



(43) International Publication Date
15 December 2016 (15.12.2016)

- (51) International Patent Classification:
H01P 7/04 (2006.01)
- (21) International Application Number:
PCT/EP2016/062908
- (22) International Filing Date:
7 June 2016 (07.06.2016)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
15305864.9 8 June 2015 (08.06.2015) EP
- (71) Applicant: **ALCATEL LUCENT** [FR/FR]; 148/152 route de la Reine, 92100 Boulogne-Billancourt (FR).
- (72) Inventors: **BULJA, Senad**; Alcatel Lucent Ireland Ltd, Blanchardstown Business Tech P, Snugborough Road, Blanchardstown, Dublin 15 (IE). **GIMERSKY, Martin**; 4 Falcon's View, Blanchardstown, Dublin, 15 (IE).
- (74) Agent: **SARUP, David Alexander**; Intellectual Property Business Group, Christchurch Way, Greenwich, London Greater London SE10 0AG (GB).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: RESONATOR ASSEMBLY AND FILTER

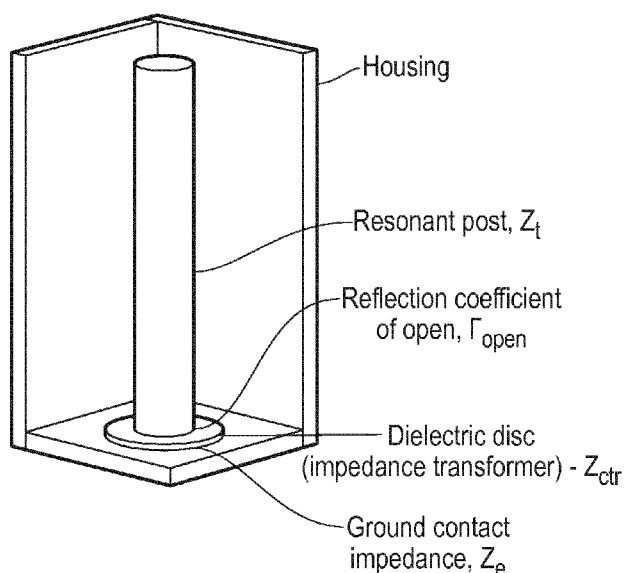


FIG. 1b

(57) Abstract: A resonator assembly and filter formed therefrom is disclosed. The resonator assembly comprises: a conductive resonator cavity; a conductive resonant member mounted within the resonator cavity; and a dielectric spacer element mounted between the conductive resonant member and the conductive resonator cavity.

RESONATOR ASSEMBLY AND FILTER

FIELD OF THE INVENTION

The present invention relates to cavity resonator assemblies and filters formed
5 therefrom.

BACKGROUND

Filters formed from resonators are essential components of radio frequency RF systems such as base stations, radar systems, point-to-point radio links, and RF signal
10 cancellation systems. Although a specific filter is chosen or designed dependent on the particular application, there are certain desirable characteristics that are common to all filter realisations. For example, the amount of insertion loss in the pass-band of the filter should be as low as possible, while the attenuation in the stop-band should be as high as possible. Further, in some applications the frequency separation between the
15 pass-band and stop-band (guard band) needs to be very small, which requires filters of high order to be deployed in order to achieve this requirement. However, the requirement for a high order filter is always followed by an increase in the cost (due to the greater number of components that such a filter requires) and space.

20 One of the challenging tasks in filter design is to reduce their size while retaining much of their electrical performance such that their performance is comparable with larger structures. One of the main parameters governing filter's selectivity and insertion loss is the so-called quality factor of the elements comprising the filter – the “Q factor”. The Q factor is defined as the ratio of energy stored in the element to the time-averaged
25 power loss. For lumped elements that are used especially at low RF frequencies for filter design Q can be of the order ~60-100, whereas for cavity type resonators Q can be as high as several 1000s. Although lumped components offer significant miniaturization their low Q factor prohibits their use in highly demanding applications where high rejection and/or selectivity is required.

30 The requirement for a high Q factor of individual resonators of a filter being important, a great deal of effort is placed on the design of resonators that offer the highest achievable Q factor in a given volume. However, very often the measured Q factor of a resonator is significantly lower than the designed Q factor available from 3D
35 electromagnetic simulations. In extreme cases, even when almost the smallest detail appears to have been taken into account, the measured Q factor trails the simulated one by 12–20%. The principal culprit in such cases is often the quality of contacts between

the constituting parts of the resonator. This is particularly pronounced in coaxial cavity resonators, where individual resonators need to be fixed to the housing, using – by and large – screws. Since the imperfect contact of the resonator with the cavity enclosure reduces the Q factor, the standard practice is to overdesign the resonator, i.e., design
5 the resonator for a Q factor that is say 20% larger than the minimum required. Clearly this is wasteful, since typically a great deal of effort and time is dedicated to the 3D computational design of a resonator.

It would be desirable to produce a resonator with of a limited size and good Q factor.
10

SUMMARY

According to a first aspect of the present invention there is provided a resonator assembly comprising: a conductive resonator cavity; a conductive resonant member mounted within said resonator cavity; and a dielectric spacer element mounted
15 between said conductive resonant member and said conductive resonator cavity.

