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(54) Temperature compensation of combline resonators using composite inner conductor

(57) The present invention relates to a coaxial resonator and a method of constructing a coaxial resonator. The inner conductor (6) of the coaxial resonator comprises at least two different materials having different coefficients of thermal expansion. It includes an outer hollow component (9) defining a cavity (11) and comprising a first material having a first coefficient of thermal expansion, and a compensation element (10), that is disposed at least partly within the cavity (11) defined by the outer hollow component (9) and comprises a second material having a second coefficient of thermal expansion different from the first coefficient of thermal expansion. The compensation element (10) is engaged by the outer hollow component (9) at least at two locations spaced in the longitudinal direction of the inner conductor (6) such that the compensation element (10) is secured in the longitudinal direction of the inner conductor (6) within the cavity (11) of the outer hollow component (9). The compensation element (10) is not in threaded engagement with the outer hollow component (9) along the major portion of the length of the compensation element (10) and has dimensions and material characteristics such that a desired temperature dependence of the resonant frequency is achieved.

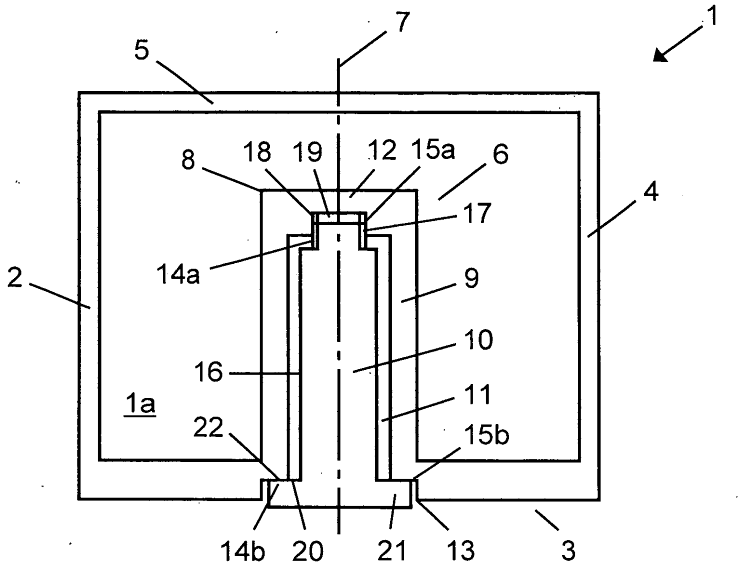

Fig. 1

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Description

[0001] The present invention relates to a coaxial resonator having an inner conductor comprising at least two different materials having different coefficients of thermal expansion, and to a method of constructing such a coaxial resonator.

[0002] Coaxial resonators are a particular type of cavity resonator. Generally, cavity resonators essentially comprise a space contained within a closed or substantially closed conducting surface. Due to their ability to maintain, upon suitable external excitation, an oscillating electromagnetic field within this space and their display of marked resonance effects at distinct resonant frequencies f_0, thereby giving maximum response over a narrow band of frequencies while rejecting frequencies outside that band, they are of great interest in various fields of technology. This is particularly true for high frequency applications utilizing frequencies for which the skin effect would make the resistance of standard tuned circuits too high and for which their open construction would cause them to act as antennas resulting in excessive radiation loss. Accordingly, cavity resonators find widespread application for receiving, generating, amplifying, processing and/or transmitting electromagnetic signals having frequencies e.g. in the radio or microwave regions of the electromagnetic spectrum.

[0003] Cavity resonators such as coaxial resonators are e.g. regularly utilized as filters or parts of filter structures for transmitting and receiving electromagnetic waves in selected frequency bands in the microwave region of the electromagnetic spectrum. Commonly, microwave filters include a plurality of resonant sections which are coupled together in series and/or in parallel in various configurations. Each resonant section constitutes a distinct cavity resonator and is characterized by the respective resonant frequency and quality factor. Exemplary applications of microwave filters include wireless communication systems, such as mobile communication and satellite communication systems, as well as navigation and radar technology. The growing number of microwave applications increases the possibility of interference occurring within a system or between different systems. Therefore, the microwave region is divided into a plurality of distinct frequency bands. The microwave filters are utilized to perform band-pass and band reject functions during transmission and/or reception in order to ensure, that a particular device only communicates within the frequency band assigned to this device. Accordingly, the filters are used to separate the different frequency bands and to discriminate between wanted and unwanted signal frequencies so that the quality of the received and of the transmitted signals is largely governed by the characteristics of the filters. Commonly, the filters have to provide for a small bandwidth, a high frequency selectivity and a high filter quality in that they must have a high attenuation outside their pass-band and a low pass-band insertion loss in order to satisfy efficiency requirements and to preserve system sensitivity.

[0004] A coaxial resonator is a resonator structure that is short-circuited at one end and open circuited at the other end, i.e. comprises a housing defining a resonator cavity having a longitudinal axis, and a coaxial inner conductor electrically connected to the housing at only one end. The housing comprises a base, from which the inner conductor extends upwardly, and a sidewall extending upwardly from the base, and in a certain distance above the open end of the inner conductor, the housing is enclosed by a cover so that a gap exists between the upper end of the inner conductor and the inner surface of the cover. Such coaxial resonators are also referred to as combline resonators, and can essentially be regarded as a section of coaxial transmission line that is short-circuited at one end and capacitively loaded (open) at the other end. Microwave energy may be coupled into the cavity by a magnetic loop antenna located near the inner conductor at the short-circuited end of the transmission line. The free space between the top of the inner conductor and the cover is referred to as the capacitive gap.

[0005] The resonant frequency of a coaxial resonator is determined by various factors and predominantly by the length of the cavity, the length of the inner conductor and the size of the capacitive gap. Therefore, setting the resonant frequency of a combline resonator is usually accomplished by determining suitable values for the length of the cavity, the length of the inner conductor, and the size of the capacitive gap. To render a coaxial resonator adjustable, a hole may be provided in the cover above the inner conductor, in which hole a tuning screw is placed. Adjusting the tuning screw, thereby moving small pieces of metal or a dielectric material into or out of the cavity, one can change the capacitive gap and thus control the resonant frequency. In some cases, the inner conductor may be provided as a partly hollow component that is open at its upper end, and the tuning screw may be arranged to at least partly penetrate this inner conductor through its the upper end. Such a resonator structure is referred to as re-entrant combline resonator. The tuning screw may also be disposed in holes provided in the sidewalls or the base of the housing.

[0006] In all of the above-mentioned applications as well as in other applications, it is essential for the coaxial resonators to have a predetermined resonant frequency and quality factor. As the resonant frequency is determined by the size and shape of those portions of the resonator structure, that define the resonator cavity, the dimensions of a particular coaxial resonator have to be thoroughly calculated and the production process has to be carefully controlled.

[0007] In this regard, it has further to be taken into account that a coaxial resonator, like any kind of resonator structure, is subject to thermal expansion and contraction of its housing and its inner conductor, which potentially lead to a change in resonant frequency as the temperature varies. Generally, the amount of expansion and contraction of a dimension depends on its size, the change in temperature and the coefficient of thermal expansion (CTE) of the material and is described by the following equation:

$$\Delta l = \left(1 + \alpha \cdot \Delta T\right) \cdot l \,,$$

where α is the CTE of the material, ΔT the change in temperature and 1 the length of the dimension. It has been shown that any resonator structure built out of only one material undergoes a shift in resonant frequency described by the following equation:

$$f\left(\Delta T\right) = f_0 \frac{1}{\left(1 + \alpha \cdot \Delta T\right)} \,.$$

[0008] Accordingly, a resonator structure made of aluminium (CTE ~ 23.8 x 10^{-6}) undergoes a shift in resonant frequency of around 23.8 ppm which corresponds to 47.6 kHz/K for a 2 GHz resonator.

[0009] As the characteristics of a particular filter device depend on the resonant frequencies of its individual resonant sections, these characteristics also change upon a change of temperature. For example, it is evident that the minimum practical bandwidth of a microwave filter becomes a function of the operating temperature range. In case of an unacceptable temperature induced drift of the resonant frequency, such systems have consequently to be stabilized with respect to temperature and/or they may require regular re-adjustment, both of which results in high costs.

[0010] For these reasons, it is of great importance to provide for a possibility to set the temperature dependence of the resonant frequency during manufacture of a coaxial resonator having predefined dimensions and thus a predetermined resonant frequency, so that the finished coaxial resonator yields a desired temperature behavior. In particular, it is desirable to provide for a possibility to construct a coaxial resonator that is stable over a wide range of working temperatures. For microwave filters, temperature stability has the advantage that the filters band pass requirements can be maintained over the whole range without using additional bandwidth. Eventually one can design the filter with a larger bandwidth without violating the band stop requirements, which decreases the insertion loss.

[0011] Various techniques have been proposed to control the temperature behavior of combline cavity resonators having predefined dimensions, and in particular to achieve their temperature compensation.

[0012] According to one approach, combline resonators have regularly been designed using Invar as the material for the housing and the inner conductor to limit the change of the length of the housing and of the inner conductor (see e.g. GB 2 305 547). Invar, an alloy of iron with 36% of nickel, has been chosen due to its very low CTE (~2 x 10^{-6}). However, Invar has an electrical conductivity which is too low for satisfactory use as the inner surface material of a cavity resonator. Therefore, when using Invar the inner surfaces have to be coated with a conductive material, e.g. silver or gold, which renders such resonators very expensive. Furthermore, Invar is relatively heavy.

[0013] In GB 2 305 547, it has been recognized that an increase in the length of the inner conductor tends to decrease the resonant frequency, whereas an increase in the size of the capacitive gap tends to increase the resonant frequency, and that it should in principle be possible to balance these effects in order to achieve temperature compensation by choosing different materials for the housing and the inner conductor. However, it is further described that it has been found that filters constructed accordingly nevertheless exhibit an unacceptable frequency drift. For this reason, GB 2 305 547 discloses a combline resonator with a composite inner conductor comprising longitudinal sections made of two materials and mounted together end-by-end by means of soldering or screwing, so that the composite inner conductor has an effective CTE which is a function of the CTEs of the individual sections. Therefore, this construction has the advantage that for a coaxial resonator having predetermined geometrical dimensions including a predefined length of the inner conductor (and thus a predetermined resonant frequency), the effective CTE of the inner conductor can be adjusted by suitably changing the length and the material of the individual sections. In this way, it is possible to control the temperature dependence of the resonant frequency and to realize an effective CTE of the inner conductor resulting e.g. in improved temperature compensation characteristics of the resonator. However, the quality factor of this coaxial resonator is lowered due to ohmic contact losses at the joint between the different sections. Furthermore, these joints tend to cause passive inter-modulation that decreases the performance of a filter constructed from such coaxial resonators.

[0014] Similarly, US 4,112,398 discloses a combline or interdigital microwave filter having inner conductors which comprise two segments of different materials in order to maintain the resonant frequency of the microwave filter relatively constant over a predetermined temperature range.

