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

(11) EP 1 962 369 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
27.08.2008 Bulletin 2008/35

(51) Int Cl.:
H01P 1/208 *(2006.01)* ***H01P 7/10*** *(2006.01)*

(21) Application number: **07003578.7**

(22) Date of filing: **21.02.2007**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR MK RS

(71) Applicant: **Matsushita Electric Industrial Co., Ltd.**
Kadoma City
Osaka 571-8501 (JP)

(72) Inventor: **Höft, Michael**
21271 Asendorf (DE)

(74) Representative: **UEXKÜLL & STOLBERG**
Patentanwälte
Beselerstrasse 4
22607 Hamburg (DE)

(54) Dielectric multimode resonator

(57) The present invention relates to a dielectric multimode resonator comprising a plurality of walls (2,3,4) enclosing a resonator cavity (6) a resonator element (7) made of dielectric material and disposed in the resonator cavity (6) The plurality of walls (2,3,4) includes a first wall (2), an opposing second wall (3) and at least on one third wall (4) extending between and connecting the first wall (2) and the second wall (3). The resonator element (7) comprises a central portion (8) and exactly four elongate leg portions (9a,9b,9c,9d) extending longitudinally from the central portion (8) towards the walls (2,3,4), such that one (10) of the two longitudinal ends (10,11) of each elongate leg portion (9a,9b,9c,9d) is directly joined to the central portion (8) and the other longitudinal end (11) is connected to only one of the walls (2,3,4). Elongate leg portions (9a,9b,9c,9d) included in a first set are connected to a different wall (2,3,4) than elongate leg portions (9a, 9b,9c,9d) included in a second set.

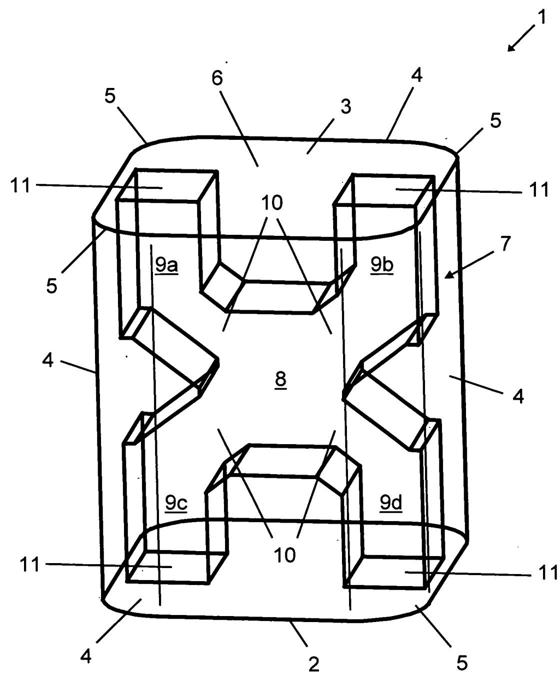

FIG. 1

EP 1 962 369 A1

Description

[0001] The present invention relates to a dielectric multimode resonator comprising a plurality of walls enclosing a resonator cavity, wherein the plurality of walls includes a first wall, an opposing second wall and at least one third wall extending between and connecting the first wall and the second wall, and a resonator element made of dielectric material and disposed in the resonator cavity, wherein the resonator element comprises a central portion and exactly four elongate leg portions extending longitudinally from the central portion towards the walls, such that one of the two longitudinal ends of each elongate leg portion is directly joined to the central portion and the other longitudinal end is connected to only one of the walls. The invention further relates to a microwave filter comprising at least one of such dielectric multimode resonators.

[0002] Dielectric resonators are commonly used as basic components of microwave filters which are e.g. utilized in various devices, such as base stations and mobile units, of wireless communications systems. Generally, a dielectric resonator comprises a piece of material having a large dielectric constant and disposed within an electrically conductive housing or enclosure acting as a shield against coupling of radiation between the inside and the outside of the enclosure. Electromagnetic energy coupled into the piece of dielectric material is internally reflected at the interfaces between the dielectric material and air. In this way, at certain frequencies resonances are supported by the piece of dielectric material, so that the piece of dielectric material functions as a miniature microwave resonator or resonator element. This results in the electric field being guided by the resonator element and, thus, in confinement of electromagnetic energy within and in the vicinity of the resonator element. Such resonance modes may therefore be referred to as "guided modes". Depending on their shape and construction, such resonator elements may support one or more TE (transverse electric) modes and/or one or more TM (transverse magnetic) modes.

[0003] At the resonance frequency of a dielectric resonator, the magnetic field energy equals the electric field energy and electromagnetic fields can be transmitted with minimal loss. The resonance frequencies of a multimode dielectric resonator are controlled by the shape, the cross sectional area and the per-mittivity constant of its resonator element. Important characteristics of a dielectric resonator are the field patterns, the Q factor, the resonance frequencies and the spurious free bandwidth. It is known that these factors depend on the dielectric material used, the shape of the resonator element, and the resonance mode(s) used. The quality factor Q, which is determined by losses in a structure, is an important design parameter in the design of dielectric resonator filters. The resonator bandwidth is inversely proportional to Q. A high Q is a desirable property of a dielectric resonator as it infers low insertion losses.

[0004] Another factor that is important in the design of dielectric resonator filters is the tuning of the individual resonance frequencies of the dielectric resonator(s) to achieve a desired filter response. Such adjusting means are usually realized by a screw extending in a direction orthogonal to the reflection surface effective to change the resonance frequency of a particular resonator element or resonance mode. Further tuning of the filter response may be effected by a screw between two dielectric resonators to adjust the coupling between these dielectric resonators.

[0005] The first dielectric resonator arrangements included cylindrical resonator elements commonly known as pucks. As a fundamental mode such pucks support the TE01δ mode in which the electric field is concentrated within the dielectric material and rotates inside the puck forming closed circular rings. To avoid ohmic losses, any contact between the dielectric puck and the walls of the enclosure has to be avoided and sufficient distance between the puck and the walls has to be provided to minimize the surface currents which are induced by the magnetic field circularly surrounding the electric field and not confined by the dielectric material. For these purposes, the pucks were usually supported within the enclosure by a supporting structure made of low dielectric constant material.