Conventionally, the problem of a reduction in Q factor due to the imperfect contact of the resonator member with the cavity has been addressed by trying to improve this contact and/or by overdesigning the resonator assembly to compensate for the
20 inevitable reduction in Q factor due to the imperfect contact. The inventors of the present invention have addressed the problem in a different, and in many ways, counter-intuitive manner by adding an element between the cavity and the resonant member rather than by seeking to reduce the resistance at the junction between the cavity and resonant member.

25 The inventors recognised that the quality or Q factor of a resonator is dependent on the reflection coefficient at the end of the resonant member adjacent to the conductive cavity and that defects in the contact surfaces increase reflective losses. The use of a dielectric spacer element between the resonant member and cavity produces a
30 reflection coefficient at the cavity resonant member interface that is due to an open rather than closed circuit and the requirement to continually try to reduce the resistance between two touching conductive elements is removed. Imperfections in the contact surfaces of the dielectric spacer elements and the cavity walls and resonant member will affect the relative permittivity of this element which in turn affects the
35 frequency of operation of the resonant member rather than the reflection coefficient.

The Q factor of this resonant assembly is affected by the characteristic impedance of the dielectric spacer element and the value of this can be selected and can be more easily

controlled than can the parasitic impedance due to imperfect contacts in a resonator assembly without the dielectric spacer. Thus, a resonant assembly where the Q factor can be more accurately determined and controlled is achieved.

5 In some embodiments, said dielectric spacer element is mounted on a first inner surface of said resonator cavity, said conductive resonant member being mounted on said dielectric spacer element and extending from said dielectric spacer element towards an opposing second inner surface of said resonator cavity.

10 The conductive resonant member is spaced from the inner surface of the resonator cavity by in some embodiments mounting the dielectric spacer element on the cavity and the resonant member on the dielectric spacer element.

The dielectric spacer element may be operable as an impedance transformer
15 introducing a 90° phase change in a signal travelling through said dielectric spacer element.

The dielectric spacer element acts as an impedance transformer and this introduces a phase shift in the signal. The resonant member is a $\frac{1}{4}$ wavelength or 90° long and the
20 dielectric spacer acts as an impedance transformer and is therefore also 90° long, in view of this, the signal that travels along the combined structure of the conductive post and the dielectric spacer (from top of the conductive post to the part of the dielectric spacer that is in direct contact with the housing) exhibits a phase change of 180°. The losses due to the reflection of the signal at the conductive cavity are dependent upon
25 the characteristic impedance of the dielectric spacer. In effect a spacer element which acts as an impedance transformer provides a resonant assembly where the characteristic impedance of this impedance transformer is the feature that affects the Q factor rather than the more difficult to control contact resistance between the conductive resonant post and conductive cavity. Dielectric spacer elements provide a
30 suitable characteristic impedance in a compact and practical manner.

In some embodiments, said dielectric spacer element has a characteristic impedance that is less than a parasitic impedance of the reflective load between said resonant member and said resonator cavity were said dielectric spacer not present and said
35 resonant member were mounted directly on said first inner surface of said resonator cavity.

Where the characteristic impedance of the dielectric spacer element is lower than the parasitic resistance that would exist between the conductive resonant member and cavity if it were mounted directly on the inner surface of the cavity, then the reflection coefficient will be improved by the presence of the dielectric spacer element and reflection losses will be reduced. As noted previously reducing the parasitic resistance between the resonant member and cavity wall below a certain value becomes increasingly difficult, while providing a dielectric spacer element with a characteristic impedance that is less than this, is relatively straightforward requiring a thin element, which, where an expensive dielectric material is used, is itself an advantage.

In some embodiments, said dielectric spacer element is formed of a ceramic material.

Although a number of different materials are suitable for the dielectric spacer element, their suitability depending on their characteristic impedance, relative permittivity, compactness and strength, ceramics have been found to be particularly suitable, being rigid, robust and providing a low characteristic impedance in a small element. These materials are often expensive, however as only a thin element is required, this is not prohibitive.

In some embodiments the dielectric spacer element is formed of a low-temperature co-fired ceramic material.

Low-temperature co-fired ceramic material can be used to generate spacer element that are relatively inexpensive, easy to fabricate and provide suitable electrical properties.

One advantage of forming the dielectric spacer from low-temperature co-fired ceramic materials is that they may be applied to the surface of the cavity by depositing techniques and this provides a good contact with the inner cavity wall removing air voids which affect the permittivity of the material. Furthermore, this method of manufacture effectively fixes the material to the cavity without requiring additional fixing means and furthermore, a very thin element is easily achievable.

The dielectric spacer element can have a number of forms including a disk type form which may make it particularly suitable where the conductive resonant member is in the form of a post.

In some embodiments, said conductive resonant member is fixed within said resonator cavity by a dielectric fixing element.

One challenge with resonant members is how to fix them firmly to the cavity while
5 preserving their required electrical properties. Where an additional element is present then this can add additional challenges. One way of affixing the resonant member to the cavity where an intermediate dielectric spacer element is present is to use a dielectric fixing element such that no conductive link between the conductive cavity and the conductive member is inadvertently provided by the fixing means and the
10 properties provided by the spacing element are preserved.

In some embodiments, said dielectric fixing element comprises a ceramic screw.

One fixing element that can be used is a ceramic screw. These are readily available and
15 have properties similar to that of the spacing element.

In other embodiments, said resonant member is glued to said dielectric spacing element.