[0015] It is an object of the present invention to provide a high quality coaxial resonator which can be constructed with predetermined dimensions, wherein the temperature dependence of the resonant frequency can be easily adjusted by the way of construction of the coaxial resonator, and to a method of constructing such a coaxial resonator.

[0016] This object is achieved by a coaxial resonator with the features of claim 1 and a method with the features of claim 34. Further preferred embodiments of the invention are the subject-matter of the respective dependent claims.

[0017] In a conventional manner, the coaxial resonator of the present invention comprises a housing defining a resonator cavity having a longitudinal axis. The housing has a base, a sidewall extending upwardly from the base, and an upper cover, and the coaxial resonator further comprises a coaxial inner conductor extending upwardly from the base along the longitudinal axis of the coaxial resonator and electrically connected to the base. In the present specification, the longitudinal (or axial) direction of the resonator cavity or of the inner conductor and its components is defined as usual as the direction along which the inner conductor extends upwardly from the base. According to the present invention, the inner conductor includes an outer hollow component which comprises a first material having a first coefficient of thermal expansion. Within the meaning of the present invention, the term "hollow" merely indicates that the outer hollow component comprises a cavity, i.e. a space in the outer hollow component that is completely enclosed by the outer hollow component or that is open to the outside. However, the term "hollow" does not exclude a component in which the cavity only extends over a small portion of the length of the component. Preferably, the cavity is formed in and extends along the length of a tubular section of the outer hollow component. Further, it is preferred that the cavity is closed towards the resonator cavity.

[0018] Further, the inner conductor includes a compensation element that comprises a second material having a second coefficient of thermal expansion different from the first coefficient of thermal expansion. The compensation element is disposed completely or partly within the cavity defined by the outer hollow component, i.e. in the case of a cavity having an opening to the outside, a part of the compensation element may or may not protrude from the outer hollow component. In the case of a compensation element partly protruding from the outer hollow component, the compensation element preferably protrudes from the outer hollow component in the direction of the longitudinal axis of the inner conductor.

[0019] The compensation element is engaged by the outer hollow component at least at two locations spaced in the longitudinal direction of the inner conductor such that at least a part (generally the part between the two spaced locations) of the compensation element is secured, in the longitudinal direction of the inner conductor, within the cavity of the outer hollow component. The compensation element is not in threaded engagement with the outer hollow component along the major portion (i.e. along at least 50%) of the length of the compensation element, preferably along at least 60%, more preferably at least 70%, even more preferably at least 80% and most preferably at least 90% of the length of the compensation element. Preferably, along the major portion of the length of the compensation element, it is spaced from the inner sidewalls of the outer hollow component or those parts of the outer sidewall of the compensation element and the inner sidewall of the outer hollow component abutting each other extend parallel to the longitudinal axis of the inner conductor. The compensation element is chosen to have dimensions and material characteristics such that a desired temperature dependence of the resonant frequency is achieved.

[0020] Thus, the compensation element is fixedly secured to the outer hollow component at or between two spaced locations, so that the portion of the compensation element between these locations cannot expand and contract freely upon a change of temperature. The same applies to the corresponding portion of the outer hollow component. Rather, in these portions, the outer hollow component and the compensation element expand and contract together as a unit in the axial direction, and the two portions are kept at the same length. Thus, the corresponding longitudinal section of the inner conductor constitutes a composite section that has an effective CTE (at least for thermal expansion and contraction in the axial direction) that is a function of the individual CTEs of the materials of the outer hollow component and the compensation element. The CTE of the composite section, and in this way the dependence of the length of the inner conductor on the temperature and thereby the temperature dependence of the resonant frequency, can be set by choosing a suitable compensation element (e.g. suitable dimensions and/or suitable material characteristics) without changing the outer hollow component. In fact, only the portion of the compensation element in the composite section has to be modified to change the temperature behavior. Therefore, it is possible to adapt the temperature behavior while retaining the outer appearance of the inner conductor.

[0021] The above construction is arranged such that the fixing provided at the two spaced locations resulting in an effective CTE of a composite section of the inner conductor is effective at least in a predetermined temperature range, which is preferably -40 °C to 85 °C and more preferably -10 °C to 70 °C.

[0022] As already noted above, the coaxial resonator of the present invention provides the advantage that during-construction of the coaxial resonator, setting of an effective CTE of at least a section of the inner conductor, and therefore of the temperature behavior of the resonant frequency of the coaxial resonator, is advantageously possible by choosing a suitable compensation element without an impact on the physical structure of the inner walls defining the resonator cavity, e.g. by generating additional joints or transition regions between different materials, and thus without affecting other properties of the coaxial resonator such as its electrical performance. In particular, it is possible to avoid the prior art contact problems associated with the joints between different longitudinal sections. For example, in a preferred embodiment the inner conductor may be constructed integrally in one piece with the base of the housing, and subsequently a bore may be drilled from the bottom into the inner conductor (e.g. consisting of aluminum) and a compensation element (e.g. consisting of iron) may be disposed and secured in the bore in such a way that it can provide the above effects in the entire range of temperature in which the resonator is considered to operate. The inner walls of the resonator cavity, including the outer surface of the inner conductor are not affected by this modification. Therefore, the performance of the resonator (quality factor and passive inter-modulation) will not be affected. The size and the shape of the resonator can be chosen to yield a coaxial resonator having a predetermined resonant frequency and an optimum quality factor, and the control of the temperature behavior can be treated as a separate problem.

[0023] In the most important case, in which it is desired to improve the temperature compensation characteristics of a coaxial resonator, and ideally to construct a temperature compensated coaxial resonator, the material characteristics and the geometric dimensions of the compensation element (in fact of its portion forming part of the composite section) are chosen to yield an effective CTE of the composite section of the inner conductor, such that, at least in a predetermined temperature range, which is preferably -40 °C to 85 °C and more preferably -10 °C to 70 °C, the temperature induced variation of the resonant frequency is smaller than for the same coaxial resonator without the compensation element. In other words, at least in the composite section, the material characteristics and/or the dimensions of the compensation element are chosen such that the compensation element counteracts and at least partially compensates for the particular temperature dependence of the length of the outer hollow component, and thus the entire inner conductor, that causes the temperature induced variation of resonant frequency. Because generally the effect of increase of the length of the inner conductor upon an increase in temperature (resulting in a decrease of resonant frequency) is dominant as compared to the simultaneous increase of the size of the capacitive gap (resulting in an increase of resonant frequency); the compensation element will generally, and thus preferably, be arranged to decrease the thermally induced length expansion of the inner conductor.

[0024] In a preferred embodiment, the compensation element is in contact with and frictionally coupled to (but not in positive engagement with) the inner sidewall along the entire length of the compensation element between the two spaced locations. The frictional coupling forces are chosen such that in the composite section defined by the region of frictional engagement, the outer hollow component and the compensation element expand and contract together as a unit in the axial direction characterized by an effective CTE, at least in a predetermined temperature range, which is preferably -40 °C to 85 °C and more preferably -10 °C to 70 °C. In this construction, the compensation element can simply be formed by a suitably shaped member that is press fitted into the cavity. In this regard, the compensation element may advantageously be formed by an elongate member which is frictionally coupled to the inner sidewall of the cavity of the outer hollow component along the entire length of the elongate member. Further, it is preferred that the cavity of the outer hollow component extends through an opening in the base or through an opening in the upper end of a tubular section.

[0025] In a particularly preferred embodiment, the compensation element comprises two engagement sections that are engaged by two corresponding engagement sections of the outer hollow component such that at least a part of the compensation element is secured, in the longitudinal direction of the inner conductor, within the cavity of the outer hollow component. Both the engagement sections of the compensation element and the engagement sections of the outer hollow component are spaced in the longitudinal direction of the inner conductor, and along the major portion (i.e. along at least 50%) of the length of the compensation element, preferably along at least 60%, more preferably at least 70%, even more preferably at least 80% and most preferably at least 90% of the length of the compensation element, the compensation element is not in threaded engagement with the outer hollow component.

[0026] In this case, the compensation element is fixedly secured to the outer hollow component at or between two spaced locations by means of the corresponding engagement sections, so that the portion of the compensation element between its two engagement sections cannot expand and contract freely upon a change of temperature. Similarly, the portion of the outer hollow component between its two engagement sections is likewise not able to expand and contract freely upon a variation of temperature. Rather, in these portions, the outer hollow component and the compensation element expand and contract together as a unit in the axial direction, and the two portions are kept at the same length. Thus, the corresponding longitudinal section of the inner conductor together with the engagement sections constitutes a composite section that has an effective CTE (at least for thermal expansion and contraction in the axial direction) that is a function of the individual CTEs of the materials of the outer hollow component and the compensation element. The CTE of the composite section, and in this way the dependence of the length of the inner conductor on the temperature and thereby the temperature dependence of the resonant frequency, can be set by choosing a suitable compensation element (e.g. suitable dimensions and/or suitable material characteristics) without changing the outer hollow component. In fact, only the portion of the compensation element in the composite section has to be modified to change the temperature behavior. Therefore, it is possible to adapt the temperature behavior while retaining the outer appearance of the inner conductor.

[0027] Under the assumption that the engagement sections securing the compensation element have a negligible extension in the axial direction, and that the compensation element does not touch the outer hollow component between the engagement sections, the effective CTE α_{eff} of a cylindrical composite section can be approximated as

$$\alpha_{\text{eff}} = \frac{\alpha_1 A_1 E_1 + \alpha_2 A_2 E_2}{A_1 E_1 + A_2 E_2},$$

where α_1 and α_2 are the CTEs of the outer hollow component and the compensation element, respectively, in the composite section, A_1 and A_2 are the cross-sectional areas of the outer hollow component and the compensation element, respectively, in the composite section, and E_1 and E_2 are the coefficients of elasticity of the outer hollow component and the compensation element, respectively, in the composite section. For example, for aluminum α_1 ~ 23.8 10^{-6} 1/°C, E_1 ~ 72 G N/m^2, and for iron α_2 ~ 11.5 10^{-6} 1/°C, E_2 ~ 200 G N/m^2. If aluminum is chosen as the material for.the outer hollow component in the composite section having an outer diameter of 10 mm and inner diameter of 8 mm, and iron is chosen for the composite element having a diameter of 7.5 mm, the resulting effective CTE is calculated to be α_{eff} = 13.8 10^{-6} 1/°C. With regard to the above equation, it is to be noted, that the effective CTE is only valid for the length variation, while the CTE for the diameter is defined by the outer material, i.e. the composite section has to be considered anisotropic. Furthermore, the above expression is only an approximation for the effective CTE, since in reality the fixing provided by the spaced engagement sections will not show the ideally assumed behavior.

[0028] The above construction is arranged such that the fixing provided by the engagement sections resulting in an effective CTE of a composite section of the inner conductor is effective at least in a predetermined temperature range, which is preferably -40 °C to 85 °C and more preferably -10 °C to 70 °C.