[0006] Other common dielectric resonator elements are formed by a straight dielectric rod disposed centrally inside a cylindrical cavity extending between and in electrical contact with the bottom wall and the top wall. As a fundamental mode such resonator elements support the TM010 mode, wherein for mode designation purposes the direction of extension of the rod is chosen as z axis. In this mode, the electric field is again concentrated within and guided by the dielectric material, i.e. the electric field lines extend along the direction of extension of the dielectric rod and are perpendicular to the bottom wall and the top wall. The magnetic field lines are circularly closed and surround the rod in planes perpendicular to the rod. Surface currents are induced, which are flowing between the two contact locations of the rod with the enclosure and together with the electric field lines form closed loops.

[0007] For dielectric rods supporting the TM010 mode, good electric contact between the dielectric material and the top wall and the bottom wall has to be maintained because an air gap between the dielectric rod and the walls leads to an undesired frequency shift. Mechanical stress due to different coefficients of thermal expansion for the walls and the dielectric rod poses a problem which has to be taken into account upon construction of the dielectric resonator. For example, it is known to avoid mechanical stress and increase temperature stability by letting the dielectric rod extend into bores in the top wall and the bottom wall (see e.g. Y. Kobayashi, S. Yoshida, "Bandpass filters using TM010 dielectric rod resonators", Proc. IEEE MTT-Symposium, 1978, pages 233-235). However, this construction has been found to be insufficient in solving the problem of frequency stability. Another approach utilizes a dielectric shielding enclosure made of the same material as the dielectric rod. This technique was improved by constructing the dielectric shielding enclosure and the rod integrally in one piece (see e.g. Y. Ishikawa, J. Hattori, M. Andoh, T. Nishikawa, "800 MHz high power duplexer using TM dual mode dielectric resonators", Proc. IEEE MTT-Symposium, 1992, pages 1617-1620).

[0008] Furthermore, dual mode operation was achieved by utilizing a cross-shaped resonator element, i.e. an element that can be described as comprising two intersecting dielectric rods arranged perpendicular to each other or as comprising a central portion forming the node of the cross and four elongate leg portions extending longitudinally from the central portion at angles of 90°. With such a resonator element, each of the two rod components supports a fundamental resonance mode having a field configuration described above for the case of a single rod.

[0009] In general, multimode dielectric resonators, realized by using two or more distinct dielectric resonator elements and/or a dielectric resonator element structure, parts of which form different dielectric resonator components, are superior to single mode dielectric resonators with regard to filter production. This is because the filter characteristics are commonly enhanced when the number of resonance modes excited in the filter is increased. Thus, a single dielectric resonator having a resonator element supporting more than one mode enables a reduction in the size of the filter, because a plurality of coupled single mode dielectric resonators is avoided.

[0010] Therefore, a variety of different dielectric resonators with resonator elements simultaneously supporting two or more resonance modes are known in the prior art. For example, triple mode operation of a TM mode dielectric resonator for a channel dropping filter is described in T. Nishikawa, K. Wakino, H. Wada, Y. Ishikawa, "800 MHz band dielectric channel dropping filter using TM110 triple mode resonance", Proc. IEEE MTT-Symposium, 1985, pages 289-292. In this case, a resonator element comprising three perpendicular dielectric rods was used.

[0011] With regard to the terminology used to designate the resonance modes it has to be noted that different designations may exist for a particular resonator or mode. For example, instead of using the name TM mode resonator or filter the name dielectric-loaded waveguide filter is used in the textbook I.C. Hunter, "Theory and Design of microwave filters", IEE electromagnetic waves series No. 48, London: IEE, 2001, chapter 7.5.1 pages 314 et sqq., since the field patterns of this type of resonator are comparable to similar waveguide filters which are using air cavity resonators, i.e. resonators not comprising dielectric resonator elements. As another example, the TM010 mode in a cylindrical cavity is comparable to the TM110 mode in a rectangular cavity. Furthermore, the mode names may depend on the axis chosen to be the direction of propagation for the corresponding waveguide modes leading to the resonances. This is explained in the textbook S. Ramo, J.R. Whinnery, T. van Duzer, "Fields and waves in communication electronics", 3rd ed. New York: John Wiley & Sons, 1993, chapter 10.4 pages 494 et sqq.

[0012] Therefore, to avoid ambiguities, it is more convenient to include the direction of propagation into the mode designation. For example, in a rectangular resonator the TMy110 mode is identical to the TEz101 mode. Using this terminology, the above mentioned TM dual mode resonances of two crossed dielectric rods are designated as TMy110 and TMx110 in US 6,278,344 (Figures 12a and 12b). However, they could also be designated as TEz101 and TEz011. In the summary of US 6,278,344, the modes are designated as "pseudo TM110".

[0013] In the prior art, triple mode operation was also achieved by using the cross-shaped resonator element described above with regard to dual mode operation by choosing suitable dimensions of the resonator element. For example, such a triple mode dielectric resonator with a planar cross-shaped resonator element is disclosed in US 6,278,344. The four leg portions extending from the central portion are connected with their longitudinal ends, located opposite the central portion, to the sidewalls of a cubical enclosure in which the resonator element is disposed. In addition to the above-described pseudo TM110 modes, in which the electric field is guided in only two opposing of the four elongate leg portions, i.e. in one of the two rod components, the resonator element also supports a pseudo TM111 mode, in which the electric field is guided in all four elongate leg portions, to achieve triple mode operation. A through bore may be provided in the center of the central portion and extending perpendicular to the plane of the cross. The dimensions of the through bore are chosen to adjust the resonance frequencies of the two pseudo TM110 modes with respect to the pseudo TM111 mode, so that the resonance frequencies of the three modes are approximately equal. This adjustment is possible because the through bore mainly affects the resonant frequencies of the pseudo TM 110 modes.