20 An alternative way of fixing the resonant member is to glue it to the dielectric spacing element. This spacing element may itself be glued to the inner cavity wall or alternatively it may be deposited onto the wall.

In some embodiments, a surface of said dielectric spacing element that abuts said
25 resonant member is larger than a surface of said resonant member that abuts said dielectric spacing element such that said dielectric spacing element extends beyond said resonant member.

Although the dielectric spacing element can have the same or a smaller surface area
30 than the resonant member, in some cases the dielectric spacing element may have a larger surface area. A larger surface area reduces the current density in the dielectric spacer and increases the power handling capacity of the device. Where the resonant member is a post and the dielectric spacer is a disk then this increased surface area is reflected in a disk with a larger diameter than the diameter of the resonant post.

35 In some embodiments, said dielectric spacing element has a thickness of between 1 micron and 2 mm.

As noted previously it is desirable that the dielectric spacing element has a low characteristic impedance and a compact form so as not to unduly increase the size of the resonant assembly. Thin disks of between 1 micron and 2mm have been found to be particularly suitable.

5

In some embodiments, said dielectric material of said dielectric spacing element has a relative permittivity of between 5 and 100.

10 A dielectric material is a poor conductor of electricity which can be polarised by and therefore support an electric field. This polarisation ability is measured by the dielectric constant or relative permittivity of the material. A dielectric material having a relative permittivity of between 5 and 100 has been found to provide suitable properties.

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

The resonator assemblies may be used to form a filter and in such a case multiple resonator assemblies are linked together and a portion of an input signal within a pass band of the assemblies travels between the assemblies while signals outside of this pass
30 band are impeded.

In some embodiments, said filter is at least one of a radio frequency filter and a combline filter.

35 A further aspect of this technique provides a resonator assembly comprising: a conductive resonator cavity; a conductive resonant member mounted within said

resonator cavity; and an impedance transformer mounted between said conductive resonant member and said conductive resonator cavity.

It has been found that providing an impedance transformer mounted between said
5 conductive resonant member and said conductive cavity provides a 90° phase shift in the signal travelling through the impedance transformer and this provides a resonant assembly where the reflection coefficient is due to an open rather than a closed circuit and thus, the reflection coefficient and the Q factor are no longer affected by imperfections in the conductive connection between the conductive member and
10 conductive cavity. The impedance transformer may advantageously be a dielectric spacer element.

In summary aspects seek to address the problem of contact impedances between a conductive resonant member and conductive cavity significantly reducing the Q factor
15 of the resonator. The problem is addressed by providing an impedance transformer between the two conductive elements which removes or at least reduces the effect of the resistance of the imperfect contact between conductive members correspondingly reducing the required amount of computational overdesign, and therefore the design cost.

20 Elements that are described as being conductive are formed of a material that conducts electricity well such as a metal. Such a material will typically have a conductivity of more than 1×10^6 S/m.

25 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.

30 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

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

Figure 1a illustrates a conventional coaxial resonator;
 Figure 1b illustrates an AC-coupled coaxial resonator according to an embodiment;
 Figure 2 illustrates variations in the reflection coefficients Γ_{short} and Γ_{open} versus
 characteristic impedance of impedance transformer Z_{ctr} , when the impedance of the
 5 conductive member $Z_i = 50\Omega$ and the parasitic reflective load impedance is $Z_e = 3\Omega$;
 Figure 3 illustrates details of the anchored end of resonant post to resonator cavity
 wall; and
 Figure 4 illustrates a filter comprising multiple resonator assemblies according to an
 embodiment.

10

DESCRIPTION OF THE EMBODIMENTS

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

15 As noted previously the imperfect contact between a resonator member and the
 resonator cavity enclosure can significantly reduce the Q factor. At present there exists
 no good solution to this problem. Manufacturers and suppliers of filters usually resort
 to the design of resonators with a Q factor that is higher than needed in the hope that
 the measured Q factor will be of the order needed. In doing so, suppliers usually rely
 20 on their archive of measured data of different resonators in order to determine by how
 much the simulated Q factor needs to be increased. This is generally in the range of
 12–20% and, in practical terms, significantly and unnecessarily increases the volume of
 individual resonators.

25 Embodiments seek to address this by separating the conductive resonator member
 from the conductive resonator cavity inner wall to which it is anchored by inserting a
 spacer element between the two elements. This spacer element is formed of a dielectric
 material and provides an impedance transformation such that there is a 90° phase shift
 in the signal travelling through the spacer element. For a quarter wavelength resonator
 30 member there is thus, a total 180° phase shift in the input signal, 90° in the resonant
 post and 90° in the spacer element. The Q factor of such a resonant assembly will vary
 with the characteristic impedance of the spacer element and this can be selected to have
 a desired value. In particular, if the spacer element has a characteristic impedance with
 a lower value than the value of the parasitic impedance due to an imperfect contact
 35 between a resonant member and the cavity wall without the spacer element then a
 resonator assembly with a higher Q factor will be achieved. Thin spacer elements
 formed from ceramic materials less than 2mm thick provide a suitable characteristic

impedance and an improved resonator assembly whose size is not greatly increased by the addition of these elements.