[0029] As already noted above, the coaxial resonator of the present invention provides the advantage that during construction of the coaxial resonator, setting of an effective CTE of at least a section of the inner conductor, and therefore of the temperature behavior of the resonant frequency of the coaxial resonator, is advantageously possible by choosing a suitable compensation element. For example, it is possible to vary the effective CTE by simply varying the cross-sectional area (A_2 in the above equation) of the portion of the compensation element between the spaced engagement sections, without changing the physical structure of the inner walls defining the resonator cavity, e.g. by generating additional joints or transition regions between different materials, and thus without affecting other properties of the coaxial resonator such as its electrical performance. In particular, it is possible to avoid the prior art contact problems associated with the joints between different longitudinal sections. For example, in a preferred embodiment the inner conductor may be constructed integrally in one piece with the base of the housing, and subsequently a bore may be drilled from the bottom into the inner conductor (e.g. consisting of aluminum) and a compensation element (e.g. consisting of iron) may be disposed in the bore and secured therein in such a way that it is under tensile force in the entire range of temperature in which the resonator is considered to operate. The inner walls of the resonator cavity, including the outer surface of the inner conductor are not affected by this modification. Therefore, the performance of the resonator (quality factor and passive intermodulation) will not be affected. The size and the shape of the resonator can be chosen to yield a coaxial resonator having a predetermined resonant frequency and an optimum quality factor, and the control of the temperature behavior can be treated as a separate problem.

[0030] In the most important case, in which it is desired to improve the temperature compensation characteristics of a coaxial resonator, and ideally to construct a temperature compensated coaxial resonator, the material characteristics and the geometric dimensions of the compensation element (in fact of its portion forming part of the composite section) are chosen to yield an effective CTE of the composite section of the inner conductor, such that, at least in a predetermined temperature range, which is preferably -40 °C to 85 °C and more preferably -10 °C to 70 °C, the temperature induced variation of the resonant frequency is smaller than for the same coaxial resonator without the compensation element. In other words, at least in the composite section, the material characteristics and/or the dimensions of the compensation element are chosen such that the compensation element counteracts and at least partially compensates for the particular temperature dependence of the length of the outer hollow component, and thus the entire inner conductor, that causes the temperature induced variation of resonant frequency. Because generally the effect of increase of the length of the inner conductor upon an increase in temperature (resulting in a decrease of resonant frequency) is dominant as compared to the simultaneous increase of the size of the capacitive gap (resulting in an increase of resonant frequency), the compensation element will generally, and thus preferably, be arranged to decrease the thermally induced length expansion of the inner conductor.

[0031] In a preferred embodiment, between the two engagement sections of the compensation element and thus in the composite section, the compensation element is under compressive or tensile stress in the longitudinal direction of the inner conductor, wherein the compressive or tensile stress in the longitudinal direction of the inner conductor is generated by forces applied by the two engagement sections of the outer hollow component. In this simple arrangement, the compressive or tensile axial force generated by these engagement sections ensures that the "active" portion of the compensation element is fixedly secured between the two engagement sections.

The force should be chosen such that the compensation element is fixedly secured to the outer hollow component in a predetermined temperature range (i.e. the range of intended operation temperatures), which is preferably -40 °C to 85 °C and more preferably -10 °C to 70 °C. In the above first order approximation, the intensity of the force has no influence on the effective CTE, which can thus be determined in accordance with the above equation. It is also preferred if the engagement sections are adapted such that at a particular temperature, the compensation element is under no stress between its two engagement sections in the longitudinal-direction of the inner conductor, and that above and below this particular temperature, the compensation element is under compressive or tensile stress between its two engagement sections in the longitudinal direction of the inner conductor. In general the particular temperature should be chosen to lie in the middle of the range of intended or expected operating temperatures, and could e.g. advantageously be room temperature. In this way, the coaxial resonator can be operated in the entire temperature range in which the length changes due to the inner force are in the elastic range, i.e. in which no component breaks due to excessive mechanical stress. In case the inner conductor is constructed such that an increasing compressive or tensile stress of the outer hollow component or the compensation element builds up only either upon temperature increase or temperature decrease, care has to be taken that the resonator is not operated at a temperature at which the compensation element partly disengages from the outer hollow component at at least one of the engagement sections. On the other side of the temperature range, again the build-up of excessive mechanical stress has to be avoided.

[0032] In a preferred embodiment, the two engagement sections of the compensation element are disposed in the two longitudinal end portions of the compensation element, and most preferably at the two longitudinal ends of the compensation element. Such a compensation element can be disposed within the cavity of the outer hollow component in its entirety, so that this cavity can advantageously be constructed as a cavity which is closed towards the resonator cavity.

[0033] It is preferred that one or both of the engagement sections of the outer hollow component comprises or is a threaded portion that engages a corresponding threaded portion of the corresponding engagement section of the compensation element. It is also preferred that one or both of the engagement sections of the outer hollow component comprises or is a friction surface that is frictionally coupled to a corresponding friction surface of the corresponding engagement section of the compensation element. It is also preferred that one or both of the engagement sections of the outer hollow component or one or both of the engagement sections of the compensation element comprise an abutment surface, which rest against a part of the compensation element or the outer hollow component, respectively. In the case of an abutment surface, it is further preferred that one or both of the engagement sections of the outer hollow component comprises an abutment surface that rests against a corresponding abutment surface of the corresponding engagement section of the compensation element. Accordingly, in preferred embodiments, both engagement sections of the compensation element as well as of the outer hollow component comprise or are formed by threaded portions, friction surfaces or abutment surfaces, or one of the engagement sections comprises or is formed by a threaded portion whereas the other engagement section comprises or is formed by an abutment surface or a friction surface, or one of the engagement sections comprises or is formed by an abutment surface whereas the other engagement section comprises or is formed by a friction surface. These arrangements provide for a simple attachment of the compensation element in the cavity of the outer hollow component.

[0034] In a preferred embodiment, the cavity of the outer hollow component extends through an opening in the base. Further, one of the engagement sections of the outer hollow component is formed in the upper end wall of the cavity of the outer hollow component, and the other engagement section of the outer hollow component is formed in the sidewall of the cavity of the outer hollow component or the sidewall of the opening in the base. Such a constructions allows that during construction of the coaxial resonator, the compensation element is inserted into the cavity of the outer hollow component from below through the opening in the base. Furthermore, the compensation element can later be replace by a different compensation element without opening the coaxial resonator.

[0035] In this embodiment, the engagement section formed in the upper end wall of the cavity of the outer hollow component and the corresponding engagement section of the compensation element comprise or are formed by interengaging threaded portions, and the other engagement section of the outer hollow component and the corresponding engagement section of the compensation element comprise or are formed by abutment surfaces resting against each other, so that the compensation element is under tensile stress between its engagement sections in the longitudinal direction of the inner conductor. Alternatively, the engagement section formed in the upper end wall of the cavity of the outer hollow component and the corresponding engagement section of the compensation element comprise or are formed by abutment surfaces resting against each other, and the other engagement section of the outer hollow component and the corresponding engagement section of the compensation element comprise or are formed by interengaging threaded portions, so that the compensation element is under compressive stress between its engagement sections in the longitudinal direction of the inner conductor. In a further alternative, both engagement sections of the outer hollow component and the corresponding engagement sections of the compensation element comprise or are formed by abutment surfaces resting against each other, the lower engagement section of the outer hollow component being formed on a closure element that forms a part of the outer hollow component and that is threadedly secured in the opening of the base or the cavity of the outer hollow component, so that the compensation element is under compressive stress between its engagement sections in the longitudinal direction of the inner conductor.

[0036] In a further preferred embodiment, the cavity of the outer hollow component extends through an opening in the upper end of a tubular section of the outer hollow component. Further, one of the engagement sections of the outer hollow component is formed in the lower end wall of the cavity of the outer hollow component, and the other engagement section of the outer hollow component is formed in the sidewall of the cavity of the outer hollow component, by the annular upper end face of the tubular section or an element of the outer hollow component that is rigidly connected to the tubular section. Such an arrangement, might be advantageous for facilitating machining the filter.

[0037] In this embodiment, the engagement section formed in the lower end wall of the cavity of the outer hollow component and the corresponding engagement section of the compensation element comprise or are formed by interengaging threaded portions, and the other engagement section of the outer hollow component and the corresponding engagement section of the compensation element comprise or are formed by abutment surfaces resting against each other, so that the compensation element is under tensile stress between its engagement sections in the longitudinal direction of the inner conductor. Alternatively, the engagement section formed in the lower end wall of the cavity of the outer hollow component and the corresponding engagement section of the compensation element comprise or are formed by abutment surfaces resting against each other, and the other engagement section of the outer hollow component and the corresponding engagement section of the compensation element comprise or are formed by interengaging threaded portions, so that the compensation element is under compressive stress between its engagement sections in the longitudinal direction of the inner conductor. In these two cases, a part of the compensation element may protrude from the tubular section of the outer hollow component into the resonator cavity, wherein this part, i.e. a portion of the compensation element, forms a longitudinal section of the inner conductor. In a further alternative, both engagement section of the outer hollow component and the corresponding engagement sections of the compensation element comprise or are formed by interengaging threaded portions, the upper engagement section of the outer hollow component being formed on a closure element that forms a part of the outer hollow component and that abuts and closes the upper end of the tubular section, so that the compensation element is under tensile stress between its engagement sections in the longitudinal direction of the inner conductor. In still a further alternative, both engagement sections of the outer hollow component and the corresponding engagement sections of the compensation element comprise or are formed by abutment surfaces resting against each other, the lower engagement section of the outer hollow component being formed on a closure element that is threadedly secured in the tubular section, so that the compensation element is under compressive stress between its engagement sections in the longitudinal direction of the inner conductor.

[0038] In all of the above cases, it is preferred that the part of the compensation element, that is disposed within the cavity of the outer hollow component, is not in threaded engagement with the inner walls of the cavity of the outer hollow component along the major portion (i.e. along at least 50%) of the length of this part of the compensation element, preferably along at least 60%, more preferably at least 70%, even more preferably at least 80% and most preferably at least 90% of the length of this part of the compensation element. Preferably, along the major portion of the length of this part of the compensation element, it is spaced from the inner sidewalls of the outer hollow component or those parts of the outer sidewall of the compensation element and the inner sidewall of the outer hollow component abutting each other extend parallel to the longitudinal axis of the inner conductor. In particular, it is preferred that the compensation element is not in threaded engagement with the inner walls of the cavity of the outer hollow component between the two engagement sections and that the engagement sections have a small axial extension. In this way, the calculation of the effective CTE is substantially facilitated.

[0039] Further, it is preferred if the compensation element is removably secured within the cavity of the outer hollow component. This constructions enables the replacement of a particular compensation element with a different compensation element in order to adjust the temperature behavior of the coaxial resonator. Advantageously, such a replacement does not have any influence on the electric properties of the coaxial resonator, because due to the construction of the present invention, the replacement can be effected without changing the outer appearance of the inner conductor.

[0040] The compensation element is preferably made of a solid material. However, it is also possible that the compensation element comprises or is constituted by a liquid material.

[0041] It is further preferred that at least a part of the outer hollow component is integrally formed in one piece with the base. Most preferably, the entire outer hollow component is integrally formed in one piece with the base. Due to such a construction, disadvantageous joints between different elements, which are fixed together to form the outer hollow component, can be minimized or avoided altogether. However, it is also possible that the outer hollow component itself is a composite component comprising at least two elements which are attached to each other.

