

Fig. 2

Description

FIELD OF THE INVENTION

[0001] This invention relates to dielectric resonators and more particularly to a dielectric resonator comprising a transmission line and a capacitive element as defined in the independent claim.

BACKGROUND OF THE INVENTION

[0002] Resonators are primarily used as frequency selective components in microwave filters, oscillators, and antennas. At low frequencies, so-called lumped element capacitors and inductors form a resonator. They, however, fail to work at intermediate and high frequencies. At high frequencies, cavity resonators are used. Since the frequency of the fundamental mode of a cavity is inversely proportional to the cavity dimension, at intermediate frequencies cavity resonators become too bulky. A possibility to reduce the physical size of cavity resonators is to fill them in a suitable way with a high permittivity dielectric material. A further possibility is to use lumped elements also at intermediate and high frequencies by combining them with transmission line elements, e.g. impedances, conductors and dielectrics, forming so-called semi-lumped resonators.

[0003] A crucial item for resonators in most applications is the temperature stability of the resonance frequency of the resonator. Therefore, thermal expansion and permittivity changes of the involved parts are either sought to be minimized or are a set-up is used where the changes cancel each other out as good as possible. Such set-ups are disclosed e.g. in the documents "*Frequency tuning of rutile resonators*," *Proc. IEEE*, 1966, 413-414 by M.R. Stiglitz and "*Tunable, temperature-compensated dielectric resonators and filters*," *IEEE Trans. Microw. Theory Techn.*, vol. 38, no. 8, August 1990, pp. 1046-1051 by S.-W. Chen, K.A. Zaki, R.G. West. Some possibilities to achieve at least some temperature stability of the resonance frequency are for example to use metal alloys of minimized thermal expansion, e.g. INVAR, or the use of temperature-compensated dielectric materials, e.g. $\text{Ba}_2\text{Ti}_9\text{O}_{20}$ as mentioned in the document US-6'034'015 or many others. It is also possible to combine two dielectrics having large variations of permittivity with temperature, but of opposite sign, e.g. TiO_2 and LiNbO_3 as is disclosed in the document US 3'798'578.

[0004] Temperature compensated dielectric materials offered by several manufactures suffer from various drawbacks. For example these temperature compensated materials have a decreased electrical performance compared to the uncompensated raw materials, which means higher losses. In addition the technological complexity of the production of these ceramics result in low production yields and very high costs.

[0005] The compensation of permittivity variation by means of appropriate thermal variation is limited to dielectrics having small permittivity variations and may require tricky mechanical design.

[0006] The compensation of permittivity variation by means of another material having about the same magnitude of variation of opposite sign is e.g. disclosed in the document "*The design of a temperature-stable stepped-impedance resonator using composite ceramic materials*," *IEEE Microw. Guided Wave Lett.*, vol. 9 (1999), no. 4, 143-144 by S.-K Lim, H.-Y. Lee, J.-C. Kim, C. An. However, this way of permittivity variation compensation noticeably limits the choice of materials.

[0007] It is the object of the invention to overcome deficiencies of prior art temperature compensated resonators and especially to provide resonator for which temperature stability for a given production cost is optimized. In particular, it is an object of the invention to provide a dielectric resonator, which allows a wider range of dielectric materials to be used in the resonator than state of the art dielectric resonators. If possible, the frequency compensated resonator, should be reduced in size compared to or at least not be considerable bulkier than state of the art dielectrically loaded cavity resonators and transmission line resonators.

[0008] These objects are achieved by the dielectric resonator as defined in the claims.

SUMMARY OF THE INVENTION

[0009] An idea underlying the invention is to divide the resonator into regions where the magnetic field is dominant (i.e. where the main part of the energy is stored in the magnetic field) and regions where the electric field prevails. In the regions where the magnetic field is dominant, the resonance frequency is only weakly dependent on the permittivity, i.e. the frequency dependence on the permittivity there is a higher order effect. In these regions, therefore, a first material with a high permittivity and a high temperature coefficient of the permittivity can be used. In the regions, where the electric field is dominant, preferably a second material with a low temperature coefficient of the permittivity, e.g. of the opposing sign than the first material can be used.