[0014] EP 1 014 474 relates to a dielectric multimode resonator having a resonator element comprising a block-shaped central portions and a plurality of short dielectric support portions extending between the block and the walls of the enclosure to support the block within the cavity. The resonator element supports different TE01δ and TM01δ modes in which the electric field is guided annularly closed within the block-shaped central portion. In order to be able to support these modes, the block-shaped central portion has to have a large volume.

[0015] The prior art dielectric multimode resonators comprising a cross-shaped resonator element have several disadvantages. It is difficult to securely mount the resonator element within the resonator cavity such that a good electrical contact between the dielectric material and the walls is maintained in order to avoid an undesired frequency shift. As noted above, mechanical stress due to different coefficients of thermal expansion for the walls and the dielectric resonator element has to be taken into account in this regard. Further, it is difficult and cost intensive to place tuning elements for tuning the resonator.

[0016] It is an object of the present invention to provide a dielectric multimode resonator, and in particular a dielectric multimode resonator, which is adapted to overcome the above mentioned disadvantages.

[0017] This object is achieved by a dielectric multimode resonator with the features of claim 1. Further preferred embodiments of the dielectric multimode resonator are the subject-matter of the dependent claims.

[0018] The dielectric multimode resonator comprises a plurality of walls defining a resonator cavity enclosed by the walls. The plurality of walls includes and preferably consists of a first wall, an opposing second wall and at least one third wall extending between and connecting the first wall and the second wall, and thus separating the first wall and the second wall. Thus, there is one such third wall or a plurality of distinct such third walls, i.e. a plurality of third walls in which each two adjacent third walls are separated by a sharp or rounded edge. For example, the n sidewalls of a right prism with a polygonal base having n sides with sharp or rounded corners, are n distinct third walls. Preferably, the third walls are connected edge to edge in series in an annularly closed manner. The first wall may e.g. be the bottom wall of the resonator, the second wall may e.g. be the top wall of the resonator, and the at least one third wall may e.g. be at least one sidewall of the resonator. For example, the resonator cavity can have a circularly or elliptically cylindrical, cuboidal or cubical shape with sharp and/or rounded edges or the shape of a prism with a polygonal base having three or more sides with sharp and/or rounded corners. Preferably, the plurality of walls completely surround the resonator cavity. In general, the walls consist of or comprise, e.g. in the form of a coating, a conductive material, such as a metal material.

[0019] The dielectric multimode resonator further comprises a resonator element made of dielectric material and disposed within the resonator cavity. The dielectric material may e.g. be a ceramic, preferably a mixture of mainly zirconate and titanate, in particular about 48% ZrO_2 and about 48% TiO_2, such as e.g. a Zr-Ti-Mg-Nb-O based dielectric ceramic. Preferably, the dielectric material has a dielectric constant ε_r of between 20 and 80, preferably of between 35 and 45, and most preferred of about 42.

[0020] The resonator element comprises and preferably consists of a central portion spaced from the walls and exactly four elongate leg portions - i.e. leg portions having a length dimension that is greater than the two width dimensions - extending longitudinally from the central portion towards the walls, such that each elongate leg portion is directly joined to the central portion only with exactly one of its two longitudinal ends and is connected to a wall with only its other longitudinal end. In this regard, it should be noted that the longitudinal end, of course, includes an end section of a certain extension. The remainder of the elongate leg portions is not connected to a wall or to the central portion. Each elongate leg portion is connected to only one of the walls. Further, due to the fact that the resonance frequencies of undesired modes, in which the electric field lines are guided annularly closed within an elongate portion, are lower for plate-shaped portions than for rod-shaped portions, it is preferred that the elongate portions have the shape of a straight, curved and/or angled rod, i.e. that the two width dimensions are comparable.

[0021] One, two or three of the four elongate leg portions constitute a first set of elongate leg portions and the remaining elongate leg portion (in the case of the first set including three of the four elongate leg portions) or the remaining elongate leg portions (in the case of the first set including one or two of the four elongate leg portions) of the four elongate leg portions constitute a second set of elongate leg portions. All elongate leg portions included in the first set are connected to the same wall, and all elongate leg portions included in the second set are also connected to the same wall. The elongate leg portions of the first set are connected to a different wall than the elongate leg portions of the second set. With other words, the four elongate leg portions are connected to only two of the plurality of walls of the resonator, wherein one, two or three of the four elongate leg portions are connected to one of the two walls, and the other three, two and one, respectively, elongate leg portions are connected to the other of the two walls.

[0022] Preferably, the resonator element is integrally made in one piece.

[0023] This dielectric multimode resonator has the advantage that secure mounting of the resonator element with a reliable electric contact to the walls is greatly facilitated, because only two walls have to be taken into consideration for the mounting arrangement and mounting procedure. Further, only two walls instead of four have to be considered when determining the behavior of the resonator upon temperature increase and decrease. In addition, because at least two of the elongate leg portions are connected to the same wall, it is easier to arrange and dispose suitable tuning elements, so that the costs for placing the tuning elements are lower. In this way, manufacturing of the dielectric multimode resonator is greatly facilitated.

[0024] The resonator cavity may have the shape of a right prism with a polygonal base having three or more sides and sharp and/or rounded edges. In this case, the plurality of walls consists of the first wall and the second wall and a number of third walls, which number is equal to the number of sides of the polygonal base of the right prism. Each of these third walls extends between and connects the first wall and the second wall. The third walls are connected edge-to-edge in an annularly closed manner with the edges between adjacent third walls being sharp and/or rounded. The first wall and the second wall are perpendicular to each of the third walls and are parallel to each other. For example, the first wall may be the bottom wall of the resonator, the second wall may be the top wall of the resonator, and the third walls may be the sidewalls of the resonator.

[0025] Thus, the resonator cavity may in particular have a cuboidal shape with sharp and/or rounded edges. Then, the plurality of walls consists of six walls, each defining one side of the cuboidal resonator cavity, and includes four third walls extending between and connecting the first wall and the second wall. The third walls are connected edge-to-edge in an annularly closed manner, wherein adjacent third walls are perpendicular to each other and opposing third walls are parallel to each other. The first wall and the second wall are perpendicular to each of the four third walls and are parallel to each other. For example, the first wall may be the bottom wall of the resonator, the second wall may be the top wall of the resonator, and the four third walls may be the four sidewalls of the resonator.

