence radio et procédé de filtrage

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(56) References cited:
EP-A1- 0 038 996
EP-A1- 1 575 118
WO-A2-2007/149423
JP-A- S5 714 201
US-A1- 2004 051 603

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Description

Field of the Invention

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

Description of the Related Art

[0002] 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 is increased 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.

[0003] It is sometimes important for a filter to have good tunability, in other words to be able to vary its operating frequency and percentage bandwidth. This is particularly desirable if the variation in operating frequency and bandwidth of the filter do not significantly deteriorate other important filter characteristics, for example pass-band loss and rejection.

[0004] Several known approaches exist, depending on the topology and the technology of the filter.

[0005] For printed-circuit-board (PCB) filtering applications, electronic tunability is achieved using a varactor diode suitably connected to an open-ended part of a resonator. However, both power handling of such a resonator/filter is reduced due to the poor intermodulation performance of the varactor diode and, at the same time, the insertion losses of such a resonator/filter are increased, due to the parasitic resistance of the diode.

[0006] In high-power applications, such as those found in mobile cellular communication base stations, there is still no real practical alternative to cavity filters. The standard building block of a cavity filter is a combline resonator, depicted in its basic form in Figure 1. The combline resonator includes a resonator post in a cavity, and resonates at the frequency at which the resonator post's height is one quarter-wavelength of the electric current, *I*, induced on the surface of the resonator post.

[0007] As shown in Figure 1, a single combline resonator is provided, and as there is no significant capacitive loading at the top of the resonator post, the electrical length of the combline resonator needs to be approximately 90 degrees at the frequency of operation. This electrical length of 90 degrees means that the resonator behaves as an impedance transformer, namely where the resonator post has a short-circuit ended bottom and an open-circuit ended top.

[0008] Since manufacturing is not perfect, the practical realization of a combline resonator is typically as shown in Figure 2. In the combline resonator shown in Figure 2, a tuning screw extends from the top of the cavity toward the resonator post's ungrounded end so as to effectively balance undesired effects caused by manufacturing tolerances. To explain another way, the tuning screw allows the resonator to be tuned to the resonant frequency for which the resonator was designed.

[0009] The tuning screw can also be used to retune the resonator to a different frequency. However, the range of tunability achievable this way is in practice only a few per cent. This is primarily because the volume of space between the cavity top and the ungrounded end of the resonator is the region within the entire cavity where, at resonance, the electric field in the cavity is the strongest, i.e., the region is very susceptible to arcing. The tuning screw further reduces the size of the gap between the cavity top and the ungrounded end of the resonator, thus reducing the power-handling capability of the resonator. For reasons of power handling, the minimal size of the gap found in practical filters for wireless cellular-communication applications is about 1 mm.

[0010] Furthermore, the change of resonant frequency achieved by tuning the resonator shown in Figure 2 varies very nonlinearly with the intrusion depth of the tuning screw into the cavity; namely, the larger the intrusion depth the more rapidly the resonant frequency varies. Consequently, precisely tuning the resonator is often difficult and time-consuming.

[0011] There is no more widely accepted way to achieve greater frequency tunability than that achievable by the conventionally located tuning screw as seen in Figure 2, although it is known to seek to incorporate an electronically controllable device inside the cavity of a filter for this purpose. The electronically controllable device is usually a varactor diode (in which case the resultant filter exhibits the same problems as its PCB counterpart) or in the form of micro-electro-mechanical systems (MEMS). A cavity filter with MEMS performs substantially similarly to one with varactor diodes, with the exception that its power handling capability is relatively increased to some extent, while its tunable range is decreased due to the existence of stray capacitance between metallic contacts of the MEMS switch.

[0012] The equivalent circuit of the resonator shown in Figure 2 is shown in Figure 3.

[0013] For an example of the resonator shown in Figure 2, the variation in resonant frequency as a function of tuning screw insertion is shown in Figure 4. In this example, the cavity is 20 mm by 20 mm by 40 mm where 40 mm is the height, and the resonator post is 39 mm long. The screw is inserted between 0 and 0.5 mm. Bearing in mind that for engineering reasons that depth of screw insertion is limited, it will be seen from Figure 4 that a frequency tuning range of only about 2% is achievable.

[0014] United States Patent Publication US2004/051603A1, European Patent Publicaitons EP1575118A1 and EP0038996A1, and Japanese Patent Publication JPS714201A provide technical background.

[0015] It is know from US2004/051603A1 to provide a resonator comprising a resonant chamber, each chamber comprising a first wall, a second wall opposite the first wall, and side walls in which the resonant chamber houses two resonator posts, the two resonator posts being separated by a gap and in proximity with each other for magnetic field coupling of the two posts;

one of the two posts being grounded on the first wall so as to extend into the chamber from the first wall;

the other of the two posts being grounded on the second wall so as to extend into the chamber from the second wall.

Summary

[0016] The present invention is characterised over the disclosure of US2004/051603A1 in that each of the resonator posts is shaped to have a respective longitudinal channel along its gap-facing surface providing a recess for a body portion of the tuning screw to extend into the gap separating the two resonator posts.

[0017] The reader is referred to the appended independent claims. Some preferred features are laid out in the dependent claims.

[0018] An example of the present invention is a resonator in accordance with claim 1.

[0019] It may be considered that in preferred embodiments, due to this configuration of resonator posts, the magnetic fields created by the currents in the resonator posts act to reinforce each other in the gap between the resonators. This makes the coupling between the resonator posts readily adjustable, and hence the resonant frequency readily adjustable.

[0020] The first wall may be a top wall and the second wall may be a bottom wall.

[0021] Some embodiments include the two resonator posts for reduced size and increased frequency tenability. Some embodiments provide a mechanically tunable resonator structure with high power handling and low insertion loss.

[0022] Some embodiments provide (a) reduced dimensions (as compared to using a single resonator post) and (b) a large tunable frequency range. Regarding (a), filters are made up of one or more of the resonator structures; for example the resonator structure are put together with inlet and outlet apertures between their chambers so as to form a radio-frequency Combline filter. Filter minituarisation is desirable as in a typical base station for mobile communications filters are among the heaviest and bulkiest components, for example taking 30 % or more of the volume of the remote radiohead part of a base station.

[0023] Regarding (b), many operators of mobile telecommunications networks are in the process of moving to new radio frequency bands of operation. Rather than having to replace filters having a narrow frequency range of tunability, filters made of the resonators with wide band tunability may simply be re-tuned rather than needing to be replaced.

[0024] In some embodiments a size reduction by a factor of 2 and a tunable frequency range of 30% is possible.

[0025] Frequency tuning is possible without the need to open the filter so there is no consequential risk of degradation of RF characteristics of the filter by contamination from the outside.

[0026] In some embodiments, the resultant filters are suitable for Remote Radio Heads, being relatively small and so of lighter weight compared to known filters.

[0027] In some embodiments, the electromagnetic characteristics that arise from replacing a single resonator post by two resonator posts are exploited in which a tuning element is introduced between the two posts.