[0010] The composite dielectric resonator according to the invention (a "semi-lumped resonator") therefore comprises a first transmission line, a capacitive element and a second transmission line, as well as at least one port for coupling to external circuits. The first and the second transmission line comprise a first dielectric material, and the capacitive

element comprises a second dielectric material, the second dielectric material having a temperature coefficient of permittivity smaller in magnitude than that of the first dielectric material.

[0011] The transmission lines are electrically of about equal length as and preferably shorter than a quarter of a wavelength of the basic mode and store mainly magnetic field.

[0012] The variation of the resonance frequency is mainly due to the temperature dependency of the permittivities of the materials involved. Of course, the resonance frequency in addition is also influenced by thermal expansion. However, usually permittivity variations and thermal expansion have a similar effect, but the latter is generally smaller than the former. Therefore, in the following description only the permittivity variations are discussed. It, however, goes without saying that the temperature dependence due to thermal expansion is also addressed. Thus, the argumentation presented for permittivity changes in the following always includes the thermal expansion effects. To be specific, in order to entirely exclude an effect of temperature dependencies, it is not a requirement that the permittivity be temperature constant but that:

$$2 \cdot \text{coeff. of thermal expansion} + \text{temperature coeff. of permittivity} = 0$$

holds.

[0013] In the dielectric resonator according to the invention, thus, the transmission line, the capacitive element and dielectric materials are arranged in a way that the resonator has a stabilized resonance frequency against temperature-induced variations of the permittivity of the involved dielectric materials as well as against thermal expansion of dielectric and metallic parts. The first dielectric material, i.e. the dielectric material of the transmission lines can have a much larger magnitude of temperature dependence of permittivity than the dielectric material on which the capacitive element is based.

[0014] An advantage of the inventive resonator structure is that the resonator can be made physically small when high permittivity dielectric materials are used. A further reduction in size compared to, e.g. dielectrically loaded, cavity resonators can be achieved by a so called semi-lumped structure containing transmission line elements, and e.g. capacitive and/or inductive elements.

[0015] In addition, the dielectric materials of transmission line elements may have much larger magnitudes of temperature dependencies of permittivity than the dielectric material of which the capacitive element is based on.

[0016] Preferably, the first dielectric material has a permittivity value exceeding 30, possibly exceeding 60, e.g. exceeding 80 or amounting to 100 (TiO_2). The second dielectric material should preferably have a temperature coefficient of permittivity which is of an opposite sign and 1.5 to 20 times, preferably two to ten times smaller in magnitude than the temperature coefficient of permittivity of the first dielectric material. It may e.g. have an absolute value below 0.00015 K^{-1} , e.g. of less than 0.0001 K^{-1} .

[0017] A third well known criterion for choosing materials is the minimization of losses, e.g. due to scattering at grain boundaries. In the GHz region, the product $Q \cdot f$ is an essentially constant where Q is the Quality factor of the material (i.e. the inverse of the loss tangent at a given frequency) and f is the frequency (in GHz). Both involved dielectric materials should preferably have low losses and high $Q \cdot f$ products. As a matter of fact, dielectric materials of high permittivity exhibit lower $Q \cdot f$ products than low permittivity materials. Furthermore, temperature-compensated high permittivity dielectric materials show even lower $Q \cdot f$ products than uncompensated raw materials. Thus, an advantage of the resonator structure presented here is that low-loss raw materials can be used. For example, uncompensated TiO_2 (permittivity 100) exhibits $Q \cdot f$ of about 40'000 ($f=1\text{GHz}$), whereas compensated $\text{Ba}_2\text{Ti}_9\text{O}_{20}$ exhibits similar $Q \cdot f$ having a permittivity of about 39 only, and compensated commercial BaSmTiO may have a permittivity of about 87 but $Q \cdot f$ of 4'500 (see J. Deriso, "Ceramic-filled transmission lines for circuit miniaturization", in: Materials and Processes for Wireless Communications, Ceramic Transactions, vol. 53, Amer. Ceram. Soc., 1995, pp. 73-82). According to an embodiment of the invention, $Q \cdot f$ should exceed 30'000 for the first material and 80'000 for the second material.

[0018] Examples of dielectric materials that can be used in the present invention are:

- Materials having large permittivity with large, negative temperature coefficients of permittivity, e.g. TiO_2 , CaTiO_3 , SrTiO_3 .
- Materials having large permittivity with large, positive temperature coefficients of permittivity, e.g. LiNbO_3 , CaZrO_3 , SrZrO_3 , CaTiSiO_5 , PbZrO_3 .
- Materials having medium permittivity with small, positive temperature coefficients of permittivity, e.g. Al_2O_3 , SiO_2 , MgO , MgTiO_3 .