[0026] The resonator cavity may also have a circularly or elliptically cylindrical shape with sharp and/or rounded edges. Accordingly, in this case, the plurality of walls consists of three walls and includes one cylindrical third wall extending between and connecting the first wall and the second wall. The third wall is extending annularly closed in a circular or oval shape. The first wall and the second wall are perpendicular to the single third wall and are parallel to each other. For example, the first wall may be the bottom wall of the resonator, the second wall may be the top wall of the resonator, and the single third wall may be the sidewall of the resonator.

[0027] In a preferred embodiment, the first wall and the second wall are planar and parallel to each other. In a further preferred embodiment, each of the third walls is planar. Of course, it is also possible that the first wall and the second wall are planar and parallel to each other and that each of the third walls is planar. In any case, the edges between adjacent walls may be sharp and/or rounded.

[0028] In a preferred embodiment, the first and the second set of elongate leg portions are connected to opposing walls, such as to the bottom wall and the top wall, respectively, of a cylindrical or cuboidal resonator, or to two non-adjacent sidewalls of a cuboidal resonator. This arrangement provides the advantage that in connection with the problem of mechanical stress only mechanical forces need to be considered that mainly dominate in one axis. By contrast, in case of resonator elements connected to four different walls or to two adjacent walls, mechanical forces acting in two axes have to be taken into consideration.

[0029] For this embodiment, it can be advantageous if one or both of the two opposing walls to which the two sets of elongate leg portions are connected comprises a resilient portion which is adapted to exert a spring or biasing force on the resonator element generating a clamping force that at least contributes to securing the resonator element within the resonator cavity. Each resilient portion is further adapted to accommodate expansion and contraction of the resonator element, while ensuring good electric contact between the resonator element and the respective wall. In this way, the resonator element is even securely held in place and electric contact is maintained by the clamping force if the resonator element changes its dimensions due to a change in temperature. Each resilient wall portion is associated with at least one of the elongate leg portions connected to the respective wall. In case of two or three elongate leg portions being connected to a particular wall, it should be noted that it is, of course, possible that this wall comprises two or three resilient portions, wherein each of the two or three resilient portions of the wall are associated with one of the two or three elongate leg portions.

[0030] In an alternative preferred embodiment, the first and the second set of elongate leg portions are connected to adjacent walls. Such an arrangement may be advantageous in case it is desired to construct at least the walls to which the elongate leg portions are connected from dielectric material and integrally with the resonator element. Further, if clamping forces are not required for securing a separate resonator element within the resonator cavity, e.g. because the coefficients of thermal expansion of the resonator element and the walls are similar or substantially identical, it is particularly easy in this arrangement to connect the elongate portions to the walls e.g. by soldering, brazing, welding or by using adhesives.

[0031] The longitudinal end opposite the central portion of one or more or all of the elongate leg portions may be directly joined to the respective wall. Further, the longitudinal end opposite the central portion of one or more or all of the elongate leg portions may be connected to the respective wall via one or more intermediate elements that are made of dielectric material having a dielectric constant that is smaller than that of the dielectric material of the resonator element. It is also possible that some of the elongate leg portions are directly connected to their associated wall and some of the elongate leg portions are connected to their associated wall via one or more intermediate elements. The intermediate element(s) may also take the form of a dielectric shielding cavity provided instead of metallic walls or between the electrically conductive portions of the walls and the elongate leg portions. In the latter case, the resonator element may also be integrally formed in one piece with such a shielding cavity. If intermediate elements are used, it is preferred that they are made of a ceramic or other dielectric material having a much lower dielectric constant than the resonator element, e.g. a dielectric constant ε_r of between 8 and 12, and preferably of about 10. Advantageous materials are alumina, forsterite or quartz. By utilizing intermediate elements it is easily possible to shift the resonance frequencies of the modes supported by the resonator element to higher frequencies as compared to an arrangement without intermediate elements or with smaller intermediate elements.

[0032] It is preferred that the maximum diameter of the central portion is smaller than the length of the elongate leg portions. Accordingly, the central portion does not form the main portion of the resonator element. In particular, it is preferred that at the connection to the central portion, each elongate leg portion is in direct contact with at least one adjacent elongate leg portion.

[0033] In a preferred embodiment, one of the elongate leg portions of the first set of elongate leg portions and one of the elongate leg portions of the second set of elongate leg portions together form a first elongate member, such as e.g. a first elongate rod member, and the remaining two elongate leg portions together form a second elongate member, such as e.g. a second elongate rod member, wherein the first and the second elongate member intersect each other. In this case, the region of intersection of the two elongate members is the central portion of the resonator element. In case of two straight elongate rod members, the resonator has an X-shape, and the central portion is the center of the X. In case the elongate members are not straight, the resonator element has an X-shape with deformed arms, such as angled and/or curved arms.

[0034] In an alternative preferred embodiment, the central portion of the resonator element is itself an elongate portion. Two of the elongate leg portions extend from one longitudinal end of the central elongate portion and the remaining two elongate leg portions extend from the other longitudinal end of the central elongate portion. In case the elongate leg portions are perpendicular to the central elongate portion and the resonator element is planar, the resonator element has an H-shape.

[0035] In a preferred embodiment, the resonator element is planar, so that all elongate leg portions extend in a common plane. In an alternative preferred embodiment, the first set of elongate leg portions extends in a first plane, and the second set of elongate leg portions extends in a second plane, wherein the first plane is extending transverse to the second plane. In this case, it is particularly preferred that the first plane is perpendicular to the second plane. In this way, it is possible to achieve a geometrical symmetry resulting in two of the fundamental modes supported by the resonator element being at essentially the same frequency.