[0028] Some preferred embodiments provide a resonator, in which the resonator posts are shaped so that the gap between the resonator posts allows a body portion of a tuning screw to be extended into the gap between the resonator posts. Preferably, the resonator posts each have a respective longitudinal channel along their gap facing surface. Preferably, each resonator post is at least substantially C-shaped in cross-section.

[0029] Alternatively preferably the two resonator posts are each of at least substantially circular cross-section.

[0030] Alternatively preferably the resonator posts are at least substantially semi-circular in cross-section so the gap is of a substantially constant width.

[0031] Preferably the resonator comprises a tuning element mounted in proximity to an end of one of the resonator posts that extends into the chamber, the tuning element between mounted on the wall opposite to the wall on which that resonator post is grounded. Preferably the tuning element is a screw.

[0032] The present invention also relates to corresponding radio frequency filters and methods of filtering.

[0033] Another example of the present invention relates to a radio frequency filter comprising at least one resonator as outlined above.

[0034] Another example of the present invention relates to a method of radio frequency filtering in accordance with claim 7.

Brief Description of the Drawings

[0035] 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 combline resonator (PRIOR ART),
Figure 2 is a diagram illustrating a known combline resonator including a tuning screw (PRIOR ART),
Figure 3 is a diagram illustrating an equivalent circuit of the resonator shown in Figure 2 (PRIOR ART),
Figure 4 is a graph illustrating resonant frequency against screw insertion in an example of the resonator shown in Figure 2 (PRIOR ART),
Figure 5 is a diagram of a resonator according to a first example.
Figure 6 is a diagram illustrating an equivalent circuit of the resonator shown in Figure 5,
Figure 7 is a graph of frequency variation as a function of transformer impedance,

$$Z_t = \frac{1}{Y_t}$$

according to equation (5) below for the coupled resonator structure shown in Figure 5,
Figure 8 is a diagram of resonator comprising two coupled resonator posts connected to opposite sides of a cavity according to a first embodiment of the invention where (a) is a side view and (b) is a cross-sectional view from top,
Figure 9 is a graph shown variation of resonant frequency as a function of tuning screw insertion in the resonator shown in Figure 8,
Figure 10 is a diagram of a resonator according to an alternative proposal for comparison (ALTERNATIVE PROPOSAL),
Figure 11 is a resonator comprising two coupled resonator posts connected to the same side of a cavity, where (a) is a side view and (b) is a cross-sectional view from top, for comparison (ALTERNATIVE PROPOSAL), and
Figure 12 is a graph shown variation of resonant frequency as a function of tuning screw insertion in the resonator shown in Figure 11 for comparison

(ALTERNATIVE PROPOSAL).

Detailed Description

[0036] Embodiments of the invention are described with reference to Figures 8 to 9.

[0037] Examples of an alternative proposal which arc not prior art nor embodiments are then described with reference to Figure 10 to 12 for comparison with the embodiments of the invention.

First Example

[0038] As shown in Figure 5, the inventors realised that a useful resonator structure 2 may be provided in which there are two resonator posts 4, 6, one 4 of which is grounded on the bottom 8 of a resonator cavity 10 and the other 6 of which is grounded on the top 12 of the resonator cavity 10.

[0039] It will be understood that the nomenclature top wall, bottom wall, sides walls, is intended to distinguish the walls from each other and resonators may function in any orientation relative to the Earth.

[0040] The equivalent circuit 14 to this resonator structure 2 is shown in Figure 6.

Equivalent Circuit Analysis

[0041] Figure 6 corresponds to two of the resonators each represented by their own equivalent - parallel LC (inductor-capacitor) - circuit connected through an admittance transformer, Y_1.

[0042] The resonant frequency of each resonator is obtained from the condition that the admittance of the parallel circuit, Y_0, is equal to zero

$$Y_0 = j\omega_0 C_0 + \frac{1}{j\omega_0 L_0} = 0 \quad (1)$$

to yield $\omega_0 = \frac{1}{\sqrt{L_0 C_0}}$.

[0043] The resonant frequency of the circuit shown in Figure 6 is, similarly, obtained from the condition that the input admittance, Y_{in}, is equal to zero. In order to do so, the expression for Y_{in} is obtained:

$$Y_{in} = \frac{1}{j\omega L_0} + j\omega\left(C_0 + \frac{L_0 Y_1^2}{1 - \omega^2 L_0 C_0}\right) \quad (2)$$

[0044] The inventors then inferred from equation (2) that the first term on the right corresponds to the susceptance of inductor L_0, while the second term represents the equivalent capacitive susceptance, composed of the susceptance of capacitor C_0 and the susceptance contribution of the second resonator. The susceptance contribution of the second resonator is of capacitive character for frequencies below the resonant frequency of the individual resonators, $\omega_0 = \frac{1}{\sqrt{L_0 C_0}}$; and of inductive character for frequencies above the resonant frequency of the individual resonators. The resonant frequencies of the resonator structure shown in Figure 6 are obtained by setting $Y_{in} = 0$, to yield

$$\left(\omega^2 L_0 C_0 - 1 - \omega L_0 Y_1\right)\left(\omega^2 L_0 C_0 - 1 + \omega L_0 Y_1\right) = 0 \quad (3).$$

[0045] Since (3) is a polynomial of order four, it has four roots, two out of which are always negative and the remaining two are positive. Discarding the negative roots as unphysical, the two positive roots are

$$\omega_1 = \frac{L_0 Y_1 + \sqrt{L_0^2 Y_1^2 + 4 L_0 C_0}}{2 L_0 C_0} \quad \text{and} \quad \omega_2 = \frac{-L_0 Y_1 + \sqrt{L_0^2 Y_1^2 + 4 L_0 C_0}}{2 L_0 C_0} \quad (4).$$

[0046] Equation (4), upon substitution of $\omega_0 = \frac{1}{\sqrt{L_0 C_0}}$, becomes

$$\omega_1 = \omega_0 \frac{\left(\sqrt{\left(\omega_0^2 L_0^2 Y_1^2 + 4\right)} + L_0 \omega_0 Y_1\right)}{2} \quad \text{and} \quad \omega_2 = \omega_0 \frac{\left(\sqrt{\left(\omega_0^2 L_0^2 Y_1^2 + 4\right)} - L_0 \omega_0 Y_1\right)}{2} \quad (5).$$

[0047] Equation (5) indicates that the introduction of an admittance transformer, Y_1, results in two resonant frequencies: one above and the other below the resonant frequency of an individual resonator. In other words, for a given resonant frequency of an individual resonator post, the resonant frequencies of the resonator structure 2 shown in Figure 6 can be adjusted by a selection of the admittance transformer, Y_1.

[0048] The frequency difference between the two roots of (4) or (5) may be written as

$$\Delta\omega \approx \frac{Y_1}{2C_0} = \frac{\omega_0^2 L_0}{2} Y_1 \quad (6)$$

which states that the frequency separation between the two resonant frequencies is proportional to the admittance transformation between the two resonators. The inventors realised that this enables a way of obtaining frequency tunability, which, rather than focusing on the variation of the equivalent capacitance of a single resonator, introduces frequency tunability as a function of the coupling between two adjacent resonators.