[0042] It can be advantageous if the outer hollow component comprises a solid section, i.e. a section not comprising a cavity, between the lower end of the cavity of the outer hollow component and the plane defined by the upper surface of the base, so that the cavity is spaced from the base.

[0043] It can further be advantageous if the outer hollow component includes at least two cavities separated in the longitudinal direction of the inner conductor, wherein in each such cavity a compensation element is secured. The various compensation elements may be made of the same or different materials. This inner conductor includes two or more of the composite sections of the present invention. While such a construction is more complex, it can enhance the precision of achieving a particular temperature behavior.

[0044] In a preferred embodiment, at least one of the coaxial resonators of the present invention is part of a microwave filter comprising a plurality of coupled resonators. Thus, the present invention also relates to a microwave filter comprising a plurality of coupled resonators, wherein the plurality of coupled resonators includes one or several of the above defined coaxial resonators according to the present invention. In a particularly preferred embodiment, the plurality of coupled resonators only includes coaxial resonators according to the present invention.

[0045] A coaxial resonator of the present invention having a specified temperature dependence of its resonant frequency can be constructed advantageously by first choosing a nominal operating temperature for the coaxial resonator to be constructed, a nominal resonant frequency f_0 at the nominal operating temperature, and a range of operating temperatures ΔT. Then, a geometrical shape and geometrical dimensions, including the length of the inner conductor, of the resonator cavity of the coaxial resonator to be constructed is determined, such that the resonator cavity yields the resonant frequency f_0 at the nominal operating temperature. Subsequently, a coaxial resonator of the present invention, i.e. a coaxial resonator as described above, is provided that has a resonator cavity with the determined geometrical shape and the determined geometrical dimensions. Accordingly, the interior of the housing has a particular length, a particular diameter and a particular cross-sectional shape, and the inner conductor, the outer surface of which is commonly formed entirely or essentially by the outer hollow component, likewise has a particular length, a particular diameter and a particular cross-sectional shape. According to the present invention, a value for at least one construction parameter of the compensation element is chosen such that the compensation element, after being secured to the outer hollow component, yields a minimum temperature induced change of resonant frequency f_0 in the temperature range ΔT with respect to the at least one construction parameter, which constitutes a free parameter in the optimization procedure. Thus, setting the temperature behavior is a problem separate from the problem of achieving the desired resonant frequency and the desired electrical properties.

[0046] It is preferred that the at least one construction parameter includes the cross-sectional diameter of the portion of the compensation element between its two engagement sections, i.e. of the portion of the compensation element in the composite section of the inner conductor. It is further preferred that the at least one construction parameter includes the material of the compensation element.

[0047] Determination of the values of the free construction parameters of the compensation element may be achieved by first calculating the resonant frequency f_0 as a function of temperature for particular initial values of the set of free construction parameters. Then, the values of the set of construction parameters are varied and this calculating step is repeated to eventually derive from the result of the calculation specific values for the set of construction parameters, the specific values being optimum values in that they yield a minimum temperature induced change Δf_0 of resonant frequency f_0 in the given temperature range ΔT with respect to the set of construction parameters. The optimum values and the minimum temperature induced change Δf_0 may be an absolute minimum, a local minimum, or an absolute or local minimum under at least one boundary condition or constraint.

[0048] In the following, the invention is explained in more detail for preferred embodiments with reference to the figures.

Figure 1 is a schematic cross-sectional view of a coaxial resonator of the present invention.

Figure 2 is a schematic cross-sectional view of a further embodiment of a coaxial resonator according to the present invention.

Figure 3 is a schematic cross-sectional view of a further embodiment of a coaxial resonator according to the present invention.

Figure 4 is a schematic cross-sectional view of a further embodiment of a coaxial resonator according to the present invention.

Figure 5 is a schematic cross-sectional view of a further embodiment of a coaxial resonator according to the present invention.

Figure 6 is a schematic cross-sectional view of a further embodiment of a coaxial resonator according to the present invention.

Figure 7 is a schematic cross-sectional view of a further embodiment of a coaxial resonator according to the present invention.

[0049] In Figure 1, a coaxial resonator 1 is shown in cross section. The resonator 1 comprises a hollow housing 2, that is constituted by a plate shaped base 3, a sidewall 4 extending upwardly from the base 3, and a plate shaped cover 5 secured to the upper end (throughout the application, terms like "upper" and "lower" relate to the orientation of a coaxial resonator shown in the Figures) of the sidewall 4. Thus, the housing 2 encloses and defines a resonator cavity 1a. The base 3 and the cover 5 may have, e.g., a circular or rectangular shape. Accordingly, the sidewall 4 may have a cylindrical configuration or may have a rectangular cross section. For reasons of weight and costs, the housing 2 is preferably composed of aluminum. However, it may also advantageously be composed of iron, copper, brass or Invar, or may be a composite component comprising two or more of these or other materials. Further advantageous choices of materials include PVC or ceramic materials. It is only important that the coefficient of thermal expansion is known and that the material is a good conductor or is plated with a good conducting material such as silver.

[0050] The coaxial resonator 1 further comprises a coaxial cylindrical inner conductor 6 that extends upwardly from the base 3 along the longitudinal axis 7 of the cylindrical housing 2 and is located in the center of the base 3. The longitudinal axis 7 also forms the longitudinal axis of the inner conductor 6. The length L of the inner conductor is lower than the length H of the resonator cavity so that a capacitive gap is formed between the upper end 8 of the inner conductor 6 and the cover 5 of the housing 2.

[0051] The field in the resonator 1 is excited by an external circuit (not shown) through suitable coupling means (not shown), which may e.g. comprise an aperture or a coupling loop and radiate a wave into the resonator cavity.

[0052] According to the invention, the inner conductor 6 of the coaxial resonator 1 is a composite element comprising an outer hollow component 9 and a compensation element 1'0. The outer hollow component 9 defines a cavity 11 in which the compensation element 10 is secured. In the present embodiment, the outer hollow component 9 is formed integrally in one piece with the base 3 of the housing 2. While the base 3 and the outer hollow component may be formed at least partly as a solid element, in the embodiment shown in Figure 1, the base 3 and the inner conductor 6 are formed from sheet metal, e.g. by means of cold extrusion. However, the same structure could also be produced by providing a solid inner conductor that is constructed integrally in one piece with the base, and by subsequently drilling a bore from the bottom into the inner conductor. In the present case, the cavity 11 extends from an upper end wall 12 of the outer hollow component 9, that forms the upper end 8 of the inner conductor 6, downwardly along the longitudinal axis 7 of the inner conductor 6 and through an opening 13 in the base 3. Thus, the cavity 11 is accessible from below through the opening 13, but is completely separated from the resonator cavity 1a by the outer hollow component 9.

[0053] The compensation element 10 is disposed in the cavity 11 of the outer hollow component 9 with only a small portion protruding downwardly out of the opening 13 of the base 3, and is secured therein by means of two spaced engagement sections 14a, 14b formed at the upper and lower end, respectively, of the compensation element 10 that are engaged by two corresponding spaced engagement sections 15a, 15b formed at the upper and lower end, respectively, of the outer hollow component 9. Between the two engagement sections 14a, b of the compensation element 10, the compensation element 10 comprises an intermediate section 16 that extends over most of the length of the compensation element, whereas the two engagement sections 14a, b only extend along a small portion of the length of the compensation element 10.

[0054] The upper engagement section 14a of the compensation element 10 is constituted by an external thread 17 formed on the outer circumferential surface of a reduced diameter end section of the compensation element 10. The upper engagement section 15a of the outer hollow component 9 is constituted by a corresponding internal thread 18 that is formed in a recess 19 in the upper end wall 12 of the outer hollow component 9 and that threadedly engages the external thread 17 of the upper engagement section 14a. The lower engagement section 14b of the compensation element 10 is constituted by an annular abutment surface 20 that is formed on the upper surface of an enlarged diameter section 21. at the lower end of the compensation element 10 that forms a circumferential flange shaped projection. The lower engagement section 15b of the outer hollow component 9 is constituted by a corresponding annular abutment 22 that is formed on the lower surface of a step in the sidewall of the cavity 11. During manufacture of the coaxial resonator 1, the compensation element 10 is inserted into the cavity 11 through the opening 13 in the base 3, and is screwed by means of its external thread 17 into the internal thread 18 of the outer hollow component 9, until and slightly beyond the point at which the two abutment surfaces 20, 22 contact each other. In this way, the two engagement sections 15a, 15b of the outer hollow component 9 exert longitudinal forces on the compensation element 10 which result in the compensation element 10 being under tensile stress along its longitudinal axis 7.

[0055] It is evident, that the outer hollow component 9 cannot change its length freely. Rather, as outlined in detail above, the CTE of the inner conductor 6 is influenced by the properties of the compensation element 10, and the longitudinal portion of the inner conductor 6 between and including the abutment surfaces 20 and 22 and the upper end of the external thread 17 of the compensation element 10 (i.e. between and including the outermost points of actual engagement) constitutes a composite section having an effective CTE. Due to the integral construction of the outer hollow component 9 and the base 3 and due to the outer hollow component 9 completely separating the cavity 11 from the resonator cavity 1a, the dimensions and the further characteristics of the compensation element 10 advantageously have no influence whatsoever on the outer appearance and structure of the inner conductor 6 as seen from within the resonator cavity 1a.

[0056] In Figure 2, a further embodiment of a coaxial resonator 1’ of the present invention is shown, wherein identical parts are designated by the same reference numerals and are not discussed again in detail. The coaxial resonator 1 shown in Figure 2 differs from the coaxial resonator shown in Figure 1 only in that the interior of its outer hollow component 9’ is modified in order to receive a differently shaped compensation element 10’, thus forming a modified inner conductor 6’. In this regard, the outer hollow component 9’ and the compensation element 10’ comprise modified engagement sections 14a’, 14b’, 15a’, 15b’. The upper engagement section 14a’ of the compensation element 10’ is constituted by an abutment surface 23 formed on the upper end face of the compensation element 10’. The upper engagement section 15a’ of the outer hollow component 9’ is constituted by a corresponding abutment surface 24 formed by the upper end face of a recess 19’ in the upper end wall 12’ of the outer hollow component 9’. The lower engagement section 14b’ of the compensation element 10’ is constituted by an external thread 25 that is formed on the outer circumferential surface of an enlarged diameter section 21’ at the lower end of the compensation element 10’ that forms a circumferential flange shaped projection. The lower engagement section 15b’ of the outer hollow component 9’ is constituted by a corresponding internal thread 26 that is formed on the inner surface of the cavity 11’ at the lower end thereof. During manufacture of the coaxial resonator 1, the compensation element 10’ is inserted into the cavity 11’ through the opening 13’ in the base 3’, and is screwed by means of its external thread 25 into the internal thread 26 of the outer hollow component 9’, until and slightly beyond the point at which the two abutment surfaces 23, 24 contact each other. In this way, the two engagement sections 15a’, 15b’ of the outer hollow component 9’ exert longitudinal forces on the compensation element 10’ which result in the compensation element 10’ being under compressive stress along its longitudinal axis 7.