Figure 1a shows a coaxial resonator according to the prior art, while Figure 1b shows a
 5 similar coaxial resonator according to an embodiment, where the resonant member is attached to the housing via a dielectric spacer. Conventionally, as depicted in Fig. 1(a), the resonant member is attached directly to the housing using a screw. Even though this connection appears to be adequate to form a good short connection, in reality – due to the fact that the surface of the bottom of the resonator is not perfectly flat and
 10 smooth – there are small air voids formed, which results in an imperfect contact. This imperfect contact manifests itself in the form of equivalent impedance between the bottom of the resonator and the housing.

Even though the quality of the contact may be improved by increasing the force that
 15 binds the resonator post and the housing, such a solution has obvious limitations. Firstly, this would demand more robust screws that are able to withstand the increased force and, secondly, the increased force may cause damage to the housing itself, e.g., the housing wall may buckle. Furthermore, this would still not fully solve the problem of contact, as the air voids would still continue to exist, albeit somewhat reduced in
 20 volume and/or number.

The effort to make the equivalent contact impedance Z_e zero results in the reflection coefficient at the bottom of the resonator being

$$\lim_{Z_e \rightarrow 0} (\Gamma_{short}) = \frac{Z_e - Z_t}{Z_e + Z_t} \rightarrow -1 \quad (1)$$

25 where Z_t represents the characteristic impedance of the resonant post. That is, the reflection coefficient at the bottom of the resonator has a magnitude of 1. This infers that the connection to the ground must be such that perfect reflection occurs. However, it has been shown that making $Z_e = 0$ by conventional means is difficult and an asymptotic lower limit is quickly reached – this is dictated by the machining
 30 processes of the resonator post and the housing. Although the exact value of this impedance is very difficult to measure; an estimate may be derived by examining the deterioration of the measured Q factor compared to the simulated one. This has been shown even in extreme cases, when almost the smallest detail appears to have been taken into account, to provide a measured Q factor that trails the simulated one by 12–
 35 20%.

Embodiments, seek to address this by using an impedance transformer positioned at the point of contact of the resonator and the housing, see Fig. 1(b). The impedance transformer in this case takes the form of a thin dielectric spacer, where the spacer's height and relative dielectric constant dictate the spacer's characteristic impedance and frequency of operation.

It is instructive to perform a mathematical analysis in order to determine the conditions imposed on the impedance transformer which lead to the resonator with the transformer of Fig. 1(b) outperforming the resonator without it, shown in Fig. 1(a).

10

With reference to Fig. 1(a), let Z_e refer to the equivalent parasitic resistance of the reflective load. The reflection coefficient, Γ_{short} , of resonant post terminated by the parasitic resistance is given by

$$\Gamma_{short} = \frac{Z_e - Z_t}{Z_e + Z_t} \quad (2)$$

15

Similarly, with reference to Fig. 1(b), let Γ_{open} represent the reflection coefficient of the resonant post connected to the equivalent parasitic impedance Z_e through an impedance transformer with characteristic impedance Z_{ctr}

20

$$\Gamma_{open} = \frac{Z_{ctr}^2 - Z_t Z_e}{Z_{ctr}^2 + Z_t Z_e} \quad (3)$$

In order for the resonator of Fig. 1(b) to outperform the resonator of Fig. 1(a), the following must hold: $|\Gamma_{open}| > |\Gamma_{short}|$. Solving this equation for the characteristic impedance, Z_{ctr} , one obtains the values of the characteristic impedance of the impedance transformer that satisfy this requirement

25

$$Z_{ctr} > Z_t \text{ or } Z_{ctr} < Z_e \quad (4)$$

with a condition that

$$Z_t > Z_e \quad (5)$$

30

The condition given by (5) is always achieved for practical resonators. In the arrangement presented in Fig. 1(b), the solution $Z_{ctr} > Z_t$ would indicate that the height of the dielectric cylinder acting as an impedance transformer would need to be high, which would negatively impact the length of the resonant post. In effect, this would result in a significant shortening of the resonant post (metal part), inferring that the resonant frequency of such a resonator would be increased. As such, the solution, $Z_{ctr} > Z_t$, should be discarded.

35

The second solution, $Z_{ctr} < Z_e$, requires the height of the cylinder to be small in order for the characteristic impedance of the transformer to be small. The demand for the small height is beneficial from the point of view that it does not result in a significant shortening of the resonant post, i.e., the resonator's frequency of operation is not impacted. As such, in the light of (4), it can be stated that the deterioration of the Q factor of coaxial resonators using an impedance transformer will be lower than that of its counterpart without the transformer, provided that the characteristic impedance of the transformer is lower than the equivalent impedance of the practically-achievable contact to the ground.

Figure 2 shows a graphical depiction of (1) and (2) for the case when $Z_t = 50\Omega$ and $Z_e = 3\Omega$ while Z_{ctr} is varied from 1 to 100Ω . As predicted by (3), the reflection coefficient, Γ_{open} , of the resonant post through an impedance transformer whose characteristic impedance is Z_{ctr} is greater than the resonator's short circuit reflection coefficient counterpart, Γ_{short} , in two regions.

The regions of interest in Fig. 2 are the ones for which Γ_{open} is greater than Γ_{short} . As predicted by the equations, these regions are when $Z_{ctr} < Z_e = 3$ and $Z_{ctr} > Z_t = 50$. If the second solution, $Z_{ctr} > Z_t = 50$, is discarded as unrealistic, the solution that remains is $Z_{ctr} < Z_e = 3$. Thus, provided an impedance transformer such as a ceramic disk is used that has a characteristic impedance of less than the equivalent parasitic impedance of the reflective load without the impedance transformer, a resonant assembly with an improved quality factor when compared to the same resonant assembly without the disk is obtained. This arises due to the ceramic disk acting as an impedance transformer and reducing reflective losses due to defects in the contact surfaces of the resonant member and the inner surface of the resonator cavity.