- Materials having small or medium permittivity with negative temperature coefficients of permittivity, e.g. PS (polystyrene), PTFE (polytetrafluoroethylene).
- Materials having small or medium permittivity with positive temperature coefficients of permittivity, e.g. quartz (SiO₂), alumina (Al₂O₃), GaAs, MgTiO₃, ZnNb₂O₆.

[0019] The temperature coefficient of the capacitance is found to be determined by both the temperature coefficient of permittivity and the coefficient of thermal expansion of the second dielectric material such that

$$\text{temp. coeff of cap.} = \text{temp. coeff. of perm.} - \text{coeff. of thermal expan}$$

[0020] A small positive temperature coefficient of the capacitance can e.g. be realized by using a dielectric material having a positive temperature coefficient of permittivity or/and by using e.g. an air filled capacitor which electrodes approaching one another by an appropriate thermal expansion of their respective mechanical holders as is disclosed e.g. in the aforementioned document of S.-W. Chen et. al.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] In the following, preferred embodiments of the invention are described with reference to drawings. In the drawings:

FIG. 1 shows schematically a perspective cutaway view of a composite dielectric resonator embodying the present invention. A portion of the resonator has been cut away in order to illustrate more clearly the internal structure thereof.

FIG. 2 is a circuit schematic diagram representing the resonator shown in fig. 1 comprising a series arrangement of transmission lines TL and a series capacitor C. Two transmission lines are short-circuited at one of their respective ends.

FIG. 3 is a circuit schematic diagram showing a series arrangement of transmission lines TL and a series capacitor C. It is a simplification of the schematics of fig. 2 neglecting two transmission lines.

FIG. 4 shows a function plot relating the electrical length of the transmission line required for complete compensation versus the ratio of the permittivity temperature coefficients of the capacitor's and the transmission line's respective dielectric materials.

FIG. 5 shows schematically a perspective cutaway view of a composite dielectric resonator embodying the present invention. A portion of the resonator has been cut away in order to illustrate more clearly the internal structure thereof.

FIG. 6 is a circuit schematic diagram representing the resonator shown in fig. 4 comprising a series arrangement of transmission lines TL and a series capacitor C. These components form a ring circuit.

FIG. 7 is a circuit schematic diagram showing a series arrangement of a transmission line TL1 and a series capacitor C. It is a simplification of the schematic of fig. 6 neglecting two transmission lines.

FIG. 8 is a perspective view of a resonator showing a possibility to connect the resonator to an external circuits by means of a slot coupled microstrip line.

FIG. 9 is a perspective view of a resonator showing a possibility to connect the resonator to external circuits by means of a parallel coupled microstrip line.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] **FIG. 1** shows a perspective cutaway view of a composite dielectric resonator 100 according to the present invention. A portion of the resonator 100 has been cut away in order to illustrate the internal structure thereof. The resonator 100 contains an outer metallic conductor 101, an inner metallic conductor 102, and an isolating dielectric

103 of a first dielectric material that form a coaxial line section. This line section is short-circuited at one end by a metallic conductor 104. The resonator contains a second short-circuited coaxial line section made of the outer metallic conductor 101, a second inner metallic conductor 105, a second isolating dielectric 106 also made of the first dielectric material, and a second shorting metallic conductor 107. The inner metallic conductor 102 of one first transmission line is connected to a metallic capacitor electrode 108, whereas the second inner metallic conductor 105 of a second transmission line is connected to a second metallic capacitor electrode 109. The electrodes 108 and 109 are isolated from each other and form a capacitor. The space between these electrodes 108, 109 can be filled with an isolating second dielectric material 110. The capacitor formed by 108, 109, 110 as well as the short sections of 102, 107 are embodied in a third isolating dielectric material 112.

[0023] The third dielectric material 112 can be air or another material having a permittivity which differs from the permittivity of the isolating materials of 103 and 106. Especially, the third dielectric material may have a low permittivity, the transmission lines being formed between the first and second transmission lines, respectively, and the capacitive element by the outer metallic conductor 101, the inner metallic conductor 105 and this third dielectric material 112 is e.g. electrically short and mainly functions to prevent boundary effects at the capacitor electrodes from influencing the mode properties in the first and the second transmission line. In other words, they avoid unwanted electrical coupling of fields between the short-circuited first and second transmission lines and the capacitive element.