[0036] It is possible that all elongate leg portions have the same shape and dimensions, or that one or more or all of the leg portions has/have a different shape and/or different dimensions as compared to the other leg portions. For example, at one or more or all of the elongate leg portions may be straight and/or one or more or all of the elongate leg portions may be curved and/or angled. The design of the individual elongate leg portions depends on the desired values of the resonance frequencies of the modes of interest.

[0037] By suitably choosing the dimensions, shape, orientation and relative arrangement of the elongate leg portions, it is easily possible to adapt the resonators for use with different frequencies and to set the filter characteristics. For example, as compared to a prior art resonator element comprising at least two perpendicular dielectric rods, there is advantageously more freedom to individually choose the design and construction characteristics of each elongate leg portion, such as its length, width, height and shape.

[0038] Thus, such a resonator element supports several guided orthogonal resonance modes, i.e. resonance modes in which in the ideal case energy is transmitted separately from the other orthogonal resonance modes with no cross-coupling between any two orthogonal resonance modes. In this regard, it is to be noted that there might be different sets of orthogonal resonance modes and that sets of non-orthogonal resonance modes may be constructed by superposition of the members of a set of orthogonal resonance modes.

[0039] In a preferred embodiment, the first set of elongate leg portions consists of exactly one of the four elongate leg portions and the second set of elongate leg portions consists of the remaining three elongate leg portions.

[0040] In an alternative preferred embodiment, the first set of elongate leg portions consists of exactly two of the four elongate leg portions and the second set of elongate leg portions consists of the remaining two elongate leg portions.

[0041] In the latter embodiment, it is further preferred if one set of guided orthogonal resonance modes supported by the present resonator element includes a first resonance mode in which the electric field is only dominant in and guided in one elongate leg portion of the first set of elongate leg portions, one elongate leg portion of the second set of elongate leg portions, and at least a part of the central portion. With other words, while a small amount of electric field may be present in the other elongate leg portions, the electric field lines are essentially confined or concentrated in the two elongate leg portions considered. In the present application, wordings such as "the electric field is only dominant in a particular part of the resonator element" mean that the electric field strength in the remainder of the resonator element is negligible as compared to the electric field strength in the particular part. Preferably, the maximum electric field strength in the remainder of the resonator element is less than 5% of the maximum electric field strength in the particular part, more preferably less than 1%, and most preferably less than 0.5%. In this context it has to be noted, however, that some electric field "leaks out of" parts of the resonator element in which the electric field is guided, so that e.g. even in case of a leg portion in which essentially no electric field is concentrated and guided, some electric field may be present immediately adjacent the end connected to a part of the annularly closed portion in which electric field is concentrated and guided. Such electric field components, that exponentially decrease with the distance from the guiding part, are disregarded in the above definition. In this first resonance mode, the electric field in one of the elongate leg portions is oppositely directed as compared to the other elongate leg portion relative to the central portion, i.e. in one elongate leg portion the electric field is guided longitudinally towards the central portion, and in the other elongate leg portion the electric field is guided longitudinally away from the central portion.

[0042] In this embodiment, the set of orthogonal resonance modes further includes a second resonance mode in which the electric field is only dominant in and guided in one elongate leg portion of the first set of elongate leg portions, one elongate leg portion of the second set of elongate leg portions, and at least a part of the central portion, wherein these two elongate leg portions are different from the elongate leg portions in which the electric field is guided in the first resonance mode, and wherein, relative to the central portion, the electric field in one of the elongate leg portions is oppositely directed as compared to the other elongate leg portion, i.e. in one elongate leg portion the electric field is guided longitudinally towards the central portion, and in the other elongate leg portion the electric field is guided longitudinally away from the central portion.

[0043] Thus, the first resonance mode and the second resonance mode correspond to the two pseudo TM110 modes described above for a cross-shaped planar resonator element.

[0044] In this embodiment, the set of orthogonal resonance modes further includes a third resonance mode in which the electric field is dominant in and guided in the entire resonator element, wherein in each two non-adjacent elongate leg portions the electric field is identically directed relative to the central portion, i.e. either directed towards or away from the central portion, and the electric field is oppositely directed relative to the annularly closed portion in the two sets of non-adjacent elongate leg portions. In this connection, it should be noted that in some arrangement of the elongate leg portions around the central portion, all elongate leg portions may be equal with regard to a particular elongate leg portion. It is then not possible refer to a particular elongate leg portion as adjacent or non-adjacent. Thus, in these cases any of the remaining three elongate leg portions might equally be regarded as non-adjacent to a particular elongate leg portion.

[0045] In this embodiment, the elongate leg portions and the central portion are further arranged, e.g. by choosing suitable material, dimensions such as width and/or length, shape and relative positions of the individual elongate leg portions and the central portion, such that the central frequencies of the first resonance mode and the second resonance mode are within the same pass band of the dielectric multimode resonator, so that they contribute to this pass band. Preferably, these central frequencies are equal, or they are substantially equal to deviate not more than 25% from their mean value, preferably not more than 20%, more preferably not more than 15%, even more preferably not more than 10%, even more preferably not more than 5%, even more preferably not more than 2% and most preferably not more than 1%. It is further preferred that the elongate leg portions and the central portion are arranged and constructed such that the resonance frequency of the third resonance mode also contributes to this pass band and lies within the ranges indicated above.

[0046] It can be advantageous if a through bore is provided in the central portion of the resonator element. Due to the path of the electric field lines within the resonator element in each of the first, the second and the third resonance mode, the through bore shifts the resonance frequencies of the first mode and the second mode to values, but has a much smaller effect on the resonance frequency of the third mode. Thus, by choosing a suitable diameter of the through bore, it is possible to bring the three resonance frequencies closer together such that they contribute to the same pass band.