The low characteristic impedance of the impedance transformer is beneficial from two aspects:

The frequency of operation of the resonator is not unduly disturbed; and
The cost of short dielectric spacers is typically smaller than the cost of tall dielectric spacers.

It is worth noting that the introduction of an impedance transformer with $Z_{ctr} < Z_e$ changes the sign of the reflection coefficient, i.e. introduces a phase shift of 180° – this is equivalent to changing a series resonance into a parallel one and vice versa.

5

As discussed above Fig. 1(b) represents a basic conceptual embodiment of the proposed solution. In essence, the technique relies on the insertion of thin dielectric spacers at the bottom of the resonant post. The footprint of the dielectric spacer may take a variety of forms, suitably shaped to accommodate readily available stock or to ease
10 manufacturability and improve performance. For example, the footprint may be of circular, rectangular, hexagonal, octagonal or any other shape.

More specifically, a possible practical embodiment is shown in Fig. 3(a), which is a detailed depiction of the anchored end of the resonant post and the resonator cavity
15 wall. The dielectric spacer between the resonant post and the resonator cavity wall is of a cylindrical shape and depicted in light shading. Dielectric disks, produced by processes such as sintering, are available on the market. The dielectric disk is bonded to the resonant post and the resonator cavity wall. In an alternative production process, the dielectric spacer can be made of a low-temperature co-fired ceramic
20 (LTCC) material; a variety of appropriate LTCC materials – e.g. DuPont™ GreenTape™ – are readily available in the form of tapes of suitable thicknesses and dielectric properties. Although in the figure the dielectric disk's diameter is shown to be identical with that of the resonant post, workable filters can be obtained when the disk diameter is larger or smaller than the diameter of the resonant post.

25

Bold arrows in the figure show the flow of electric currents on the surfaces of the resonant post and the resonator cavity wall. Since the electric currents on the surface of the resonant post's anchored end come into contact with the dielectric spacer, it is preferable that the dielectric spacer be made of a low-loss material.

30

Fig. 3(b) shows another possible embodiment of the present invention. In this embodiment, the dielectric cylinder – depicted in light shading– features a hole providing room for a dielectric screw, which is depicted in black, to affix the resonant post to the resonator cavity wall in a bolted-joint fashion. Bold arrows show the flow of
35 electric currents on the surfaces of the resonant post and the resonator cavity: When compared with the surface-current flow in Fig. 3(a), it is apparent that in Fig. 3(b) some currents on the surface of the resonant post come into contact with the dielectric screw,

in addition to the dielectric spacer. Therefore it is important that not only the dielectric spacer but also the dielectric screw be made of a low-loss material. Such screws – made of various ceramics, etc. – are readily available on the market; they are produced for applications such as tuning screws in conventional combline resonators.

5

In the following, a performance comparison between a conventional coaxial resonator of Fig. 1(a) and an AC-coupled resonator of Fig. 1(b) will be presented. The reported performance was obtained by utilizing the full-wave analysis software tool of CST Studio Suite. For the purpose of this comparison, both resonators are made to occupy
 10 the same volume, specifically $20 \times 20 \times 40 \text{ mm}^3$. The length of the resonant post is 39 mm for the case of a conventional, DC-coupled coaxial resonator, while in the case of the proposed AC-coupled resonator, this length is reduced by the value that corresponds to the thickness of the dielectric cylinder, namely 0.2 mm; this yields an overall length of 38.8 mm for the AC-coupled resonant post. The radius of the resonant
 15 post is the same in both cases and equals 3 mm. The performance comparison is presented in Table I. The dielectric properties of the dielectric cylinder are typical of a ceramic material, and for the purpose of this comparison, they are chosen to be $\epsilon_r = 20$ and $\tan \delta = 1 \times 10^{-4}$. Three cases are presented for the AC-coupled resonator, depending on the radius of the dielectric cylinder.

20

	Q factor	Centre frequency (GHz)
Quarter-wave post of Fig. 1(a)	2561 ($\leftarrow$ 2910)	1.512
AC-coupled resonator (transformer radius = 3 mm) with ceramic	2864	1.563
AC-coupled resonator (transformer radius = 4 mm) with ceramic	2884	1.558
AC-coupled resonator (transformer radius = 5 mm) with ceramic	2884	1.558
AC-coupled resonator (transformer radius = 3 mm) with DuPont GreenTape	2869	1.592

Table I: Performance comparison between conventional resonator and AC-coupled resonator for various radii of dielectric discs.

The computed value of the Q factor for the reference case of the conventional, DC-coupled resonator is 2910. Accounting for the least-deterioration scenario when the surface roughness and imperfect surface flatness on the interface between the resonant post and the resonator cavity wall degrade the Q-factor value by only 12%, the best
 5 practically achievable value of the Q factor is 2561 ($= 2910 \times 0.88$).