[0057] In Figure 3, a further embodiment of a coaxial resonator 1’’ of the present invention having a modified inner conductor 6’’ is shown. The coaxial resonator 1’’ is largely identical to the coaxial resonator 1’ shown in Figure 2 and in particular the upper engagement sections 14a’, 15a’ of the modified compensation element 10’’ and the modified outer hollow component 9’’, respectively, are the same as shown in Figure 2. However, the lower engagement sections 14b’’, 15b’’ of the compensation element 10’’ and the outer hollow component 9’’, respectively, are likewise constituted by abutment surfaces. Thus, the lower engagement section 14b" of the compensation element 10" is constituted by an abutment surface 27 formed on the lower end face of the compensation element 10’’, and the lower engagement section 15b’’ of the outer hollow component 9" is constituted by a corresponding abutment surface 28 formed on the upper end face of a closure element 29 that itself is a part of the outer hollow component 9". The closure element 29 comprises an external thread 30 on its outer circumferential surface, and a corresponding internal thread 31 is formed on the inner surface of the cavity 11’ at the lower end thereof. During manufacture of the coaxial resonator 1’’, the compensation element 10’’ is inserted into the cavity 11’ through the opening 13’ in the base 3’. Subsequently, the closure element 29 is screwed by means of its external thread 30 into the internal thread 31 of the cavity 11’’, until and slightly beyond the point at which the two abutment surfaces 23, 24 as well as the two abutment surfaces 27, 28 contact each other. In this way, the two engagement sections 15a, 15b’’ of the outer hol= low component 9" exert longitudinal forces on the compensation element 10’’ which result in the compensation element 10" being under compressive stress along its longitudinal axis 7. In the embodiment of Figure 3, the material of the compensation element can be chosen almost arbitrarily, and could e.g. be a ceramic material or concrete. Further, the compensation element could even be a liquid, such as e.g. oil, with suitable parameters. However, in this case, it would have to be taken into account that the compensation element contacts the inner walls of the cavity 11" between the two engagement sections 14a, 14b", so that a careful design is required and also the CTE for a diameter change depends on the properties of both the outer hollow component 9" and the compensation element 10’’.

[0058] In Figure 4, a further embodiment of a coaxial resonator 101 of the present invention is shown. In this case, the outer hollow component 109 includes a tubular section 132 and a lower end wall 134. Both the tubular section 132 and the lower end wall 134 are formed integrally in one piece with the base 103. This structure could e.g. be produced by providing a solid inner conductor that is constructed integrally in one piece with the base, and by subsequently drilling a bore from the top into the inner conductor. The cavity 111 extends from the lower end wall 134 upwardly along the longitudinal axis 107 of the inner conductor 106 and through the opening 135 of the tubular section 132. The outer hollow component 109 further includes a closure element 133 that is secured to the upper end of the tubular section 132 in order to close the cavity 111 such that it is completely separated from the resonator cavity 101a by the outer hollow component 109.

[0059] The lower engagement section 114b of the compensation element 110 is constituted by an external thread 136 formed on the outer circumferential surface of a reduced diameter end section of the compensation element 110. The lower engagement section 115b of the outer hollow component 109 is constituted by a corresponding internal thread 137 that is formed in a recess

140 in the lower end wall 134 of the outer hollow component 109 and that threadedly engages the external thread 136 of the lower engagement section 114b. The upper engagement section 114a of the compensation element 110 is constituted by an external thread 138 formed on the outer circumferential surface of a reduced diameter end section of the compensation element 110. The upper engagement section 115a of the outer hollow component 109 is constituted by a corresponding internal thread 139 that is formed in a recess 141 in the lower surface of closure element 133 and that threadedly engages the external thread 138 of the upper engagement section 114a. , Thus, the cavity 111 is accessible from above through the opening 135 if the closure element 133 is removed. During manufacture of the coaxial resonator 101, the compensation element 110 is inserted into the cavity 111 through the opening 135 of the tubular section 132, and is screwed by means of its external thread 137 into the internal thread 138 of the outer hollow component 109. Subsequently, the closure element 133 is screwed by means of its internal thread 139 onto the external thread 138 of the compensation element 110 until and slightly beyond the point at which the lower surface of the closure element 133 abuts the annular end face of the tubular section 132. In this way, the two engagement sections 115a, 115b of the outer hollow component 19 exert longitudinal forces on the compensation element 110 which result in the compensation element 110 being under tensile stress along its longitudinal axis 107.

[0060] Such an arrangement, in which a tubular section is integrally formed in one piece with the base and in which the tubular section is closed by a closure element might be advantageous for machining a filter body. However, such an arrangement has the possible drawback of a reduced performance due to passive inter-modulation and ohmic contact losses caused by the transition region at the joint between the tubular section and the closure element. Nevertheless, such a design is an improvement over the prior art composite inner conductors, because the maximum current flow in a coaxial resonator takes place at the bottom of the inner conductor and shows a cosinusoidal decay in the longitudinal direction of the inner conductor. Since the tubular section can be manufactured integrally in one piece with the base, the transition region is shifted to the top of the inner conductor, where its impact on the quality factor and passive inter-modulation is reduced.

[0061] In Figure 4, the closure element 133 forms the upper part of the inner conductor 106. While it is shown to have an enlarged diameter, it could also have the same diameter as the tubular section 132. Further, the closure element 133 could include at least one further cavity in which a further compensation element is disposed. Thus, it is evident, that the inner conductors of the present invention can also comprise two or more spaced apart composite sections as well as one or more sections made of only one material.

[0062] In Figure 5, a further embodiment of the coaxial resonator 101' of the present invention is shown, which is a modified version of the coaxial resonator 101 shown in Figure 4, and in which the tubular section 132 and the lower engagement sections 114b, 115b of the modified compensation element 110' and the modified outer hollow component 109', respectively, are identical to the embodiment of Figure 4. However, the coaxial resonator of Figure 5 differs from the coaxial resonator of Figure 4 in that the outer hollow component 109' does not include an upper closure element that closes the opening 135 of the tubular section 132. Rather, the opening 135 is closed by the compensation element 110'. In this regard, the upper engagement section 114a' of the compensation element 110' is constituted by an abutment surface 142 formed on the lower annular surface of an upper enlarged diameter section 144 of the compensation element 110'. The upper engagement section 115a' of the outer hollow component 109' is constituted by a corresponding abutment surface 143 formed by the upper annular end face of the tubular section 132. During manufacture of the coaxial resonator 101', the compensation element 110' is inserted into the cavity 111 through the opening 135 of the tubular section 132, and is screwed by means of its external thread 136 into the internal thread 137 of the outer hollow component 109', until and slightly beyond the point at which the two abutment surfaces 142, 143 contact each other. In this way, the two engagement sections 115a', 115b of the outer hollow component 109' exert longitudinal forces on the compensation element 110' which result in the compensation element 110' being under tensile stress along its longitudinal axis 107. In this embodiment, the upper enlarged diameter section of the compensation element 110' forms an upper portion of the inner conductor 106'.

[0063] Figure 6 shows a modification 101" of the coaxial resonator of Figure 5 resulting in a re-entrant coaxial resonator. In this embodiment, the outer hollow component 109" further includes a cup shaped element 145 which has a bore 146 in the center of its bottom wall 147. The cup shaped element 145 is arranged on top of the tubular section 132 with the bottom wall 147 of the cup shaped element 145 abutting the annular end face of the tubular section 132. While the upper engagement section 114a" of the compensation element 110" is again constituted by an abutment surface 142'' formed on the lower annular surface of an upper enlarged diameter section 144'' (having reduced length) of the compensation element 110'', the upper engagement section 115a'' of the outer hollow component 109" is constituted by a corresponding abutment surface 148 formed by the upper annular upper surface of bottom wall 147 of the cup shaped element 145 adjacent the bore 146. A tuning screw 149 is provided which extends through a hole in the cover 105" above the inner conductor 106'' and into the interior of the cup shaped element 145 of the outer hollow component 109''. The tuning screw 149 can be moved into or out of the resonator cavity 1a in order to change the capacitive gap, and to thereby adjust the resonant frequency of the resonator 1. During manufacture of the coaxial resonator 101'', the compensation element 110'' is inserted into the cavity 111'' through the bore 146 and through the opening 135 of the tubular section 132, and is screwed by means of its external thread 136 into the internal thread 137 of the outer hollow component 109" , until and slightly beyond the point at which the two abutment surfaces 142 ", 148 contact each other. In this way, the two engagement sections 115a'', 115b of the outer hollow component 109" exert longitudinal forces on the compensation element 110'' which result in the compensation element' 1101 ' being under tensile stress along its longitudinal axis 107.

[0064] In Figure 7, a further embodiment 1''' of the coaxial resonator of the present invention is shown. With regard to the housing 2 and the outer hollow component 9''', this embodiment is largely identical to the embodiments shown in Figures 1, to 3, i.e. the outer hollow component 9''' is formed integrally in one piece with the base 3'''. However, the embodiment of Figure 7 comprises a differently constructed compensation element 10'''. The compensation element 10''' is press fitted into the cavity 11''', which extends from the upper end wall 12''' of the outer hollow component 9''' downwardly along the longitudinal axis 7 of the inner conductor 6''' and through an opening 13''' in the base 3'''. Thus, the circumferentially extending surface or sidewall 50 of the compensation element 10''' abuts the inner sidewall 51 of the outer hollow component 9''' along the entire length of the compensation element 10'''. The diameter and the material of the compensation element 10''' are chosen such that it is frictionally secured within the cavity 11''' against a movement in the longitudinal or axial direction. During manufacture of the coaxial resonator 1''', the compensation element 10''' is inserted into the cavity 11''' through the opening 13''' in the base 3''', and is press fitted into place. Due to the frictional forces effective between the compensation element 10''' and the outer hollow component 9''', the outer hollow component 9''' and the compensation element 10''' expand and contract together as a unit as long as the frictional forces are not overcome.

[0065] In all embodiments, the parameters of the materials have to be chosen in such a way, that the system does not break due to excessive mechanical stress. Thus, the resonator should only be operated in a temperature range, in which the length changes due to the inner force are in the elastic range.

[0066] Further, in all embodiments at least the portion of the compensation element between its two points of engagement can be modified without affecting the outer appearance and structure of the inner conductor as seen from within the resonator cavity.