[0047] The dielectric multimode resonator preferably comprises an input coupling means for coupling electromagnetic energy into the resonator element and/or an output coupling means for coupling electromagnetic energy out of the resonator element. In one advantageous embodiment, the input coupling means or the output coupling means is an inductive coupling means or both the input coupling means and the output coupling means are inductive coupling means. Such an inductive coupling means may e.g. comprise an electrically conductive rod, wire-shaped element or plate. In this case, it is further preferred that the distance between the rod, wire-shaped element or plate or portions thereof and the resonator element and/or its width or the width of portions thereof is adjustable in order to adjust the coupling strength. The input coupling means and the output coupling means may be arranged such that the input coupling means selectively couples electromagnetic energy predominantly into one resonance mode and that the output coupling means selectively couples electromagnetic energy predominantly out of another resonance mode. In this case, the resonator element and/or suitable tuning elements are constructed and arranged such that electromagnetic energy is transferred between these two modes directly or in series via one or more additional modes. In this way, the modes are coupled in series, and the dielectric resonator can be regarded as comprising a number of individual resonators connected in series between input and output. In the alternative, the input coupling means and the output coupling means may be arranged such that the input coupling means simultaneously excites two or more or all utilized modes and that the output coupling means simultaneously receives electromagnetic energy from two or more or all of the utilized modes. In this way, at least some of the modes are coupled in parallel, and the dielectric resonator can be regarded as comprising a number of individual resonators connected in parallel between input and output.

[0048] It is also preferred that the dielectric multimode resonator comprises at least one frequency or coupling adjustment screw extending through a wall into the resonator cavity towards the resonator element, wherein the distance between the terminal ends of the tuning screws and the resonator element can be adjusted in order to increase or decrease the influence of the screw. Instead of or in addition to such adjustment screws, there may advantageously be provided at least one frequency or coupling adjustment screw that is arranged differently. For each of these adjustment screws, a bore is provided in a portion of a wall to which a longitudinal end of one of the elongate leg portions is connected, which bore extends longitudinally into the respective elongate leg portion. The screw extends through the bore in the wall into the bore provided longitudinally in the elongate leg portion. The extension of the tuning screw into the bore in the elongate leg portion can be modified to thereby adjust the resonator element.

[0049] The dielectric multimode resonators described above can be advantageously used in a microwave filter comprising a plurality of coupled resonators. The coupling to and/or from the at least one dielectric resonator to the adjacent resonators may preferably be effected by means of coupling loops or coupling apertures. Such microwave filter may only comprise dielectric resonators of the present invention, or at least one dielectric resonator may be mixed with other types of microwave resonators, such as e.g. other dielectric resonators or coaxial resonators.

[0050] In the following, the invention is explained in more detail for preferred embodiments with reference to the figures.

Fig. 1 shows a schematic elevational view of one embodiment of a dielectric multimode resonator according to the present invention.

Fig. 2 shows a cross-sectional view of the planar resonator element of the embodiment shown in Figure 1.

Fig. 3a shows a simplified branch model of the dielectric resonator shown in Figure 1.

Figs. 3b to 3d show the distribution of the electric field in the resonator element for a set of three fundamental orthogonal resonance modes supported by the resonator element shown in Figure 3a.

Figs. 3e to 3g show the distribution of the electric field in the resonator element for a different set of three fundamental orthogonal resonance modes supported by the resonator element shown in Figure 3a.

Fig. 4 shows a schematic elevational view of another embodiment of a dielectric multimode resonator according to the present invention.

Fig. 5a shows a schematic top elevational view of the resonator element of the embodiment shown in Figure 4 as viewed from above perpendicularly to the top wall in Figure 4.

Fig. 5b shows a schematic side elevational view of the resonator element of the embodiment shown in Figure 4 as viewed from the side perpendicularly to the right sidewall in Figure 4.

Fig. 6a shows a simplified branch model of the dielectric resonator shown in Figure 4.

Figs. 6b to 6d show the distribution of the electric field in the resonator element for a set of three fundamental orthogonal resonance modes supported by the resonator element shown in Figure 6a.

Figs. 6e to 6g show the distribution of the electric field in the resonator element for a different set of three fundamental orthogonal resonance modes supported by the resonator element shown in Figure 6a.

Fig. 7 shows a schematic elevational view of another embodiment of a dielectric multimode resonator according to the present invention.

Fig. 8 shows a schematic elevational view of another embodiment of a dielectric multimode resonator according to the present invention.

Fig. 9 shows a schematic elevational view of another embodiment of a dielectric multimode resonator according to the present invention.

Fig. 10 shows a schematic elevational view of another embodiment of a dielectric multimode resonator according to the present invention.

Fig. 11 shows a schematic elevational view of another embodiment of a dielectric multimode resonator according to the present invention.

Fig. 12 shows a schematic elevational view of another embodiment of a dielectric multimode resonator according to the present invention.

Fig. 13 shows a schematic elevational view of another embodiment of a dielectric multimode resonator according to the present invention.

Fig. 14a shows a simplified branch model of the dielectric resonators shown in Figures 11 and 12.

Figs. 14b to 14d show the distribution of the electric field in the resonator element for a set of three fundamental orthogonal resonance modes supported by the resonator element shown in Figure 14a.

Fig. 15a shows a simplified branch model of a dielectric resonator having a symmetric resonator element with elongate portions defining angles of 109.47°.

Figs. 15b to 15d show the distribution of the electric field in the resonator element for a set of three fundamental orthogonal resonance modes supported by the resonator element shown in Figure 15a.

[0051] In Figure 1 a schematic elevational view of a dielectric multimode resonator 1 according to the present invention is shown. The dielectric resonator 1 comprises a first wall 2, a second wall 3 opposite the first wall 2, and four third walls 4. In Figure 1, the first wall 2 is the bottom wall, the second wall 3 is the top wall and the four third walls 4 are the sidewalls. The planar top wall 3 is parallel to and spaced from the planar bottom wall 2. The sidewalls 4 are perpendicular to the bottom wall 2 and the top wall 3 and extend between and connect them. The four sidewalls 4 are interconnected in series edge-to-edge in an annular manner. The edges 5 between each two adjacent sidewalls 4 are rounded. Apart from the rounded edge regions, each two adjacent sidewalls 4 extend perpendicularly to each other, and each two opposing sidewalls 4 extend parallel to each other. Thus, the six walls 2, 3 and 4 enclose and define a cuboidal resonator cavity 6, wherein some of the edges are rounded. The walls 2, 3, 4 are, at least in part, electrically conductive.