[0024] The resonator further comprises one or two ports (not shown in the figure) for interacting with external components. These ports e.g. slot feeds placed in the endface metallic conductors 104, 107. Such ports shortly described further below with reference to Figs. 8 and 9.

[0025] FIG. 2 shows the simplified circuit schematic of the resonator of fig. 1. To be seen is a series connection of a first short-circuited transmission line TL1, a first transmission line TL2, a series capacitor C, a second transmission line TL3, and a second short-circuited transmission line TL4.

[0026] The short-circuited transmission lines TL1 and TL4 are based on high permittivity dielectric material 103, 106 with temperature variation coefficients α_{TL} . They are electrically shorter than a quarter of a wavelength and store mainly magnetic field.

[0027] The transmission lines TL2 and TL3 are based on low permittivity dielectric material 112 and are electrically very short. As mentioned, they avoid unwanted electrical coupling of fields between short-circuited transmission lines TL1 and TL4 and the capacitor C. Since the transmission lines TL2 and TL3 are electrically short, their thermally induced influence on the resonance frequency is small and can be compensated by the interaction between short-circuited transmission lines TL1 and TL4 and the capacitor C as a higher order effect. This effect amounts to about the same magnitude as thermal expansion effects.

[0028] The capacitor C can be based on a dielectric material 110 and has the temperature variation coefficient α_C of the capacitance, which is due to permittivity variation and thermal expansion of the dielectric material.

[0029] FIG. 3 shows an even more simplified circuit diagram of the resonator of fig. 1 than the one shown in fig. 2: transmission lines TL2 and TL3 are neglected. A circuit analysis of the circuit shown in fig. 3 reveals that the resonance frequency ω_0 is given by $\tan \Theta_L = \frac{1}{2\omega_0 C Z_L}$, where Θ_L denotes the electrical line length, C the capacitance, and Z_L the line impedance. Consider a linearized definition of the thermal variation of permittivity as $\epsilon_{rel}(T_0 + \Delta T) = \epsilon_{rel}(T_0) \cdot (1 + \alpha_{\Delta T})$, then the coefficients of the thermal variation of the respective permittivities of the capacitor and the transmission line are α_{CAP} and α_{TL} . Hereby, α_{LINE} affects both Z_L and Θ_L of the line. The value of the thermal variation of the capacitance required for complete compensation can be found from the above formulae as

$$\frac{\sin(2\Theta_L(T_0))}{2\Theta_L(T_0)} = \frac{1}{\frac{2\alpha_{CAP}}{\alpha_{TL}}}.$$

The latter formula assumes TEM lines, but it holds approximately also for other practically relevant transmission lines. The equation shows that, for a given ratio of temperature coefficients, α_{CAP} and α_{TL} , a certain transmission line length Θ_L yields compensation.

[0030] FIG. 4 shows a plot of the compensation formula. A complete temperature compensation requires α_{CAP} and α_{TL} having opposite sign, and α_{TL} shall preferably be two to ten times larger in magnitude than α_{CAP} .

[0031] FIG. 5 shows another embodiment of a resonator of the present invention. A portion of the composite dielectric resonator 200 has been cut away in order to illustrate in more detail the internal structure thereof. The resonator 200 contains two coaxial line sections formed by an outer metallic conductor 204, inner conductors 206 and 208, respectively, and a high permittivity first dielectric material 205. The first dielectric material 205 may have a large temperature coefficient of permittivity. A metallic strip 207 connects the inner conductors 206 and 208 of the first and the second coaxial transmission lines. A second dielectric material 202 has an appropriate, but small temperature variation of permittivity and forms a series capacitor between the respective ends of the inner conductors 206, 208 of the coaxial

lines. In the drawing, the series capacitor is composed of the metallic electrodes 201, 203, 209, and the dielectric 202. Between the electrodes 203, 209 of the capacitor and the first dielectric material 205 an air gap is formed, air being the third dielectric material.