Claims

1. A coaxial resonator comprising:

    - a housing (2) defining a resonator cavity (1a) and having a base (3, 3', 3''', 103), a sidewall (4) extending upwardly from the base (3, 3', 3''', 103), and an upper cover (5), and
    - an inner conductor (6, 6', 6", 6''', 106, 106', 106'') extending upwardly from the base (3, 3', 3''', 103) along the longitudinal axis (7, 107) of the coaxial resonator and electrically connected to the base (3, 3', 3''', 103), the inner conductor (6, 6', 6'', 6''', 106, 106', 106") comprising at least two different materials having different coefficients of thermal expansion,

    characterized in that
    the inner conductor (6, 6', 6", 6''', 106, 106', 106'') includes

    - an outer hollow component (9, 9', 9'', 9''', 109, 109', 109'') defining a cavity (11, 11', 11" , 11''', 111, 111'') and comprising a first material having a first coefficient of thermal expansion, and
    - a compensation element (10, 10', 10", 10''', 110, 110', 110'') disposed at least partly within the cavity (11, 11', 11", 11''', 111, 111'') defined by the outer hollow component (9, 9', 9'', 9''', 109, 109', 109'') and comprising a second material having a second coefficient of thermal expansion different from the first coefficient of thermal expansion,

    wherein the compensation element (10, 10', 10", 10''', 110, 110', 110'') is engaged by the outer hollow component (9, 9', 9'', 9''', 109, 109', 109'') at least at two locations spaced in the longitudinal direction of the inner conductor (6, 6', 6", 6''', 106, 106', 106'') such that the compensation element (10, 10', 10'', 10''', 110, 110', 110'') is secured in the longitudinal direction of the inner conductor (6, 6', 6'', 6''', 106, 106', 106'') within the cavity (11, 11', 11'', 11''', 111, 111'') of the outer hollow component (9, 9', 9'', 9''', 109, 109', 109''),
    wherein the compensation element (10, 10', , 10", 10''', 110, 110', 110'') is not in threaded engagement with the outer hollow component (9, 9', 9", 9''', 109, 109', 109'') along the major portion of the length of the compensation element (10, 10', 10'', 10''', 110, 110', 110'') and has dimensions and material characteristics such that a desired temperature dependence of the resonant frequency is achieved.

2. The coaxial resonator according to claim 1, wherein between the two spaced locations the compensation element (10''') is frictionally coupled to the inner sidewall (51) of the cavity (11''') of the outer hollow component (9''').

3. The coaxial resonator according to claim 2, wherein the compensation element (10''') is an elongate

member which is frictionally coupled to the inner sidewall (51) of the cavity (11''') of the outer hollow component (9''') along the entire length of the elongate member.

4. The coaxial resonator according to any of the preceding claims, wherein the cavity (11, 11', 11", 11''', 111, 111'') of the outer hollow component (9, 9' , 9", 9"', 109, 109', 109") extends through an opening (13, 13', 13''') in the base (3, 3', 3"') or through an opening (135) in the upper end of a tubular section (132).

5. The coaxial resonator according to claim 1, wherein the compensation element (10, 10', 10", 110, 110', 110") comprises two engagement sections (14a, 14a', 114a, 114a', 114a 14b, 14b', 14b", 114b) that are engaged by two corresponding engagement sections (15a, 15a', 115a, 115a', 115a''; 15b, 15b', 15b'', 115b) of the outer hollow component (9, 9', 9'', 109, 109', 109'') such that the compensation element (10, 10', 10", , 110, 110', 110'') is secured in the longitudinal direction of the inner conductor (6, 6', 6", 106, 106', 106") within the cavity (11, 11', 11", 111, 111'') of the outer hollow component (9, 9', 9'', 109, 109', 109"), wherein both the engagement sections (14a, 14a', 114a, 114a', 114a''; 14b, 14b', 14b", 114b) of the compensation element (10, 10', 10", 110, 110', 110'') and the engagement sections (15a, 15a', 115a, 115a', 115a''; 15b, 15b', 15b'', 115b) of the outer hollow component (9, 9', 9'', 109, 109', 109") are spaced in the longitudinal direction of the inner conductor (6, 6', 6", 106, 106', 106"), and wherein the compensation element (10, 10', 10", 110, 110', 110'') is not in threaded engagement with the outer hollow component (9, 9', 9'', 109, 109', 109'') along the major portion of the length of the compensation element (10, 10', 10'', 110, 110', 110'') and has dimensions and material characteristics such that a desired temperature dependence of the resonant frequency is achieved.

6. The coaxial resonator according to claim 5, wherein between the two engagement sections (14a, 14a', 114a, 114a', 114a''; 14b, 14b', 14b'', 114b) of the compensation element (10, 10', 10'', 110, 110', 110''), the compensation element (10, 10', 10'', 110, 110', 110'') is under compressive or tensile stress in the longitudinal direction of the inner conductor (6, 6', 6", 106, 106', 106''), wherein the compressive or tensile stress in the longitudinal direction of the inner conductor (6, 6', 6", 106, 106', 106") is generated by forces applied by the two engagement sections (15a, 15a', 115a, 115a', 115a"; 15b, 15b', 15b'', 115b) of the outer hollow component (9, 9', 9'', 109, 109', 109'') .

7. The coaxial resonator according to claim 5, wherein the engagement sections are adapted such that at a particular temperature, the compensation element is under no stress between its two engagement sections in the longitudinal direction of the inner conductor, and that above and below this particular temperature, the compensation element is under compressive or tensile stress between its two engagement sections in the longitudinal direction of the inner conductor.

8. The coaxial resonator according to any of claims 5 to 7, wherein the two engagement sections (14a, 14a', 114a, 114a', 114a"; 14b, 14b', 14b'', 114b) of the compensation element (10, 10', 10", 110, 110', 110") are disposed in the two longitudinal end portions of the compensation element (10, 10', 10", 110, 110', 110'').

9. The coaxial resonator according to any of claims 5 to 8, wherein at least one of the engagement sections (15a, 115a; 15b', 115b) of the outer hollow component (9, 9', 109, 109', 109") comprises a threaded portion (18, 26, 137, 139) that engages a corresponding threaded portion (17, 25, 136, 138) of the corresponding engagement section (14a, 114a; 14b', 114b) of the compensation element (10, 10', 110, 110', 110'').

10. The coaxial resonator according to any of claims 5 to 9, wherein at least one of the engagement sections (15a', 115a', 115a''; 15b, 15b'') of the outer hollow component (9, 9', 9", 109', 109") or at least one of the engagement sections (14a', 114a', 114a''; 14b, 14b'') of the compensation element (10, 10', 10", 110', 110") comprises an abutment surface (20, 22, 23, 24, 27, 28, 142, 142'', 143, 148), which rest against a part of the compensation element (10, 10', 10", , 110' , 110") or the outer hollow component (9, 9', 9'', 109', 109' '), respectively.

11. The coaxial resonator according to claim 10, wherein at least one of the engagement sections (15b'') of the outer hollow component (9") comprises an abutment surface (28) that is formed on a closure element (29) which is threadedly secured inside the outer hollow component (9'').

12. The coaxial resonator according to claim 10 or claim 11, wherein at least one of the engagement sections (15a', 115a', 115a''; 15b, 15b'') of the outer hollow component (9, 9', 9'', 109', 109'') comprises an abutment surface. (22, 24, 28, 143, 148) that rests against a corresponding abutment surface (20, 23, 27, 142, 142") of the corresponding engagement section (14a', 114a', 114a"; 14b, 14b") of the compensation element (10, 10', 10", 110', 110'').

13. The coaxial resonator according to any of claims 5 to 12, wherein at least one of the engagement sec-

tions of the outer hollow component comprises a friction surface that is frictionally coupled to a corresponding friction surface of the corresponding engagement section of the compensation element.

14. The coaxial resonator according to any of claims 5 to 13, wherein the cavity (11, 11', 11'') of the outer hollow component (9, 9', 9'') extends through an opening (13, 13') in the base (3, 3'), and wherein one of the engagement sections (15a, 15a') of the outer hollow component (9, 9', 9'') is formed in the upper end wall (12, 12') of the cavity (11, 11', 11'') of the outer hollow component (9, 9', 9"), and the other engagement section (15b, 15b', 15b'') of the outer hollow component (9, 9', 9'') is formed in the sidewall of the cavity (11, 11', 11") of the outer hollow component (9, 9', 9"), the sidewall of the opening (13, 13') in the base (3, 3'), or on a closure element (29) that is secured in the opening (13, 13') of the base (3, 3') or the cavity (11, 11', 11'') of the outer hollow component (9, 9', 9").

15. The coaxial resonator according to claim 14, wherein the engagement section (15a) formed in the upper end wall (12) of the cavity (11) of the outer hollow component (9) and the corresponding engagement section (14a) of the compensation element (10) comprise interengaging threaded portions (17, 18), and the other engagement section (15b) of the outer hollow component (9) and the corresponding engagement section (14b) of the compensation element (10) comprise abutment surfaces (20, 22) resting against each other, so that the compensation element (10) is under tensile stress between its engagement sections (14a, 14b) in the longitudinal direction of the inner conductor (6).

16. The coaxial resonator according to claim 14, wherein the engagement section (15a') formed in the upper end wall (12') of the cavity (11') of the outer hollow component (9') and the corresponding engagement section (14a') of the compensation element (10') comprise abutment surfaces (23, 24) resting against each other, and the other engagement section (15b') of the outer hollow component (9') and the corresponding engagement section (14b') of the compensation element (10') comprise interengaging threaded portions (25, 26), so that the compensation element (10') is under compressive stress between its engagement sections (14a', 14b') in the longitudinal direction of the inner conductor (6').

17. The coaxial resonator according to claim 14, wherein both engagement sections (15a', 15b'') of the outer hollow component (9'') and the corresponding engagement sections (14a', 14b") of the compensation element (10'') comprise abutment surfaces (23, 24, 27, 28) resting against each other, the lower engagement section (15b") of the outer hollow component (9") being formed on a closure element (29) that is threadedly secured in the opening (13') of the base (3') or the cavity (11'') of the outer hollow component (9''), so that the compensation element (10'') is under compressive stress between its engagement sections (14a', 14b") in the longitudinal direction of the inner conductor (6'').

18. The coaxial resonator according to any of claims 5 to 13, wherein the cavity (111, 111'') of the outer hollow component (109, 109', 109") extends through an opening (135) in the upper end of a tubular section (132), and wherein one of the engagement sections (115b) of the outer hollow component (109, 109', 109'') is formed in the lower end wall (134) of the cavity (111, 111'') of the outer hollow component (109, 109', 109"), and the other engagement section (115a, 115a', 115a") of the outer hollow component (109, 109', 109") is formed in the sidewall of the cavity (111, 111'') of the outer hollow component (109, 109', 109"), by the annular upper end face (143) of the tubular section (132) or an element (133) of the outer hollow component (109, 109', 109'') that is rigidly connected to the tubular section (132).

19. The coaxial resonator according to claim 18, wherein the engagement section (115b) formed in the lower end wall (134) of the cavity (111) of the outer hollow component (109') and the corresponding engagement section (114b).of the compensation element. (110') comprise interengaging threaded portions (136, 137), and the other engagement section (115a') of the outer hollow component (109') and the corresponding engagement section (114a') of the compensation element (110') comprise abutment surfaces (142, 143) resting against each other, so that the compensation element (110') is under tensile stress between its engagement sections (114a', 114b) in the longitudinal direction of the inner conductor (106').

20. The coaxial resonator according to claim 18, wherein the engagement section formed in the lower end wall of the cavity of the outer hollow component and the corresponding engagement section of the compensation element comprise abutment surfaces resting against each other, and the other engagement section of the outer hollow component and the corresponding engagement section of the compensation element comprise interengaging threaded portions, so that the compensation element is under compressive stress between its engagement sections in the longitudinal direction of the inner conductor.