As evident from this table, the AC-coupled resonator with ceramic discs outperforms its DC-coupled counterpart by approximately 13% ($2884/2561 = 1.13$) in terms of the achievable Q factor, with a slight increase in the centre frequency. The highest
 10 computed increase in the frequency of operation is about 3%. Note the computed values of the Q factor for the cases of AC-coupled resonators do not need to be lowered, since the dielectric spacers eliminate the metal-to-metal connection between the resonant post and the resonator cavity wall that brings about the reported deterioration of the measured Q factor.

15 Also presented in the table is the case of an AC-coupled resonator employing a dielectric disc formed of DuPont™ GreenTape™ with a thickness of 1.27 mm. The material allows thick films to be deposited on metal surfaces and is commonly used in low-loss LTCC applications up to millimetre-wave frequencies, specifically from 100
 20 MHz to 150 GHz. The principal advantage of the LTCC technology compared to other materials is that it provides for a mature and relatively cheap technological process while offering ceramic-like performance: low dielectric loss (orders of $\tan \delta = 1 \times 10^{-4}$) and a relatively high dielectric constant (about $\epsilon_r = 7 - 8$). The performance of the AC-coupled resonator with GreenTape™ is somewhat lower than that of its ceramic-disk
 25 counterparts (similar Q factor but increased centre frequency); however, the material has many practical advantages. For example, once the LTCC tape material is deposited on the metal surface using thick-film technology, air voids are inherently ruled out of existence; in comparison, the risk of air voids reducing the effective dielectric constant of ceramic disks is small but existent. Both classes of materials – ceramic disks and
 30 LTCC tapes – exhibit mutually comparable performance; however, the LTCC technology has the potential to provide a cheaper and more-repeatable process.

Figure 4 shows the resonant chambers of Figure 1b arranged in series to form a combline filter according to an embodiment. A signal in this embodiment enters the
 35 filter on the left hand side and provided it is within the frequency band of resonance of the resonator assemblies it passes through the filter to exit on the right hand side. Any portion of the signal not within the pass band of the filter is impeded.

Although in this embodiment the resonant chambers are shown as arranged in a row in a combline filter other arrangements of the resonator chambers to form different filters could be envisaged.

- 5 In summary embodiments address the problem of parasitic ground contact impedance between a resonant member and resonator cavity limiting the practically achievable value of the Q factor of coaxial resonators by replacing the metal-to-metal connection with a dielectric spacer. This dielectric spacer can be manufactured by established, mature technologies. This provides for an appreciable performance improvement
10 compared to conventional coaxial resonators without significantly adding to the cost.

In summary, Q-factor values higher by at least 13% can be achieved in the same volume compared to the conventional resonator, without a significant increase in the cost. Conversely, for the same achievable Q-factor value, the volume of the resonator cavity
15 can be reduced.

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.
20

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,
25 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
30 invention, as well as specific examples thereof, are intended to encompass equivalents thereof.

CLAIMS

1. A resonator assembly comprising:
a conductive resonator cavity;
5 a conductive resonant member mounted within said resonator cavity; and
a dielectric spacer element mounted between said conductive resonant member
and said conductive resonator cavity; wherein
said dielectric spacer element is mounted on a first inner surface of said
resonator cavity, said conductive resonant member having an anchored end mounted
10 on said dielectric spacer element and extending to a non-anchored end from said
dielectric spacer element towards an opposing second inner surface of said resonator
cavity.
2. A resonator assembly according to claim 1, wherein said dielectric spacer
15 element is operable as an impedance transformer and introduces a phase change of 90°
in a signal travelling through said dielectric spacer element.
3. A resonator assembly according to any preceding claim, wherein said dielectric
spacer element has a characteristic impedance that is less than a parasitic impedance of
20 the reflective load that would exist between said resonant member and said resonator
cavity were said dielectric spacer not present and said resonant member were mounted
directly on an inner surface of said resonator cavity.
4. A resonator assembly according to any preceding claim, wherein said dielectric
25 spacer element is formed of a ceramic material.
5. A resonator assembly according to any preceding claim, wherein said dielectric
spacer element is formed of a low-temperature co-fired ceramic material
- 30 6. A resonator assembly according to claim 5, wherein said dielectric spacer
element is formed by depositing said low-temperature co-fired ceramic material on said
first inner surface of said resonator cavity.
7. A resonator assembly according to any one of claims 1 to 5, wherein said
35 dielectric spacer element comprises a disk.

8. A resonator assembly according to any preceding claim, wherein said conductive resonant member is fixed within said resonator cavity by a dielectric fixing element.
- 5 9. A resonator assembly according to any one of claims 1 to 7, wherein said resonant member is glued to said dielectric spacing element.
- 10 10. A resonator assembly according to any preceding claim, wherein a surface of said dielectric spacing element that abuts said resonant member is larger than a surface of said resonant member that abuts said dielectric spacing element such that said dielectric spacing element extends beyond said resonant member.
- 11 11. A resonator assembly according to any preceding claim, wherein said dielectric spacing element has a thickness of between 1 micron and 2 mm.
- 15 12. A resonator assembly according to any preceding claim, wherein said dielectric material of said dielectric spacing element has a relative permittivity between 5 and 100.
- 20 13. A filter comprising:
a plurality of resonator assemblies according to any preceding claim comprising an input resonator assembly and an output resonator assembly arranged such that a signal received at said input resonator assembly passes through said plurality of resonator assemblies and is output at said output resonator assembly;
25 an input feed line configured to transmit a signal to an input resonant member of said input resonator assembly such that said signal excites said input resonant member, said plurality of resonator assemblies being arranged such that said signal is transferred between said corresponding plurality of resonant members to an output resonant member of said output resonator assembly;
30 an output feed line for receiving said signal from said output resonant member and outputting said signal.
14. A filter according to claim 13, said filter being at least one of a radio frequency filter and a combline filter.