[0032] FIG. 6 shows the simplified circuit schematic of the resonator of FIG. 5, showing a ring connection of a transmission line TL1, a transmission line TL2, a series capacitor C, and transmission line TL3. In Figure 6, TL1 contains both coaxial transmission lines, i.e. the transmission lines formed by the first inner conductor 206 together with the metallic conductor 204 and the first dielectric material 205 as well as the transmission line formed by the second inner conductor 208 together with the metallic conductor 204 and the first dielectric material 205. These two lines function as one element since they are connected by the metal strip 207. The transmission lines TL2 and TL3 are formed by the air gaps between the electrodes 203 and 209, respectively, of the capacitor and the first dielectric material. They are electrically very short.

[0033] The transmission line TL1 is based on high permittivity dielectric material of temperature variation coefficient α_{TL} . It is electrically shorter than a quarter of a wavelength and stores mainly magnetic field. The transmission lines TL2 and TL3 are based on low permittivity dielectric material (air in this example) and electrically short. They avoid unwanted electrical coupling of the fields between transmission line TL1 and the capacitor. Since they are electrically short, their thermally induced influence on the resonance frequency is small and can be compensated by the interaction between transmission line TL1 and the capacitor C as a higher order effect. This effect amounts to about the same value as thermal expansion effects.

[0034] The capacitor C can be based on a dielectric material and has a temperature variation coefficient of the capacitance α_C , which is due to permittivity variation and thermal expansion.

[0035] FIG. 7 shows the resonator of fig. 5 with transmission lines TL2 and TL3 neglected. A circuit analysis of the circuit shown in Fig. 7 reveals similar results to the results given above if the electrical length of TL1 (see Fig. 7) is set to $2\Theta_L$: The resonance frequency is independent of temperature in first order, and second order effects are compensated with α_{CAP} which is again much smaller in magnitude than α_{TL} and has opposite sign.

[0036] Deviating from this design principle, the resonator can also be laid out to be open at one or two ends instead of short-circuited. In this case, the electric field prevails at the open ends of the line. The capacitive element storing energy in the form of electric field then is formed by a open line end instead of a capacitor arranged in the interior of the resonator.

[0037] FIG. 8 illustrates an example of how to couple a resonator 300, which is similar to the resonator structure 100 of fig. 1, to an external circuit by means of one or more coupling slots (302, 303) and microstrip transmission lines (301, 304).

[0038] FIG. 9 illustrates an example of how to couple a resonator 400, which is similar to the resonator structure 200 of fig. 5, to an external circuit by means of inductive coupling to a transmission line. This transmission line can be a microstrip line between line ends 401, 402, and coupled line section 403.

[0039] The resonator arrangement shown in fig. 8 realizes the coupling to external microstrip lines by means of coupling slots. A magnetic current is efficiently excited in the slot direction by both the groundplane current of the microstrip line and the radial currents in the shorting plane of the co-axial transmission line. The resonator arrangement shown in fig. 9 realizes the coupling to an external microstrip line by means of a coupled line section. Hereby, the magnetic fields caused by the microstrip current induce a current in the nearby, parallel metallic strip 207 (of fig. 5) of the resonator and vice versa. Note that the metallic strip 207 (of fig. 5) exhibits particularly high currents at resonance, thus making the coupling easy and efficient.

[0040] The resonator according to the invention, of which some examples have been described here, can have a very good temperature compensation without using much expensive highly temperature compensated dielectric material. Such a resonator, of course, can further be combined with traditional ways to compensate such as electronic feedback loops etc.

[0041] It should be noted that the resonators described here are by no means the only embodiments of the invention and that numerous other embodiments may be envisaged. As an example, the transmission lines do not have to be essentially homogeneous as described above but may also be inhomogeneous, i.e. composed of different materials. In addition, the resonator does not have to be designed to be cylindrical or rectangular as in the above examples but may have any shape allowing modes to resonate.

Claims

1. A composite dielectric resonator comprising a first transmission line (TL1), a capacitive element (C) and at least one port (301, 304, 401, 402) for coupling to external circuits, the first transmission line comprising a first dielectric material (103, 106; 205), and the capacitive element comprising a second dielectric material (110; 202) the second dielectric material having a temperature coefficient of permittivity smaller in magnitude than the temperature co-

efficient of permittivity of the first dielectric material.