[0049] By way of illustration, as a numerical example, let us consider the resonator structure shown in Figure 6, where each of the resonator posts is operating at a frequency of 2 GHz. In this example, Figure 7 shows frequency variation as a function of transformer impedance,

$$Z_1 = \frac{1}{Y_1}$$

according to equation (5). The admittance transformer, Y_1, is allowed to vary from 0.0033 S (equivalent to 300 Ω) to 0.05 S (equivalent to 20 Ω). In Figure 7, circles represent resonant frequency of each of the two resonator posts 4,6, squares represent the lower bound to the operating frequency range, and triangles represent the upper bound to the operating frequency range.

[0050] As seen in Figure 7, the inventors realised that, frequency tunability is obtained by controlling the impedance transformation between the two resonator posts.

[0051] The inventors also realised that by using two resonator posts not only is frequency tunability achievable, but also the frequency of operation is reduced, leading to reduced physical dimensions (miniaturization).

Electromagnetic Conditions

[0052] This lead the inventors to consider electromagnetic conditions that must be satisfied.

[0053] It follows from electromagnetic theory that for the coupling between two resonator posts to be strong, they must be placed in the vicinity of each other. The term "coupling" represents the amount of energy that one resonator post intercepts from another resonator post and can be expressed equally well by an equivalent loading "impedance" that one resonator post exhibits when another resonator post is placed in its vicinity.

[0054] In particular, the higher the equivalent loading "impedance" of a resonator post, the less amount of coupling exists between the two adjacently placed resonator posts. In the limiting case, when the loading impedance is infinite, no coupling exists between the resonator posts. In practice, this corresponds to the case of infinite physical separation between resonator posts.

Resonator Structure

[0055] In view of the above the inventors realised that a strong but controllable coupling between the two posts 4, 6 in the resonant cavity 12 is obtained by placing the resonator posts in the vicinity of each other such that one resonator post 4 extends from the bottom 8 of the cavity 10 and one resonator post 6 extends from the top 12.

[0056] Looking further at the resonator structure shown in Figure 5, it is seen that the resonators are positioned at opposite sides from each other. This means that the directions of the surface currents on the respective resonator posts 4,6 are such that the magnetic fields created by these two currents reinforce each other in the space 16 between the resonators. This implies that the coupling between the two resonator posts 4, 6 is strong, the resonator posts 4,6 exhibit a great deal of influence on cach other, and this influence can be controlled by manipulating the amount of coupling between the two resonator posts 4,6. As explained earlier with reference to Figure 6, coupling can be represented by an equivalent impedance/admittance transformer between the two resonators.

[0057] It can be considered that depending on the coupling between the two resonators, this notional impedance/admittance transformer has a tunable electrical length.

[0058] Furthermore, given that each individual resonator post has an electrical length of 90° in isolation and that the electrical length of the transformer is adjustable, the overall electrical length of the resonant structure shown in Figure 5 can be arbitrarily long, resulting in reduced frequencies of operation compared to a single resonator in isolation.

[0059] By adjusting the coupling between two resonators, one not only significantly alters the frequency of operation of the individual resonator posts, but also makes the resonant structure widely tuneable. The theoretical basis for this has been explained above with reference to Figure 7.

First embodiment

[0060] As shown in Figure 8, in a further resonator structure 24', the two resonator posts 4', 6' are shaped to take a C-shape cross-section for strong coupling between the resonators. The resonator post 4' is mounted on the inner bottom surface 8' of a resonant cavity 10', and resonator post 6' is mounted on an inner top surface 12' of the cavity 10'. The cavity is defined by metallic walls 11, which provide the inner top 8' and inner bottom 12' surfaces, on which a respective resonator post 4', 6' is grounded.

[0061] The resonator posts 4,6' may be considered as together constituting a split resonator where each resonator post 4'6' has two respective flat faces 26. Each flat face 26 of a resonator post 4',6' is located proximal to but not touching a corresponding flat face 26 of the other resonator post 6',4'.

[0062] The resonator posts 4',6' when located proximally in this way provide a recess 28 within which a tuning screw 30 that intrudes into the cavity 10' may extend. The length of extension 32 of the tuning screw 30 is adjustable and may be substantial as indicated schematically in Figure 8(a).

[0063] By C-shape, we mean each resonator post 4',6' has a semicircular cross-section with a semicircular cross -section cut-out that forms the recess 28 which accommodates the extending portion 34 of the tuning screw 30.

[0064] With this resonator configuration, the surface current distribution around circumference of the portion of the tuning screw that extends into the cavity 10' is essentially constant, giving the tuning screw a high tuning effect and allowing good power handling by the resonator structure 24'.

[0065] The tuning screw 30 has the effect of decreasing the capacitive coupling between the two split resonators and, as such, to increase the overall coupling. As elaborated earlier, increased coupling results in a reduced frequency of operation. To be precise, the overall coupling between two resonator posts 4',6' is a combination of magnetic and electric couplings:

$$k = k_m - k_c \quad (7)$$

where k, k_m and k_c respectively stand for the overall coupling, magnetic coupling and electrical coupling. The overall coupling, k, can be increased by either increasing the amount of magnetic coupling, k_m, or reducing the amount of capacitive coupling, k_c. In the present example, the increase of the overall coupling, k, is achieved by the reduction of capacitive coupling, k_c, by virtue of a tuning screw 30.

Alternative Proposal - for comparison with First Example

[0066] For comparison with the embodiment shown in Figure 5, an alternative approach was considered as shown in Figure 10 in which both resonators were grounded on one side.

[0067] As shown in Figure 10, the surface currents on the first and second resonator posts 20,20 give rise to magnetic fields. Due to the current directions, the magnetic fields introduced by these two currents are such that in the space 22 between the resonator posts 20,20 the magnetic fields tend to cancel each other. In simple terms, provided that the resonator posts 20,20 are of the same shape and size, the resultant magnetic field between the two resonator posts 20.20 is very low. The low density of the magnetic field between the two resonator posts 20,20 implies there is little interaction between the two resonator posts 20,20 and, as such, the frequency behaviour of the resonant structure 24 is similar to the behaviour of an individual resonator shown in Figure 1 (PRIOR ART).

[0068] In other words, placing the resonator posts 20,20 in proximity of each other as shown in Figure 10 does not yield the benefits of tunability or size reduction. It is possible that this configuration may bring certain benefits with regards to a higher unloaded Q-factor for a given volume, but these gains would likely be of limited significance.

Alternative proposal- for comparison with the first embodiment

[0069] For comparison with the embodiment shown in Figure 8, a further example of the alternative proposal is shown in Figure 11. This is similar in structure to the Figure 8 example except that the two resonator posts arc mounted on the same bottom surface.

[0070] In both the example embodiment shown in Figure 8 and the alternative proposal comparative example shown in Figure 11, the cavity size is identical, 20mm. x 20mm x 40 mm, where 40mm is the height.

[0071] A comparison between the operating frequencies, f_0, of the resonant structures of Figures 8 and 11 for different values of tuning screw intrusion, Z_{screw}, is presented in Table I. By the way, these frequency values were obtained by utilizing the full-wave analysis software tool known as CST Studio Suite 2013 from CST AG www.cst.com/Products/CSTS2.