[0052] Inside the resonator cavity 6 a planar resonator element 7 made of dielectric material is disposed electrically connected to the walls 2, 3. A cross-sectional view of the resonator element 7 alone is depicted in Figure 2. The resonator element 7 is integrally formed in one piece and can be thought of as consisting of a central portion 8 and four elongate leg portions 9a, 9b, 9c, 9d that extend longitudinally between the central portion 8 and the walls 2, 3. Each of the four elongate leg portions 9a, 9b, 9c, 9d is directly joined with one longitudinal end 10 of its two longitudinal ends 10, 11 to the central portion 8 and with the other longitudinal end 11 to one of the walls 2, 3. In this regard, the two leg portions 9a, 9b are only joined to the top wall 3, and the other two leg portions 9c, 9d are only joined to the bottom wall 2. None of the leg portions 9a, 9b, 9c, 9d is connected to one of the four sidewalls 4.

[0053] The opposite elongate leg portions 9a, 9d together with the central portion 8 can be regarded as a first elongate member extending between the bottom wall 2 and the top wall 3, and the opposite elongate leg portions 9b, 9c together with the central portion 8 can be regarded as a second elongate member extending between the bottom wall 2 and the top wall 3. In this terminology, the central portion 8 is the region or portion of intersection of the first elongate member 9a, 8, 9d and the second elongate member 9b, 8, 9c.

[0054] Each elongate leg portion 9a, 9b, 9c, 9d has the same shape and dimensions and is angled. Overall, the resonator element 7 has the shape of an X with angled branches.

[0055] The dielectric multimode resonator 1 shown in Figure 1 is particularly suitable for supporting dual mode operation. Figure 3a shows a simplified branch model of this resonator 1. The elongate leg portions 9a and 9b are electrically connected to the electrically conductive top wall 2 and the elongate leg portions 9c and 9d are electrically connected to the electrically conductive bottom wall 3. All four elongate leg portions extend from central portion 8. In Figures 3b and 3c the distribution of the electric field (arrows) for two fundamental orthogonal resonance modes supported by the resonator element 7 and guided along the general direction of extension of the elongate leg portions 9a, 9b, 9c, 9d is illustrated. In the mode shown in Figure 3b, the electric field extends towards the central portion 8 in the two elongate leg portions 9a, 9b connected to the top wall 3 and away from the central portion 8 in the two elongate leg portions 9c, 9d connected to the bottom wall 2, whereas in the mode shown in Figure 3c, the electric field extends away from the central portion 8 in the two adjacent elongate leg portions 9a, 9c and towards the central portion 8 in the other two adjacent elongate leg portions 9b, 9d. It should be noted that the direction of the electric field reverses within one oscillation period.

[0056] In case of equal resonance frequencies of the two modes illustrated in Figures 3b and 3c, another pair of fundamental orthogonal resonance modes can be generated by adding and subtracting the two modes of Figures 3b and 3c. The electric field configuration of the resulting modes are depicted in Figures 3e and 3f, respectively. They are the TEz101 and the TEz011 mode described above with respect to a cross-shaped resonator element. Thus, in these two modes the electric field extends longitudinally in one elongate leg portion 9a, 9b towards and across the central portion 8, and extends longitudinally along the respective opposite elongate leg portion 9d, 9c away from the central portion 8. Again, it should be noted that the direction of the electric field reverses within one oscillation period. With other words, in each of the two resonance modes, the electric field is guided longitudinally within the first elongate member 9a, 8, 9d or the second elongate member 9b, 8, 9c.

[0057] Due to the fact that in comparison to a cross-shaped resonator element with straight arms the geometrical symmetry is broken, the TEz101 and the TEz011 mode do not have identical resonance frequencies if the resonator cavity 6 has identical side lengths. In order to bring the two resonance frequencies closer together or even to the same value, the dimensions of the resonator cavity 6 and of the resonator element 7 have to be adapted. For example, it is possible to change the chamfers or the angle of the X-shaped structure. Further, it is possible to replace the central portion 8 shown in Figure 1 by an elongate portion (not shown) resulting in a shape similar to an "H", or to mill ridges into the bottom wall 2 and/or the top wall 3 in order to increase the path that has to be taken by the electric current flowing in the walls 2, 3, 4 in a particular resonance mode.

[0058] The resonator element 7 is also capable of supporting a further orthogonal resonance mode, namely the TEz111 mode described above with respect to a cross-shaped resonator element. The distribution of the electric field in this mode is shown in Figures 3d and 3g. Thus, in this mode the electric field extends away from the central portion 8 in the opposing elongate leg portions 9a, 9d and towards the central portion 8 in the other two opposing elongate leg portions 9c, 9d. Again, it should be noted that the direction of the electric field reverses within one oscillation period. However, for the resonator element 7 shown in Figure 1, the resonance frequency of this mode is higher than the resonance frequencies of the TEz101 and the TEz011 mode. In order to tune the three modes to approximately the same frequency, it is possible to provide a through bore through the central portion 8 extending perpendicularly to the plane of the resonator element 7. Such a through bore mainly effects the TEz101 and the TEz011 mode, and only to a lesser extent the TEz111 mode.

[0059] Each of the two groups of three modes shown in Figures 3b to 3d and 3e to 3g, respectively, is a set of fundamental orthogonal resonance modes supported by the resonator element 7.

[0060] In Figure 4, a schematic elevational view of a modified dielectric multimode resonator 1 according to the present invention is shown. Top and side elevational view of its resonator element 7 alone are depicted in Figures 5a and 5b, respectively. The resonator 1 shown in Figure 4 differs from the resonator 1 shown in Figure 1 only in that the two elongate leg portions 9a, 9b extend in a plane perpendicular to the plane in which the leg portions 9c, 9d extend, so that the resonator element 7 is not planar. This arrangement has the advantage that due to symmetry the TEz101 and the TEz011 mode are already at the same resonance frequency. Furthermore, due to the elongate leg portions 9a, 9b extending in a plane perpendicular to the plane in which the other two elongate leg portions 9c, 9d extend, the resonance frequency of the TEz111 mode is already closer to the resonance frequencies of the TEz101 and the TEz011 mode as compared to the case shown in Figure 1. Thus, it is easier to achieve triple mode operation.