2. A resonator according to claim 1 further comprising a second transmission line (TL4), comprising a dielectric material having a temperature coefficient of permittivity larger in magnitude than the temperature coefficient of permittivity of the second dielectric material.
3. A dielectric resonator as claimed in claim 2, wherein the first and the second transmission lines are shortcircuited at one of their respective ends.
4. A dielectric resonator as claimed in claim 2, wherein the first and the second transmission lines are connected together at their non-connected ends in order to form a ring circuit of all transmission lines and of the capacitor.
5. A resonator as defined in any one of the preceding claims, comprising a third and a fourth transmission line (TL2, TL3) with a third dielectric material (112) different from the first dielectric material, the first transmission line (TL1), the third transmission line (TL2), the capacitive element (C), and the fourth transmission (TL3) being connected in series.
6. A dielectric resonator as defined in any one of the preceding claims wherein the first dielectric material has a permittivity ϵ exceeding 30, preferably exceeding 80 at room temperature.
7. A dielectric resonator as defined in claim 6, wherein the first dielectric material comprises at least one of TiO_2 , CaTiO_3 , SrTiO_3 , LiNbO_3 , CaZrO_3 , SrZrO_3 , CaTiSiO_5 , and of PbZrO_3 .
8. A dielectric resonator as defined in any one of the preceding claims, wherein the second dielectric material has a temperature coefficient of permittivity which is of opposite sign and smaller in magnitude than the temperature coefficient of permittivity of the first dielectric material by a factor of between 2 and 10.
9. A dielectric resonator as defined in claim 8, wherein the second dielectric material comprises one of Alumina (Al_2O_3), Quartz (SiO_2), MgO , MgTiO_3 , ZnNbO_6 .
10. A dielectric resonator as defined in claim 8 or 9, wherein the first dielectric material comprises a large negative temperature coefficient of permittivity with an absolute value exceeding 0.00005 K^{-1} at room temperature and wherein the second dielectric material comprises a positive temperature coefficient of permittivity and/or comprises air and electrodes approaching one another by a thermal expansion of their mechanical holders.
11. A dielectric resonator as claimed in claim 8 or 9, wherein the first dielectric material comprises a large positive temperature coefficient of permittivity with an absolute value exceeding 0.00005 K^{-1} at room temperature and wherein the second dielectric material comprises a negative temperature coefficient of permittivity and/or capacitor electrodes departing from one another due to thermal expansion of the second dielectric material.
12. A dielectric resonator as claimed in any one of or the preceding claims, wherein the first and the second transmission lines are of coaxial line type, of stripline type, of microstrip type, of coplanar waveguide type, or of coplanar stripline type.