Table 1: Comparison of frequency tunability of resonant structures of Figures 8 and 11.

Z_{screw}[mm]	f_0 (resonator posts grounded on same side) [MHz]	f_0 (resonator posts grounded on opposite sides) [MHz]
0.1	1460	767
2	1460 .	758
5	1460	734

(continued)

Z_{screw}[mm]	f_0 (resonator posts grounded on same side) [MHz]	f_0 (resonator posts grounded on opposite sides) [MHz]
10	1460	704
20	1460	651
30	1460	608
35	1460	589
37	1460	582
39	1455	575

[0072] The results shown in Table 1 are plotted and shown in Figures 9 and 12.

[0073] The resonant frequency for the case of a corresponding single resonator (Figure 1(PRIOR ART) is equal to 1543 MHz.

[0074] It will be seen from Figure 12 (ALTERNATIVE PROPOSAL) that the alternative proposal shows virtually no variation in the resonant frequency versus tuning screw intrusion, albeit its frequency of operation is reduced compared to the case of an isolated resonator. This implies that a limited amount of coupling exists between the two resonators; however, the structure is not tunable.

[0075] In contrast, Figure 9 which relates to an example embodiment shows not only high frequency tunability of nearly 30%, but also reduction in the operating frequency of over two times (1543 MHz/767 MHz = 2.01). Moreover, frequency tunability exhibits a nearly linear dependence with regards to the amount of screw intrusion, which is of importance for sensitive tuning of resonators.

[0076] It follows that the example embodiment described with referecne to Figures 8 and 9 has significant advantages over the alternative proposal described with reference to Figures 11 and 12.

<u>Comparison of Second Example embodiment with prior art</u>

[0077] The tunable resonator shown in Figure 8 can be compared with the obtainable tunable frequency range of a single resonator, Figure 2 (PRIOR ART) having a tuning screw on top.

[0078] For a direct comparison, the same size of cavity was considered in the single resonator post example (Figure 2) and the second example embodiment (Figure 8). Specifically, the cavity is 20 by 20 by 40 mm where 40 mm is the height. The resonator post is 39 mm long. The screw is inserted between 0 and 0.5 mm. It is not advisable to have a gap between the top of the resonator and the tuning screw smaller than 0.5 mm, as that would negatively influence the power-handling capability of the device. For comparison, in the structure shown in Figure 8, a minimum gap of 1 mm was allowed.

[0079] The variation of the resonant frequency of the known resonator of Figure 2 (PRIOR ART), for screw intrusions between 0 and 0.5 mm, was presented earlier in Figure 4 (PRIOR ART).

[0080] Bearing in mind that for engineering reasons that depth of screw insertion is limited, it will be seen from Figure 4 (PRIOR ART) that a frequency tuning range of only about 2% is achievable.

[0081] Comparing Figure 9 and Figure 4, it is seen that the example shown in Figure 8 has tunablity over a much larger frequency range.

[0082] Also the resonator structure 24' example shown in Figure 8 has a useful reduction in frequency of operation as compared to if there were a single resonator post (Figure 2).

[0083] In some embodiments (not shown), the proposed relative compact and tunable resonator structure is used together with an additional tuning screw near the top of the or each resonator post. Consequently, additional fine-tuning using the additional tuning screw(s) is possible following the tuning using the first tuning screw having the portion that extends into the space between the two resonator posts.

[0084] In a nutshell, good course tuning in a wide frequency range is then possible using the first tuning screw having the portion that extends into the space between the two resonator posts; this is followed by fine-tuning using the known approach of using a further tuning screw extending towards the resonator top.

[0085] The present invention may be embodied in other specific forms without departing from its essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

[0086] A person skilled in the art would readily recognize that steps of various above-described methods can be performed by programmed computers. Some embodiments relate to program storage devices, e.g., digital data storage media, which are machine or computer readable and encode machine-executable or computer-executable programs of instructions, wherein said instructions perform some or all of the steps of said above-described methods. The program storage devices may be, e.g., digital memories, magnetic storage media such as a magnetic disks and magnetic tapes, hard drives, or optically readable digital data storage media. Some embodiments involve computers programmed to perform said steps of the above-described methods.

Claims

1. A resonator comprising: a resonant chamber (10'), the chamber comprising a first wall (8'), a second wall (12') opposite the first wall, and side walls (11'); in which the resonant chamber houses two resonator posts (4', 6'), the two resonator posts being separated by a gap and in proximity with each other for magnetic field coupling of the two posts;
one of the two posts (4') being grounded on the first wall (8') so as to extend into the chamber from the first wall;
the other (6') of the two posts being grounded on the second wall (12') so as to extend into the chamber from the second wall;
the resonator further comprising a tuning screw which intrudes into the resonant chamber;
characterised in that
each of the resonator posts is shaped (26, 28) to have a respective longitudinal channel along its gap-facing surface providing a recess for a body portion of the tuning screw to extend into the gap separating the two resonator posts (4', 6').

2. A resonator according to claim 1, in which each resonator post (4', 6') is at least substantially C-shaped in cross-section.

3. A resonator according to claim 1, in which the two resonator posts are each of at least substantially circular cross-section.

4. A resonator according to claim 1, in which the resonator posts (4', 6') are at least substantially semi-circular in cross-section so as to have opposing flat surfaces (26) between which the gap is of a substantially constant width.

5. A resonator according to any preceding claim, in which the tuning screw is mounted in proximity to an end of one of the resonator posts (4', 6') that extends into the chamber (10'), the tuning screw between mounted on the wall (12', 8') opposite to the wall (8', 12') on which that resonator post (4', 6') is grounded.

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

7. A method of radio frequency filtering comprising passing a signal for filtering through at least one resonator;
each resonator comprising a resonant chamber (10'), each chamber comprising a first wall (8'), a second wall (12') opposite the first wall (8'), and side walls (11'), in which the resonant chamber houses two resonator posts, the two resonator posts being separated by a gap and in proximity with each other for magnetic field coupling of the two posts;
one of the two posts (4') being grounded on the first wall (8') so as to extend into the chamber from the first wall;
the other (6') of the two posts being grounded on the second wall (12') so as to extend into the chamber from the second wall;
the resonator further comprising a tuning screw which intrudes into the resonant chamber; **characterised in that** each of the resonator posts is shaped (26, 28) to have a respective longitudinal channel along their gap-facing surface providing a recess for a body portion of the tuning screw to extend into the gap between the resonator posts.

8. A method according to claim 7, in which each resonator post (4', 6') is at least substantially C-shaped in cross-section.

9. A method according to claim 8, in which the resonator posts (4', 6') are at least substantially semi-circular in cross-section so as to have opposing flat surfaces between which the gap is of a substantially constant width.

10. A method according to any of claims 7 to 9, in which the tuning screw is mounted in proximity to an end of one of the resonator posts (4', 6') that extends into the chamber (10'), the tuning screw between mounted on the wall (12', 8') opposite to the wall (8', 12') on which that resonator post is grounded.