21. The coaxial resonator according to claim 19 or claim 20, wherein a part (144) of the compensation element (110') protruding from the tubular section (132) of the outer hollow component (109') forms a longitudinal section of the inner conductor (106').

22. The coaxial resonator according to claim 18, wherein both engagement section (115a, 115b) of the outer hollow component (109) and the corresponding engagement sections (114a, 114b) of the compensation element (110) comprise interengaging threaded portions (138, 139, 136, 137), the upper engagement section (115a) of the outer hollow component (109) being formed on a closure element (133) that abuts and closes the upper end of the tubular section (132), so that the compensation element (110) is under tensile stress between its engagement sections (114a, 114b) in the longitudinal direction of the inner conductor (106) .

23. The coaxial resonator according to claim 18, wherein both engagement sections of the outer hollow component and the corresponding engagement sections of the compensation element comprise abutment surfaces resting against each other, the lower engagement section of the outer hollow component being formed on a closure element that is threadedly secured in the tubular section, so that the compensation element is under compressive stress between its engagement sections in the longitudinal direction of the inner conductor.

24. The coaxial resonator according to any of the preceding claims, wherein the part of the compensation element (10, 10', 10", 10''', 110, 110', 110"), that is disposed within the cavity (11, 11', 11", 11''', 111, 111") of the outer hollow component (9, 9', 9", 9''', 109, 109', 109''), is not in threaded engagement with the inner walls of the cavity (11, 11', 11'', 11''', 111, 111'') of the outer hollow component (9, 9', 9'', 9''', 109, 109', 109'') along the major portion of the length of this part of the compensation element (10, 10', 10'', 10''', 110, 110', 110").

25. The coaxial resonator according to any of the preceding claims, wherein the compensation element (10, 10', 10", 10''', 110, 110', 110'') is removably secured within the cavity (11, 11' , 11", 11''', 111, 111'') of the outer hollow component (9, 9', 9" , 9''', 109, 109', 109'').

26. The coaxial resonator according to any of the preceding claims, wherein the compensation element (10, 10', 10", 10''', 110, 110', 110'') is made of a solid material.

27. The coaxial resonator according to any of claims 1 to 25, wherein the compensation element (10'') comprises a liquid material.

28. The coaxial resonator according to any of the preceding claims, wherein at least a part of the outer hollow component (9, 9' , 9", 9''', 109, 109', 109") is integrally formed in one piece with the base (3, 3', 3''', 103).

29. The coaxial resonator according to claim 28, wherein the outer hollow component (9, 9', 9''') is integrally formed in one piece with the base (3, 3', 3''').

30. The coaxial resonator according to any of claims 1 to 28, wherein the outer hollow component (9'', 109, 109'') is a composite component comprising at least two elements which are attached to each other.

31. The coaxial resonator according to any of the preceding claims, wherein between the lower end of the cavity (111, 111'') of the outer hollow component (109, 109', 109") and the plane defined by the upper surface of the base (103), the outer hollow component (109, 109', 109'') comprises a solid section.

32. The coaxial resonator according to any of the preceding claims, wherein the outer hollow component includes at least two cavities separated in the longitudinal direction of the inner conductor, wherein in each such cavity a compensation element is secured.

33. A microwave filter comprising a plurality of coupled resonators, wherein the plurality of coupled resonators includes at least one coaxial resonator (1, 1', 1'', 1''', 101, 101', 101'') according to any of claims 1 to 32.

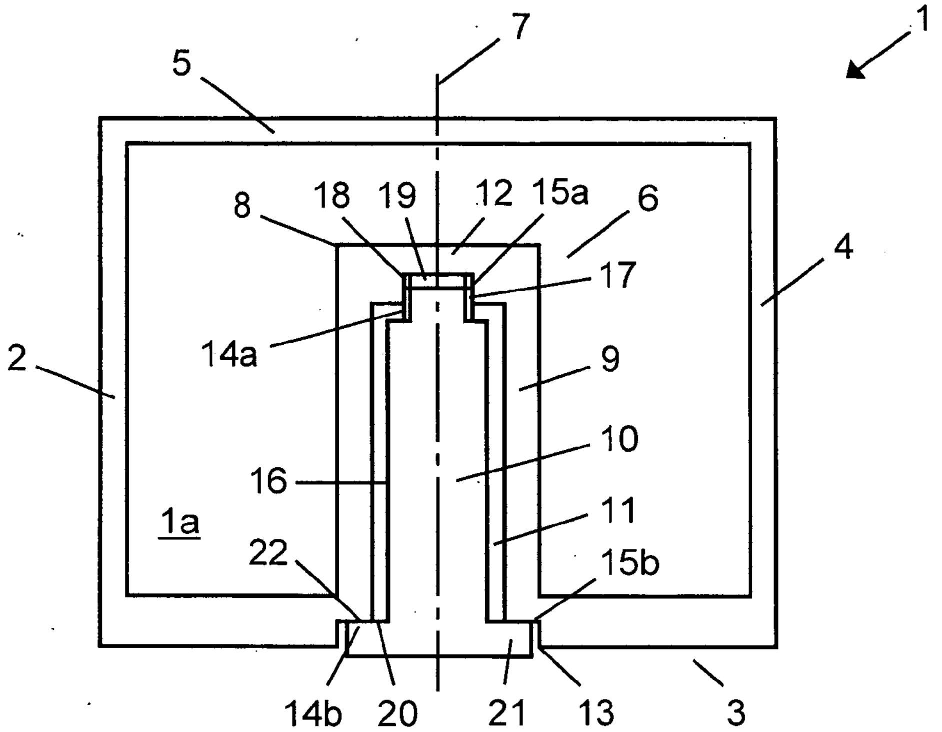
34. A method of constructing a coaxial resonator (1, 1', 1", 1''', 101, 101', 101'') according to any of claims 1 to 32 comprising the steps of:

- choosing a nominal operating temperature for the coaxial resonator (1, 1', 1", 1''', 101, 101', 101'') to be constructed,
- choosing a nominal resonant frequency f_0 at the nominal operating temperature,
- choosing a range of operating temperatures ΔT,
- determining a geometrical shape and geometrical dimensions, including the length of the inner conductor (6, 6', 6'', 6''', 106, 106', 106"), of the resonator cavity (1a) of the coaxial resonator (1, 1', 1'', 1''', 101, 101', 101'') to be constructed, such that the resonator cavity (1a) yields the resonant frequency f_0 at the nominal operating temperature, and
- providing a coaxial resonator (1, 1', 1'', 1''', 101, 101', 101'') according to any of claims 1 to 32 having a resonator cavity (1a) with the determined geometrical shape and the determined geometrical dimensions,

wherein the method further comprises the step of choosing a value for at least one construction parameter of the compensation element (10, 10', 10'', 10''', 110, 110', 110'') yielding a minimum temperature induced change of resonant frequency f_0 in the temperature range ΔT with respect to the at least one construction parameter.

35. The method according to claim 34, wherein the at least one construction parameter includes the cross-sectional diameter of the portion of the compensation element (10, 10', 10'', 10''', 110, 110', 110'') between its two engagement sections (14a, 14a', 114a, 114a', 114a"; 14b, 14b', 14b", 114b).

36. The method according to claim 34 or claim 35, wherein the at least one construction parameter includes the material of the compensation element (10, 10', 10'', 10''', 110, 110', 110").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18
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12
15a
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1a
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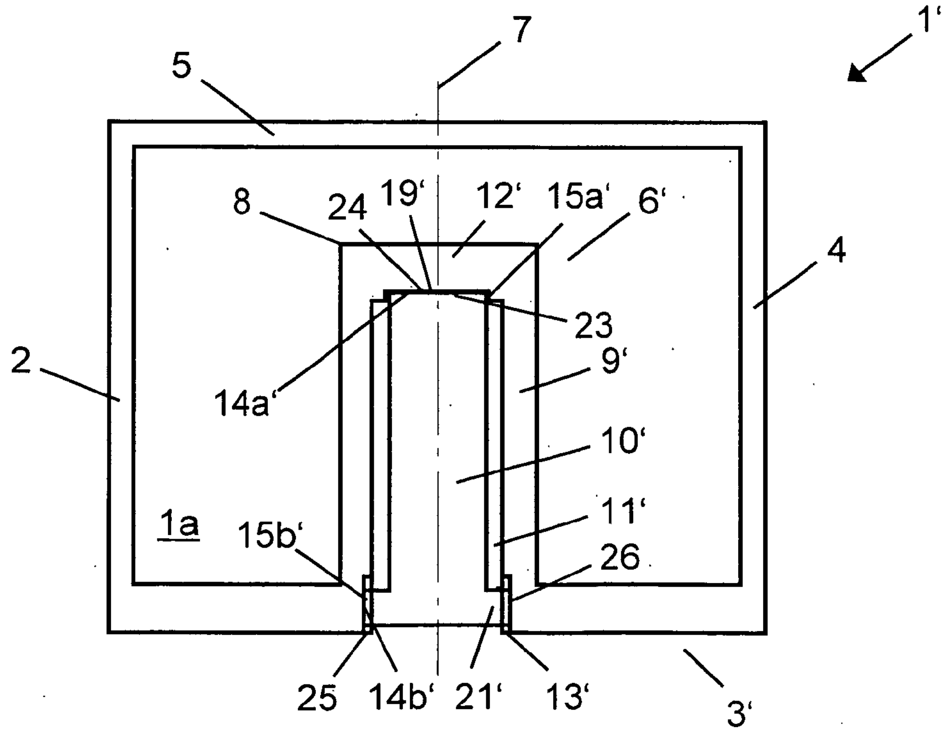
14b
20
21
13
3

Fig. 1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6'
4
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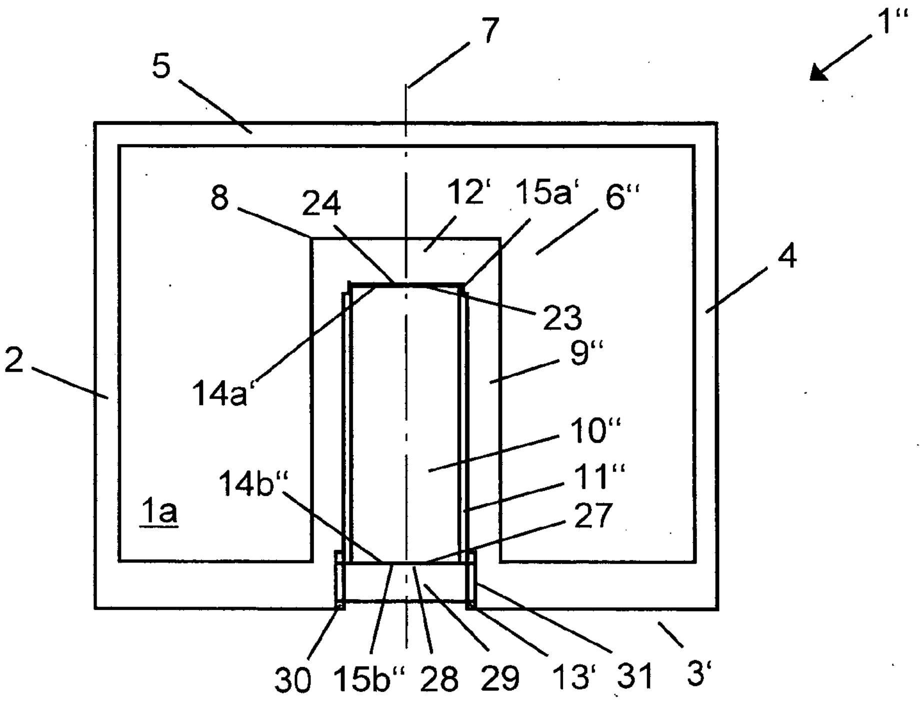
1a
15b'
26
25
14b'
21'
13'
3'