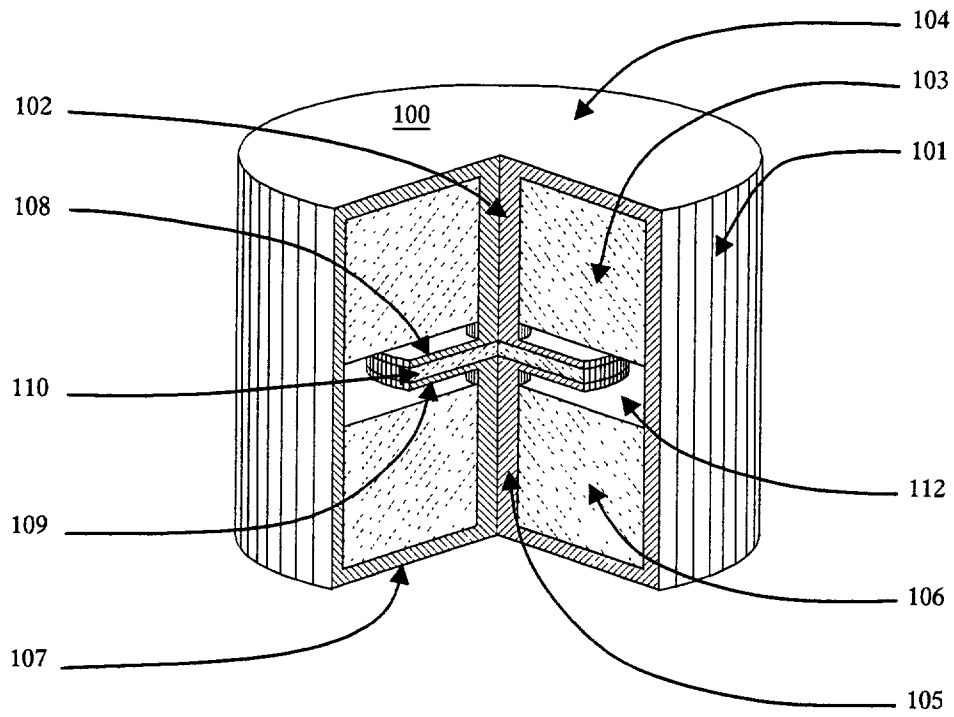


Fig. 1

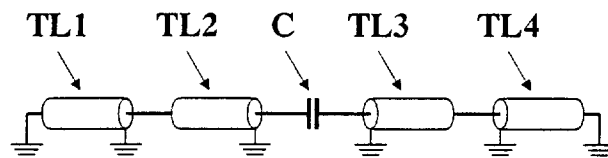


Fig. 2

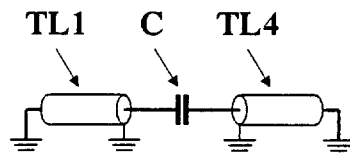


Fig. 3

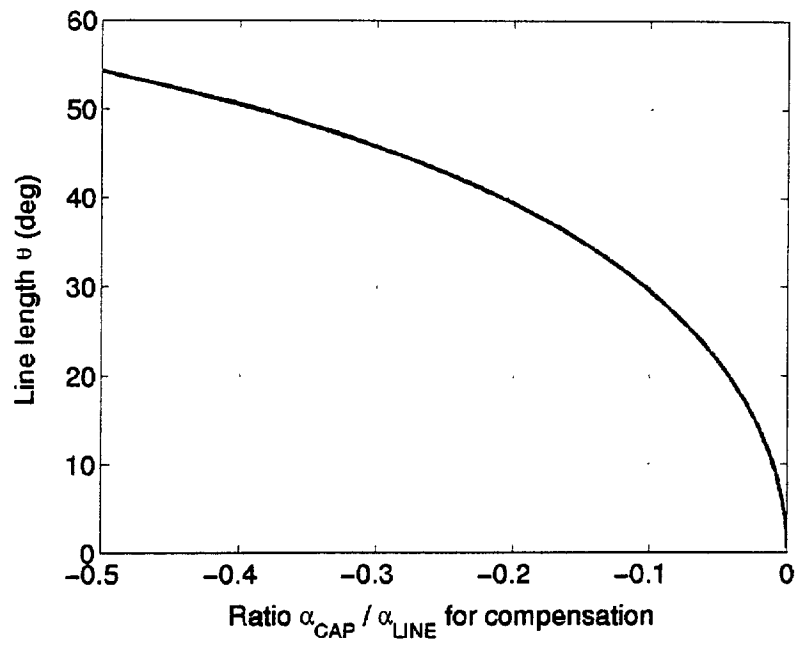


Fig. 4

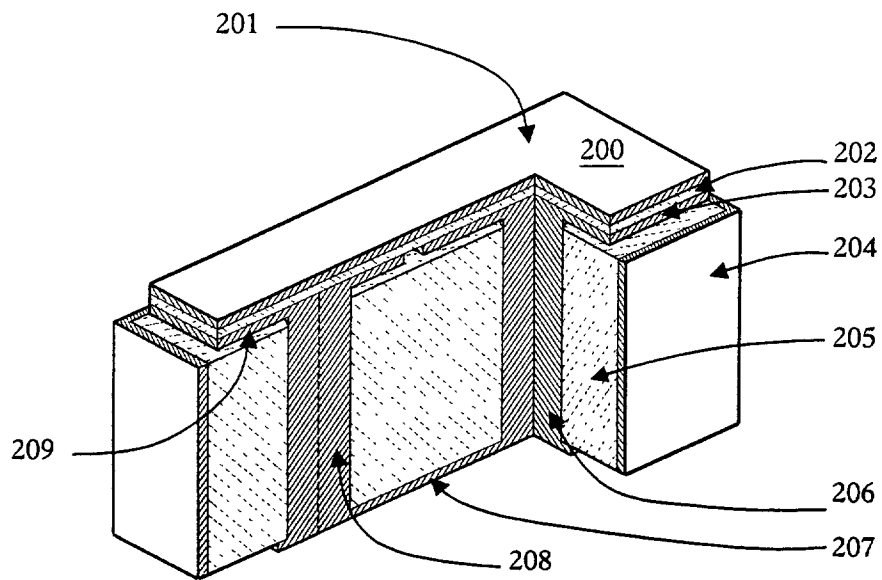


Fig. 5

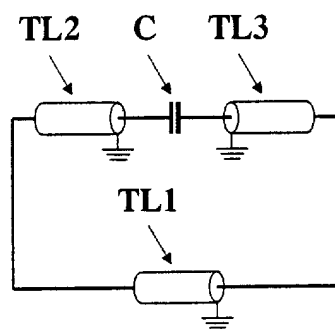


Fig. 6

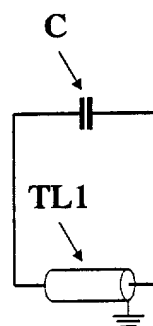


Fig. 7

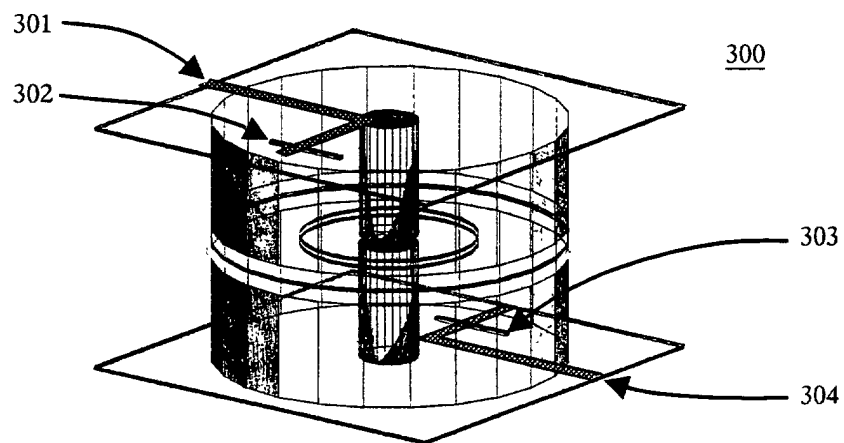


Fig. 8

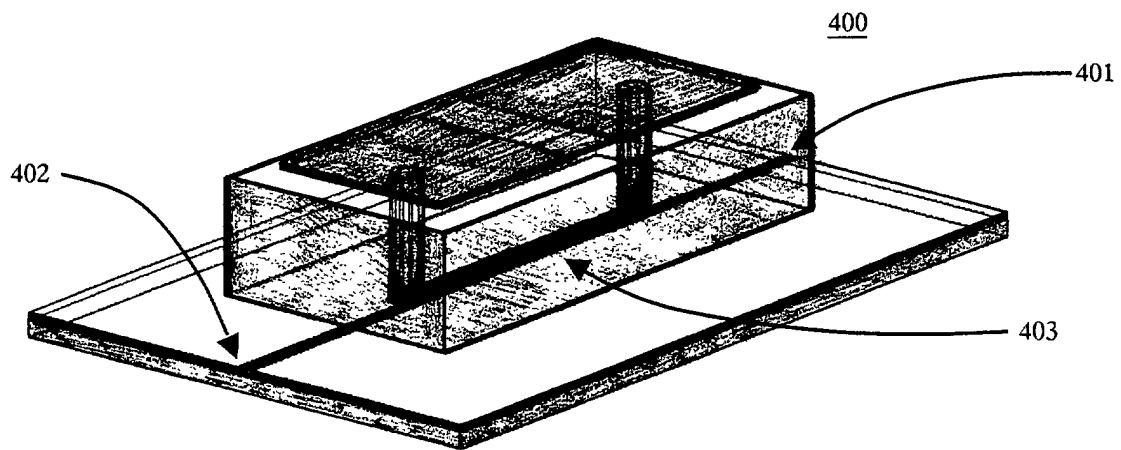


Fig. 9



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 01 81 0457

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 4 583 064 A (MAKIMOTO MITSUO ET AL) 15 April 1986 (1986-04-15) * column 1, line 38 - line 46 * * column 2, line 41 - line 62; figures 3A,3B,4A,4B *	1	H01P7/00 H01P7/04
A	US 4 491 976 A (SAITOH TAKESHI ET AL) 1 January 1985 (1985-01-01) * column 2, line 61 - column 3, line 53; figure 2 *	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
			H01P
The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 25 September 2001	Examiner La Casta Muñoa, S
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25-09-2001

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