Patentansprüche

1. Resonator, umfassend:

   eine Resonanzkammer (10'), wobei die Kammer eine erste Wand (8'), eine zweite Wand (12') entgegengesetzt zur ersten Wand, und Seitenwände (11') umfasst; wobei die Resonanzkammer zwei Resonatorstifte (4', 6') beherbergt, wobei die beiden Resonatorstifte durch einen Spalt getrennt sind und für eine magnetische Feldkopplung der beiden Stifte in der Nähe voneinander angebracht sind;
   wobei einer der Stifte (4') an der ersten Wand (8') verankert ist, um sich von der ersten Wand in die Kammer zu erstrecken;
   wobei der andere (6') der beiden Stifte an der zweiten Wand (12') verankert ist, um sich von der zweiten Wand in die Kammer zu erstrecken;
   wobei der Resonator außerdem eine Abstimmschraube umfasst, die in die Resonanzkammer eindringt;
   dadurch gekennzeichnet, dass
   jeder der Resonatorstifte so geformt ist (26, 28), dass er einen entsprechenden Längskanal entlang seiner dem Spalt zugewandten Oberfläche aufweist, wodurch eine Vertiefung für einen Körperabschnitt der Abstimmschraube bereitgestellt wird, damit diese sich in den Spalt erstreckt und die beiden Resonatorstifte (4', 6') voneinander trennt.

2. Resonator nach Anspruch 1, wobei jeder Resonatorstift (4', 6') im Wesentlichen mindestens einen C-förmigen Querschnitt aufweist.

3. Resonator nach Anspruch 1, wobei die beiden Resonatorstifte im Wesentlichen mindestens einen kreisförmigen Querschnitt aufweisen.

4. Resonator nach Anspruch 1, wobei die Resonatorstifte (4', 6') im Wesentlichen mindestens einen halbkreisförmigen Querschnitt aufweisen, um einander entgegengesetzte flache Oberflächen (26) aufzuweisen, zwischen denen der Spalt eine im Wesentlichen konstante Breite besitzt.

5. Resonator nach einem der vorhergehenden Ansprüche, wobei die Abstimmschraube in der Nähe von einem Ende von einem der Resonatorstifte (4', 6') montiert ist, der sich in die Kammer (10') erstreckt, wobei die Abstimmschraube an der Wand (12', 8') entgegengesetzt zur Wand (8', 12') dazwischen montiert ist, an welcher dieser Resonatorstift (4', 6') verankert ist.

6. Hochfrequenzfilter, der mindestens einen Resonator nach einem der vorhergehenden Ansprüche umfasst.

7. Verfahren für ein Hochfrequenzfiltern, das ein Durchleiten eines Signals zum Filtern durch mindestens einen Resonator umfasst;
   wobei jeder Resonator eine Resonanzkammer (10') umfasst, wobei jede Kammer eine erste Wand (8'), eine zweite Wand (12') entgegengesetzt zur ersten Wand (8'), und Seitenwände (11') umfasst, wobei die Resonanzkammer zwei Resonatorstifte beherbergt, wobei die beiden Resonatorstifte durch einen Spalt getrennt sind und für eine magnetische Feldkopplung der beiden Stifte in der Nähe voneinander angebracht sind;
   wobei einer der beiden Stifte (4') an der ersten Wand (8') verankert ist, um sich von der ersten Wand in die Kammer zu erstrecken;
   wobei der andere (6') der beiden Stifte an der zweiten Wand (12') verankert ist, um sich von der zweiten Wand in die Kammer zu erstrecken;
   wobei der Resonator außerdem eine Abstimmschraube umfasst, die in die Resonanzkammer eindringt; **dadurch gekennzeichnet, dass**
   jeder der Resonatorstifte so geformt ist (26, 28), dass er einen entsprechenden Längskanal entlang seiner dem Spalt zugewandten Oberfläche aufweist, wodurch eine Vertiefung für einen Körperabschnitt der Abstimmschraube bereitgestellt wird, damit diese sich in den Spalt zwischen die beiden Resonatorstifte erstreckt.

8. Verfahren nach Anspruch 7, wobei jeder Resonatorstift (4', 6') im Wesentlichen mindestens einen C-förmigen Querschnitt aufweist.

9. Verfahren nach Anspruch 8, wobei die Resonatorstifte (4', 6') im Wesentlichen mindestens einen halbkreisförmigen Querschnitt aufweisen, um einander entgegengesetzte flache Oberflächen aufzuweisen, zwischen denen der Spalt eine im Wesentlichen konstante Breite besitzt.

10. Verfahren nach einem der Ansprüche 7 bis 9, wobei die Abstimmschraube in der Nähe von einem Ende von einem der Resonatorstifte (4', 6') montiert ist, der sich in die Kammer (10') erstreckt, wobei die Abstimmschraube an der Wand (12', 8') entgegengesetzt zur Wand (8', 12') dazwischen montiert ist, an welcher dieser Resonatorstift verankert ist.

Revendications

1. Résonateur comprenant : une chambre résonnante (10'), la chambre comprenant une première paroi (8'), une deuxième paroi (12') à l'opposé de la première paroi, et des parois latérales (11') ; la chambre résonnante abritant deux piliers de résonateur (4', 6'), les deux piliers de résonateur étant séparés par un espace et à proximité l'un de l'autre pour le couplage du champ magnétique des deux piliers ;
un des deux piliers (4') étant mis à la masse sur la première paroi (8') de manière à s'étendre à l'intérieur de la chambre depuis la première paroi ;
l'autre (6') des deux piliers étant mis à la masse sur la deuxième paroi (12') de manière à s'étendre à l'intérieur de la chambre depuis la deuxième paroi ;
le résonateur comprenant en outre une vis de réglage qui pénètre à l'intérieur de la chambre résonnante ;
caractérisé en ce que
chacun des piliers de résonateur est façonné (26, 28) pour avoir, le long de sa surface faisant face à l'espace, un canal longitudinal respectif fournissant une encoche pour qu'une partie de corps de la vis de réglage s'étende à l'intérieur de l'espace séparant les deux piliers de résonateur (4', 6').

2. Résonateur selon la revendication 1, dans lequel chaque pilier de résonateur (4', 6') est au moins sensiblement en forme de C en coupe transversale.

3. Résonateur selon la revendication 1, dans lequel les deux piliers de résonateur ont chacun une section transversale au moins sensiblement circulaire.

4. Résonateur selon la revendication 1, dans lequel les deux piliers de résonateur (4', 6') sont au moins sensiblement semi-circulaires en coupe transversale de manière à avoir des surfaces plates opposées (26) entre lesquelles l'espace est d'une largeur sensiblement constante.

5. Résonateur selon une quelconque revendication précédente, dans lequel la vis de réglage est montée à proximité d'une extrémité d'un des piliers de résonateur (4', 6') qui s'étend à l'intérieur de la chambre (10'), la vis de réglage étant montée sur la paroi (12', 8') à l'opposé de la paroi (8', 12') sur laquelle ce pilier de résonateur (4', 6') est mis à la masse.