Fig. 2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4
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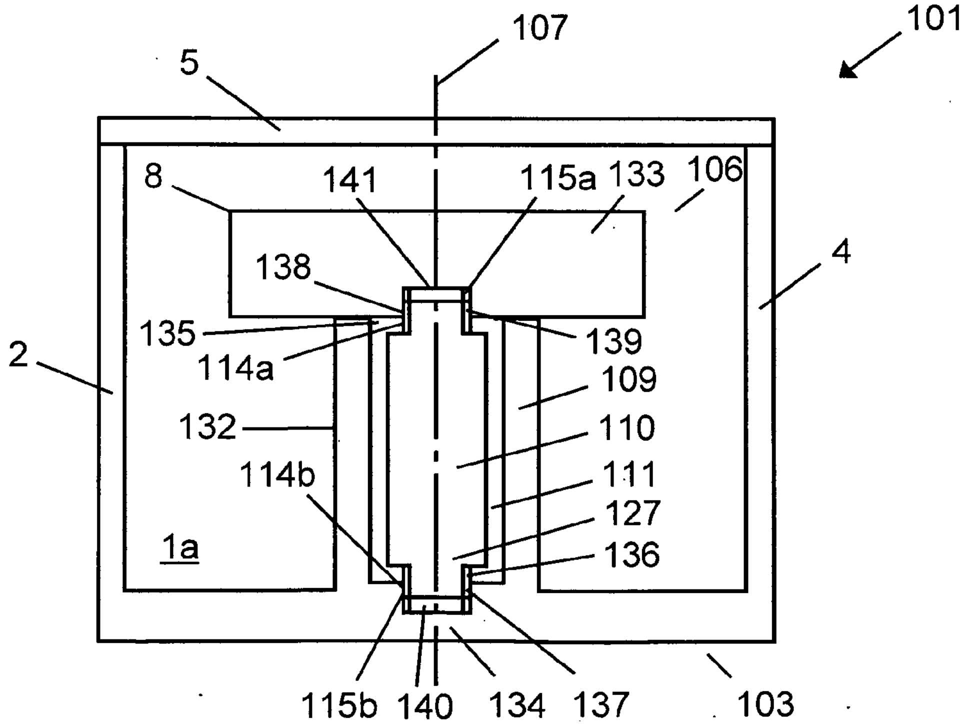
1a
27
30
15b"
28
29
13'
31
3'

Fig. 3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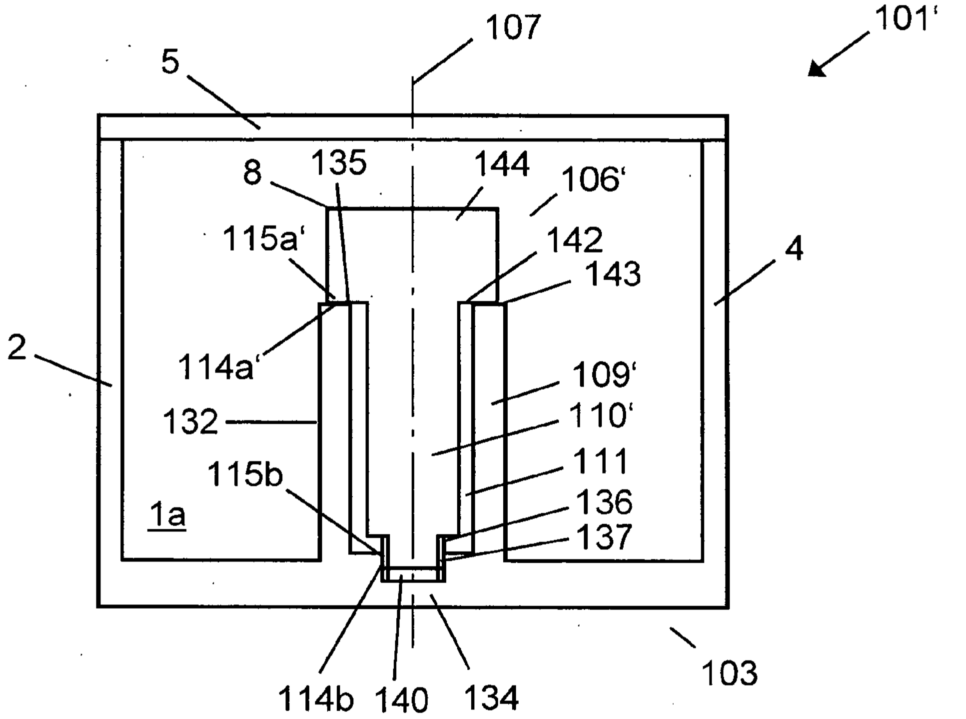
1a
136
115b
140
134
137
103

Fig. 4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144
106'
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142
143
4
2
114a'
109'
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110'
111
115b
136
1a
137
114b
140
134
103

Fig. 5

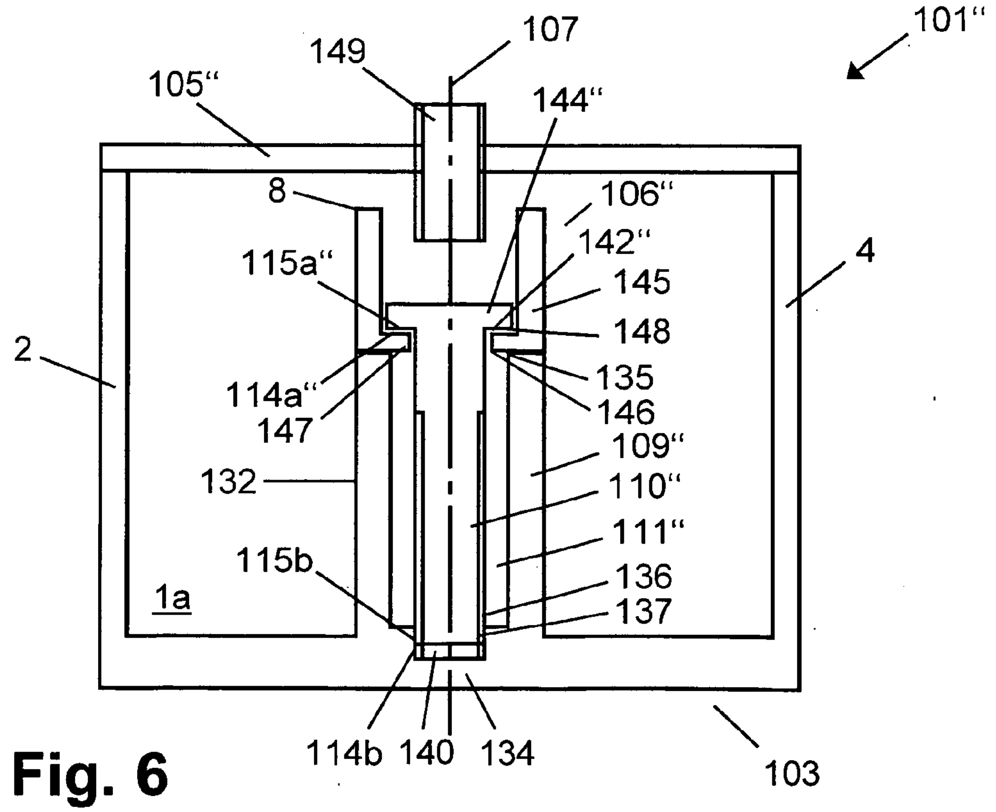
107
101''
149
105''
144''
8
106''
142''
115a''
145
4
148
2
114a''
135
147
146
109''
132
110''
111''
115b
136
1a
137
114b
140
134
103

Fig. 6

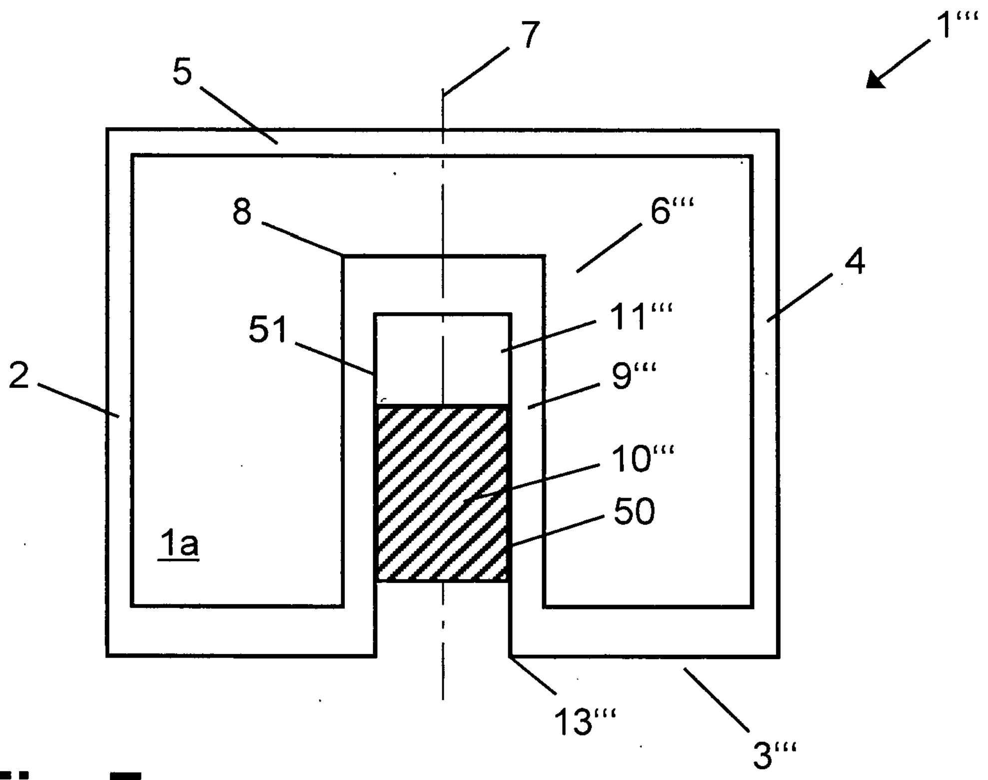

Fig. 7

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 05 01 9355

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	30 January 2006	Pastor Jiménez, J-V

CATEGORY OF CITED DOCUMENTS

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