35

1/3

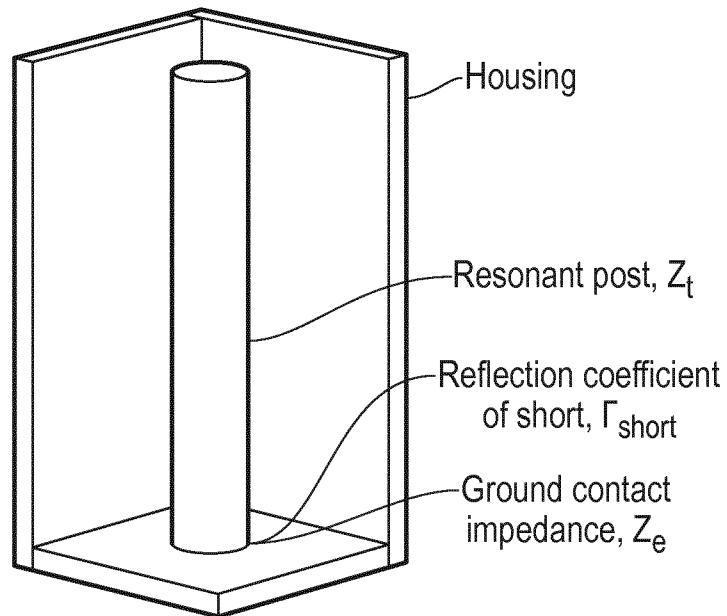


FIG. 1a

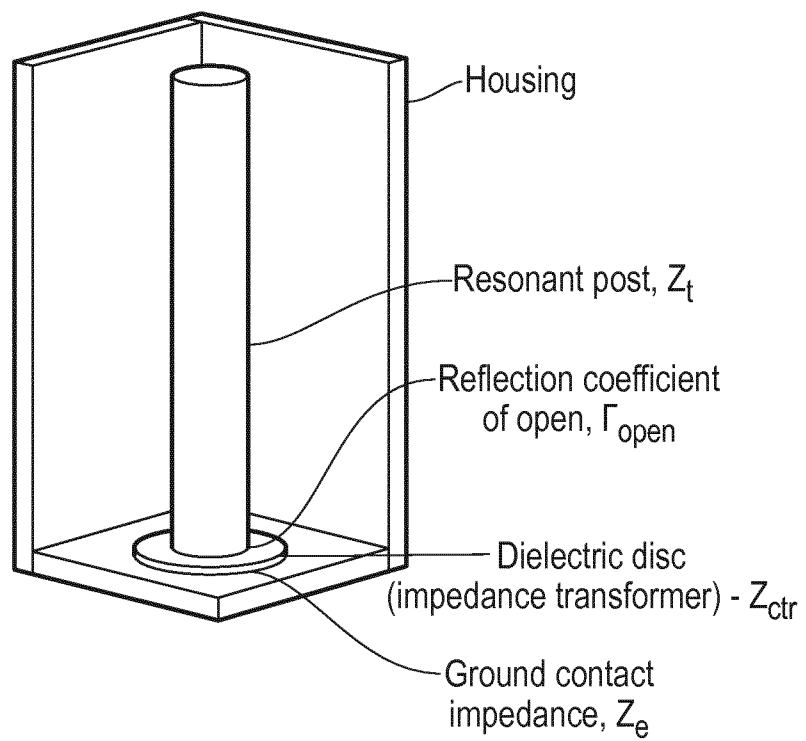


FIG. 1b

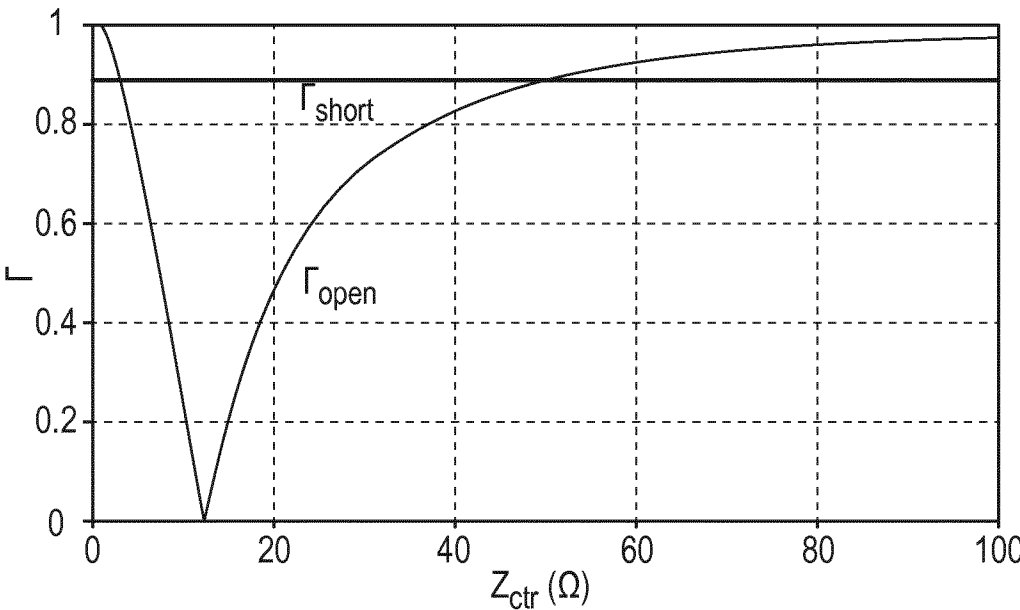


FIG. 2

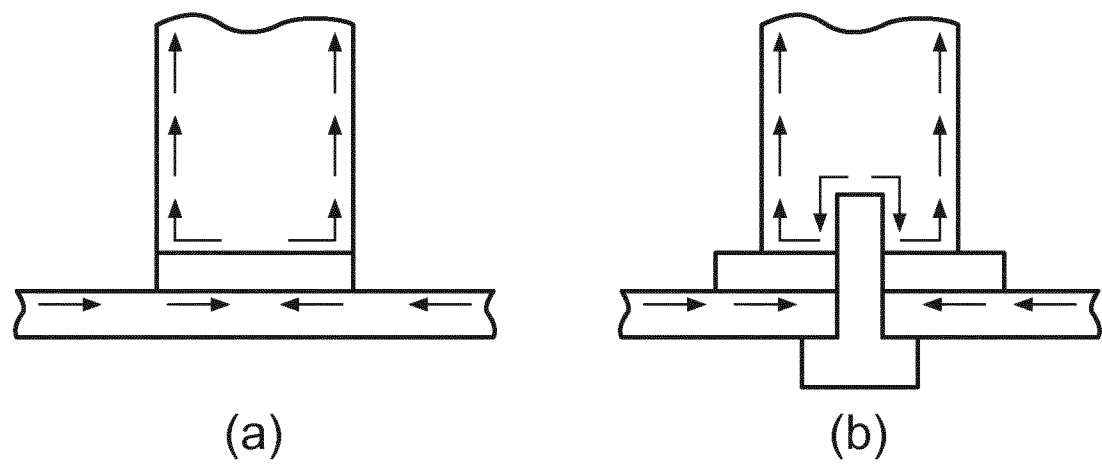


FIG. 3

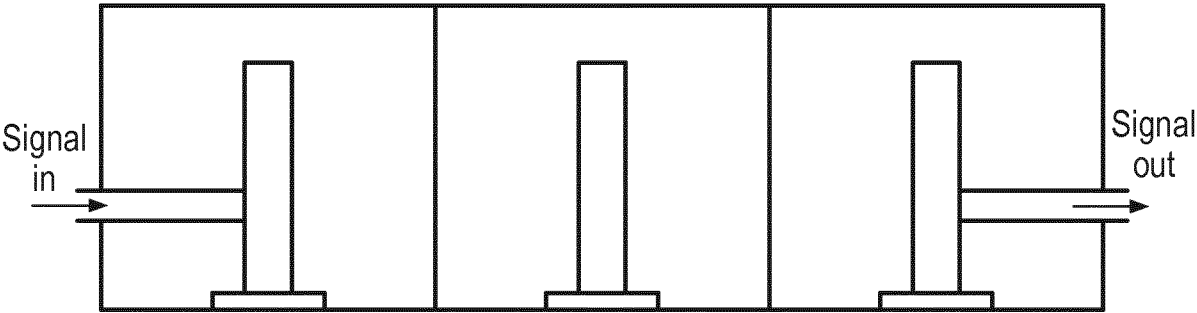


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/062908

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01P7/04
ADD.

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

B. FIELDS SEARCHED

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

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

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

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP S57 168505 A (TOYO COMMUNICATION EQUIP) 16 October 1982 (1982-10-16) abstract; figures 2,5,6 -----	1-14
X	JP S59 223005 A (TOYO COMMUNICATION EQUIP) 14 December 1984 (1984-12-14) abstract; figures 1,4,5 -----	1-14
X	US 2010/327996 A1 (KLEIN NORBERT [GB] ET AL) 30 December 2010 (2010-12-30) paragraph [0031] - paragraph [0036]; figures 1a,1b -----	1-14
X	US 2 771 516 A (BUCKSBAUM ARNOLD M) 20 November 1956 (1956-11-20) column 1, line 52 - column 2, line 27; figures 1,2 ----- -/--	1-14



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

15 September 2016

Date of mailing of the international search report

23/09/2016

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Pastor Jiménez, J

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2016/062908

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 730 174 A (NISHIKAWA TOSHIO [JP] ET AL) 8 March 1988 (1988-03-08) column 1, line 15 - line 34; figure 1 column 3, line 3 - line 60; figure 2 -----	1-14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/062908

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP S57168505 A	16-10-1982	JP S632361 B2	19-01-1988
		JP S57168505 A	16-10-1982
JP S59223005 A	14-12-1984	JP H0356001 B2	27-08-1991
		JP S59223005 A	14-12-1984
US 2010327996 A1	30-12-2010	NONE	
US 2771516 A	20-11-1956	NONE	
US 4730174 A	08-03-1988	JP S6345042 Y2	22-11-1988
		JP S59174703 U	21-11-1984
		US 4730174 A	08-03-1988