6. Filtre radiofréquence comprenant au moins un résonateur selon une quelconque revendication précédente.

7. Procédé de filtrage radiofréquence comprenant le passage d'un signal à filtrer à travers au moins un résonateur ;
chaque résonateur comprenant une chambre résonnante (10'), chaque chambre comprenant une première paroi (8'), une deuxième paroi (12') à l'opposé de la première paroi (8'), et des parois latérales (11'), la chambre résonnante abritant deux piliers de résonateur, les deux piliers de résonateur étant séparés par un espace et à proximité l'un de l'autre pour le couplage du champ magnétique des deux piliers ;
un des deux piliers (4') étant mis à la masse sur la première paroi (8') de manière à s'étendre à l'intérieur de la chambre depuis la première paroi ;
l'autre (6') des deux piliers étant mis à la masse sur la deuxième paroi (12') de manière à s'étendre à l'intérieur de la chambre depuis la deuxième paroi ;
le résonateur comprenant en outre une vis de réglage qui pénètre à l'intérieur de la chambre résonnante ; **caractérisé en ce que**
chacun des piliers de résonateur est façonné (26, 28) pour avoir, le long de sa surface faisant face à l'espace, un canal longitudinal respectif fournissant une encoche pour qu'une partie de corps de la vis de réglage s'étende à l'intérieur de l'espace entre les piliers de résonateur.

8. Procédé selon la revendication 7, dans lequel chaque pilier de résonateur (4', 6') est au moins sensiblement en forme de C en coupe transversale.

9. Procédé selon la revendication 8, dans lequel les piliers de résonateur (4', 6') sont au moins sensiblement semi-circulaires en coupe transversale de manière à avoir des surfaces plates opposées entre lesquelles l'espace est d'une largeur sensiblement constante.

10. Procédé selon l'une quelconque des revendications 7 à 9, dans lequel la vis de réglage est montée à proximité d'une extrémité d'un des piliers de résonateur (4', 6') qui s'étend à l'intérieur de la chambre (10'), la vis de réglage étant montée sur la paroi (12', 8') à l'opposé de la paroi (8', 12') sur laquelle ce pilier de résonateur est mis à la masse.

FIG. 1
(PRIOR ART)

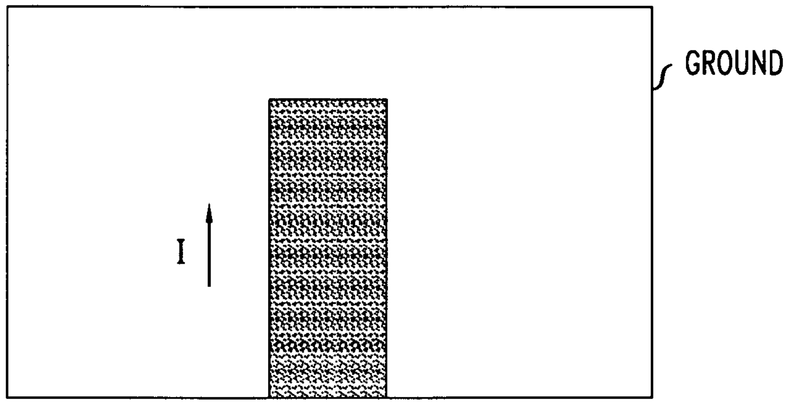


FIG. 2
(PRIOR ART)

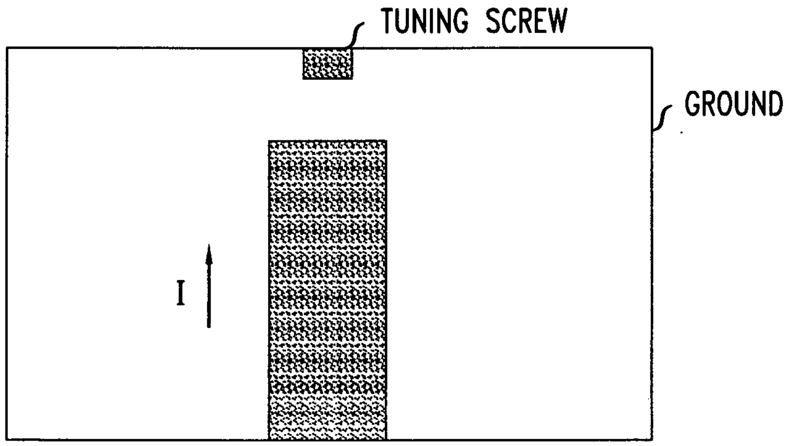


FIG. 3
(PRIOR ART)

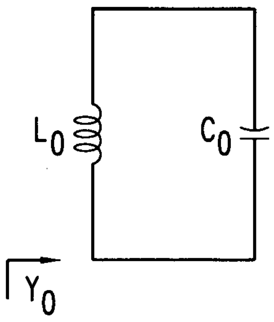


FIG. 4
(PRIOR ART)

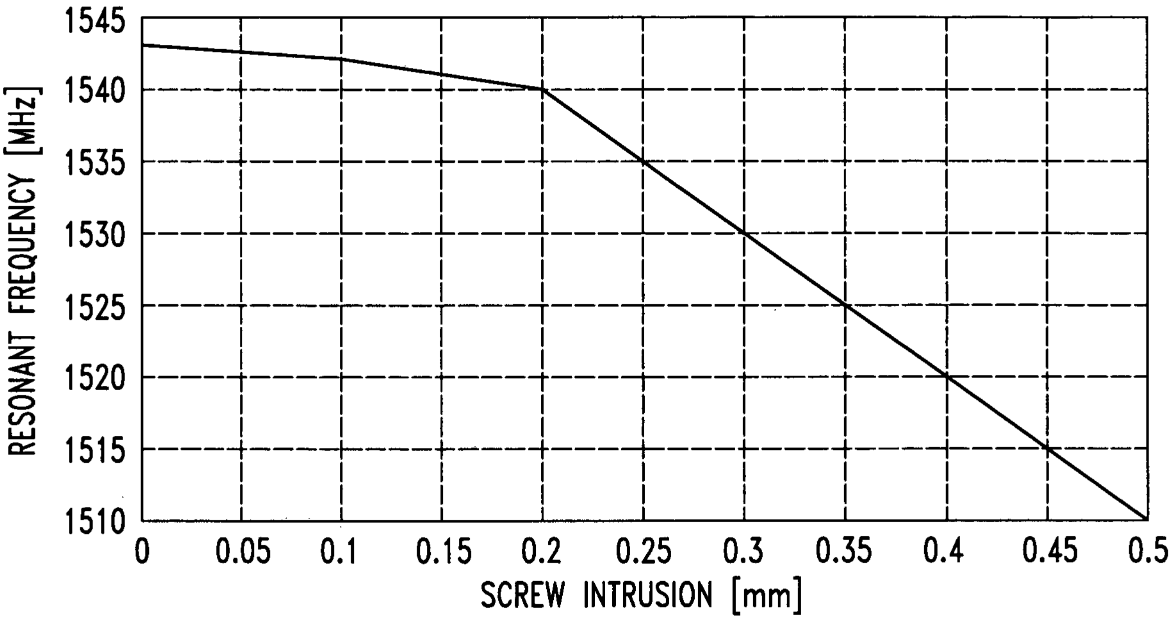


FIG. 5

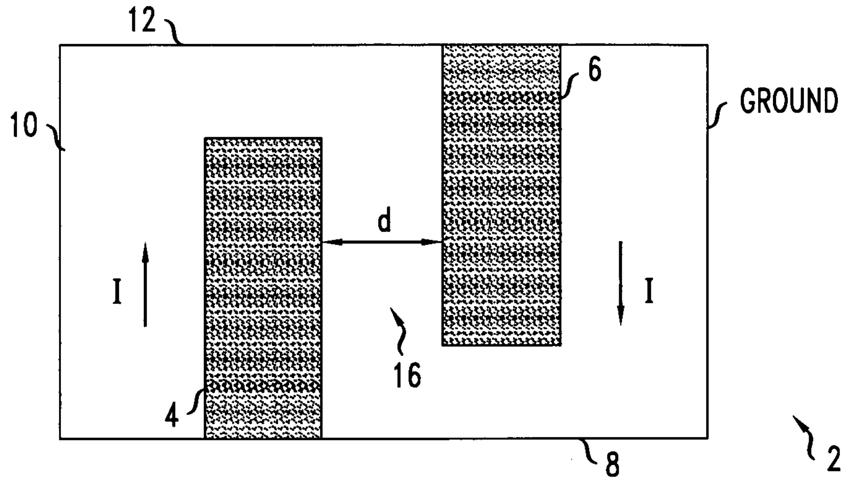


FIG. 6

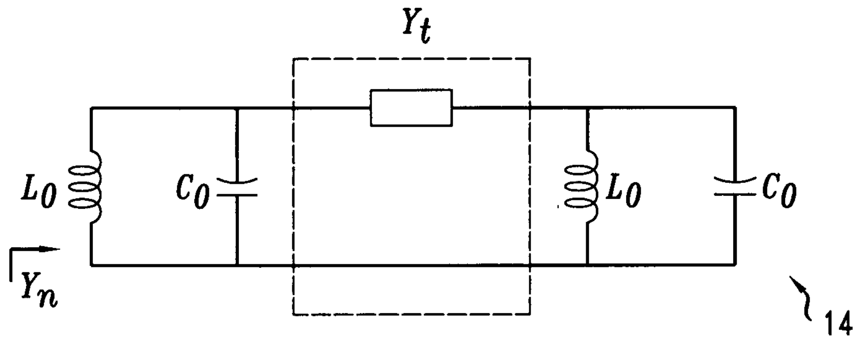


FIG. 7

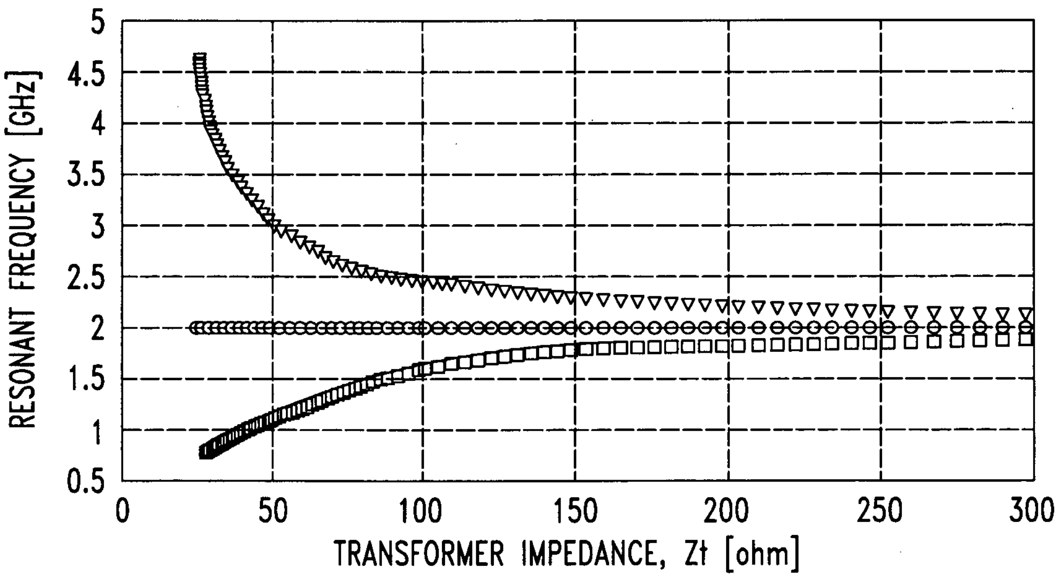


FIG. 8

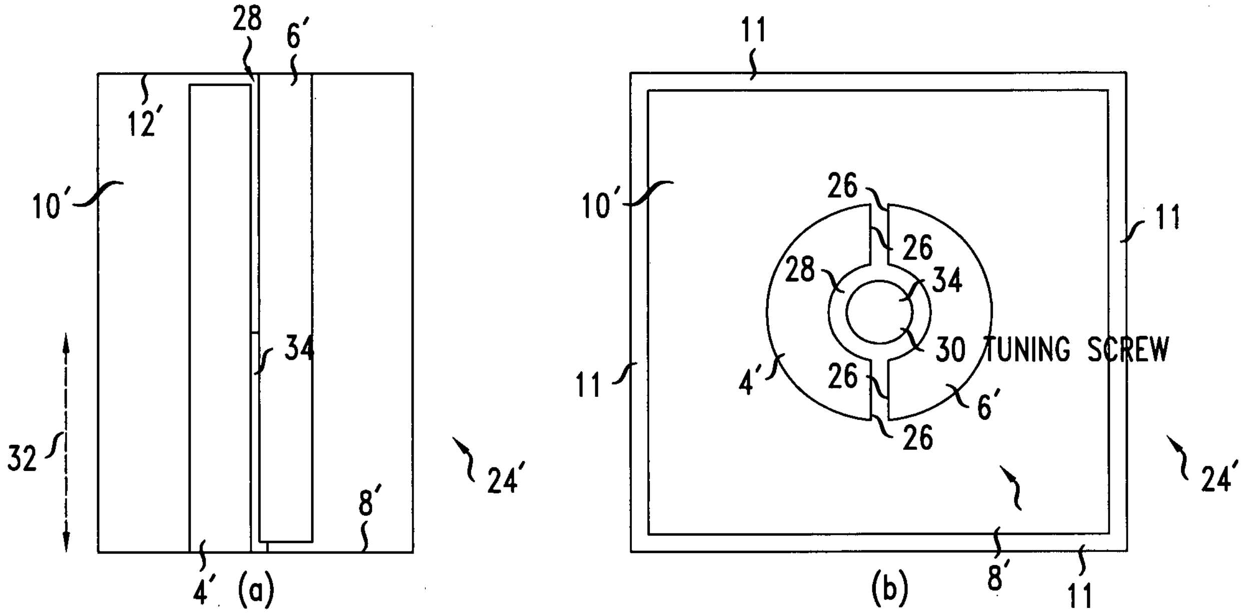

28
6′
12′
10′
34
32
24′
8′
4′
(a)
11
10′
26
26
28
34
30 TUNING SCREW
11
11
4′
26
6′
26
24′
8′
11
(b)

FIG. 9

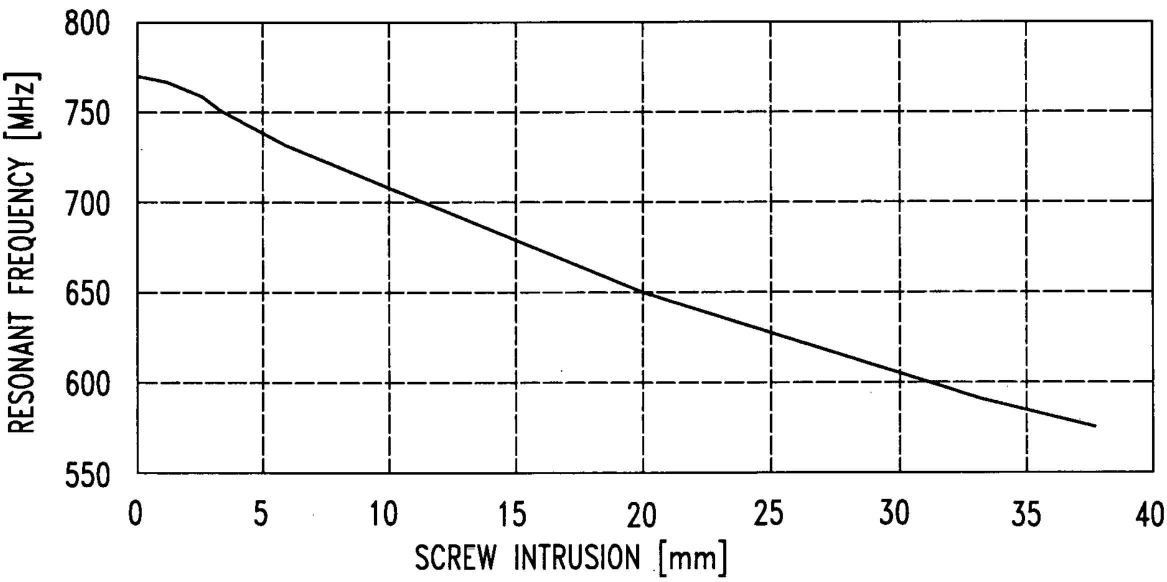

RESONANT FREQUENCY [MHz]
800
750
700
650
600
550
0
5
10
15
20
25
30
35
40
SCREW INTRUSION [mm]

FIG. 10

ALTERNATE PROPOSAL

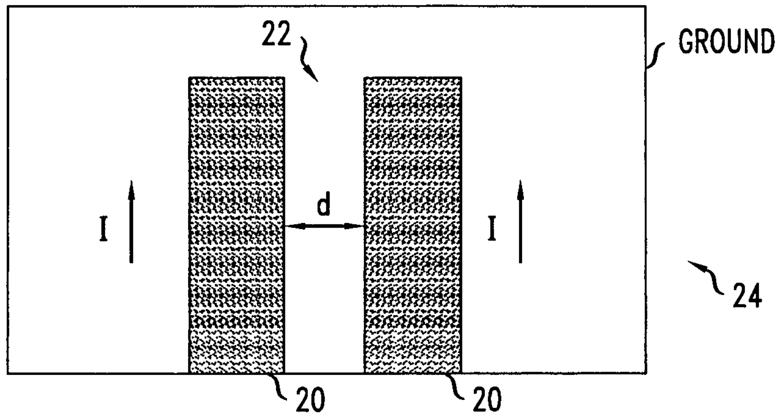


FIG. 11

ALTERNATE PROPOSAL

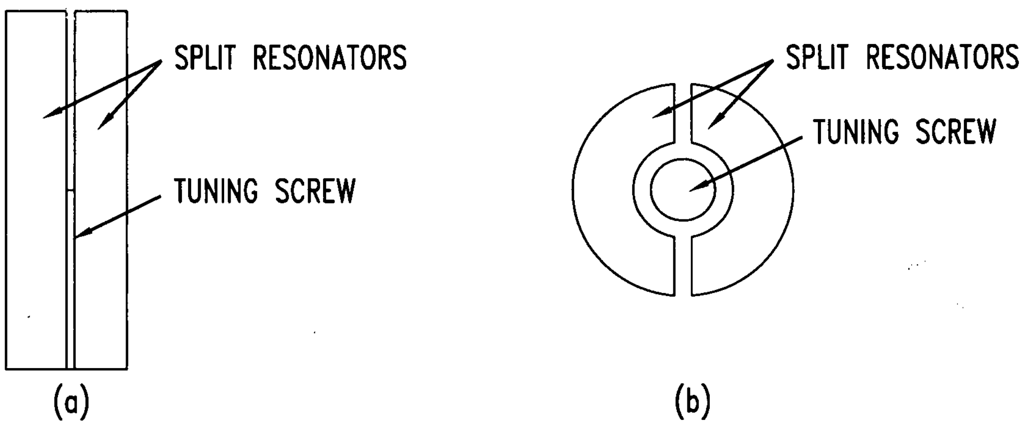
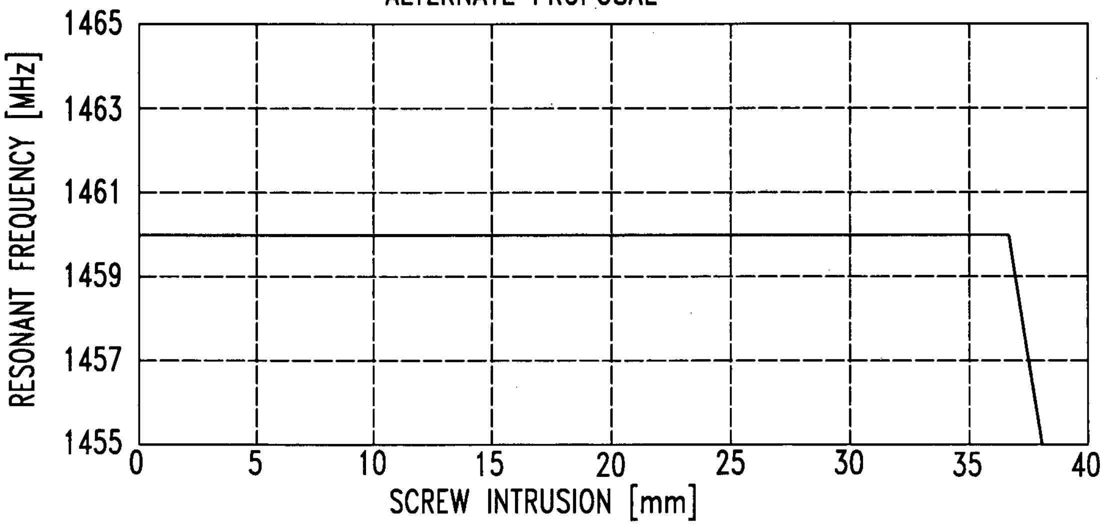


FIG. 12

ALTERNATE PROPOSAL



REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 2004051603 A1 **[0014] [0015] [0016]**
- EP 1575118 A1 **[0014]**
- EP 0038996 A1 **[0014]**
- JP S714201 A **[0014]**