[0061] Figure 6a shows a simplified branch model of this resonator 1. The elongate leg portions 9a and 9b are electrically connected to the electrically conductive top wall 2 and the elongate leg portions 9c and 9d are electrically connected to the electrically conductive bottom wall 3. All four elongate leg portions extend from central portion 8. In Figures 6b to 6d the distribution of the electric field (arrows) for a first set of three fundamental orthogonal resonance modes is shown, and in Figures 6e to 6g the distribution of the electric field for a second set of three fundamental orthogonal resonance modes is shown. Figures 6e and 6f correspond to the TEz101 and the TEz011 mode, respectively, and Figure 6g corresponds to the TEz111 mode. Again, it should be noted that the direction of the electric field reverses within one oscillation period.

[0062] In Figures 7 and 8 schematic elevational views of further modified dielectric multimode resonators 1 according to the present invention are shown. The resonators 1 shown in Figures 6 and 7 differ from the resonators 1 shown in Figure 1 and Figure 4, respectively, only in that the longitudinal ends 11 of the elongate leg portions 9a, 9b, 9c, 9d are not directly joined to the walls 2, 3, but via intermediate elements 12. These intermediate elements 12 are made of dielectric material having a dielectric constant considerably smaller than that of the resonator element 7. For example, the intermediate elements 12 could be made of alumina, forsterite or quartz with a dielectric constant of approximately 10. By means of the provision of these intermediate elements 12, the resonance frequencies are shifted to higher values as compared to the corresponding arrangements of Figures 1 and 4.

[0063] In Figures 9 to 13, schematic elevational views of various other exemplary embodiments of a dielectric multimode resonators 1 according to the present invention are shown.

[0064] While the dielectric resonator 1 shown in Figure 13 corresponds to the resonators 1 shown in Figures 1, 4, 7, and 8 in that it has six walls 2, 3, 4 enclosing and defining a cuboidal resonator cavity 6, the dielectric resonators 1 shown in Figures 9 to 12 each comprise a first wall 2, a second wall 3 opposite the first wall 2, and a single, circularly cylindrical third wall 4. In these Figures, the first wall 2 is the bottom wall, the second wall 3 is the top wall and the single third wall 4 is the sidewall. The planar top wall 3 is parallel to and spaced from the planar bottom wall 2. The sidewall 4 is perpendicular to the bottom wall 2 and the top wall 3 and extends between and connect them. Thus, the three walls 2, 3 and 4 enclose and define a circularly cylindrical resonator cavity 6.

[0065] In Figure 9, the two elongate leg portions 9a and 9b are connected to the top wall 3, and the two elongate leg portions 9c and 9d are connected to the bottom wall 2. The angle between each two elongate leg portions is 109.47°. Due to the symmetry of the arrangement depicted, the resonance frequencies of the first two resonance modes corresponding to the resonance modes shown in Figures 14c and 14d are already identical, and the value of the resonance frequency of the third resonance mode corresponding to the resonance mode shown in Figure 14b can be adjusted by adapting the dimensions of the resonator cavity. It should be noted that the angled elongate leg portions shown in Figure 1 are preferred, because they ensure a perpendicular connection to the walls 2, 3.

[0066] In Figure 10, the elongate leg portion 9b is connected to the top wall 3, and the three elongate leg portions 9a, 9c and 9d are connected to the sidewall 4. Due to the 120° rotational symmetry of the arrangement depicted, the resonance frequencies of the first two resonance modes corresponding to the resonance modes shown in Figures 14c and 14d are already identical, and the value of the resonance frequency of the third resonance mode corresponding to the resonance mode shown in Figure 14b can be adjusted by adapting the dimensions of the resonator cavity or the course of the elongate leg portions 9a, 9b, 9c, 9d. This is an embodiment, in which three of the four elongate leg portions are connected to the same wall, and the remaining elongate leg portion is connected to a different wall.

[0067] The same applies to the exemplary embodiments shown in Figures 11 to 13. In Figure 11, the elongate leg portion 9b is connected to the top wall 3, and the three elongate leg portions 9a, 9c and 9d are connected to the bottom wall 2. Due to the 120° rotational symmetry of the arrangement depicted, the resonance frequencies of the first two resonance modes corresponding to the resonance modes shown in Figures 14c and 14d are already identical, and the value of the resonance frequency of the third resonance mode corresponding to the resonance mode shown in Figure 14b can be adapted by adapting the dimensions of the resonator cavity or the course of the elongate leg portions 9a, 9b, 9c, 9d.

[0068] In Figure 12, the straight elongate leg portion 9b having a circular cross-section is connected to the top wall 3, and the three angled elongate leg portions 9a, 9c and 9d having a rectangular cross-section are connected to the bottom wall 2. Due to the 120° rotational symmetry of the arrangement depicted, the resonance frequencies of the first two resonance modes corresponding to the resonance modes shown in Figures 14c and 14d are already identical, and the value of the resonance frequency of the third resonance mode corresponding to the resonance mode shown in Figure 14b can be adjusted by adapting the dimensions of the resonator cavity or the course of the elongate leg portions 9a, 9b, 9c, 9d.

[0069] In Figure 13, the elongate leg portion 9d is connected to the bottom wall 2, and the three elongate leg portions 9a, 9b and 9c are connected to the top wall 3. The four elongate leg portions 9a, 9b, 9c, 9d are arranged in a ψ-shape. Due to the lack of 120° rotational symmetry, the resonance frequencies of two resonance modes are not automatically identical. Therefore, the dimensions of the resonator cavity and/or of the resonator element and/or the arrangement of the elongate leg portions 9a, 9b, 9c, 9d have to be adapted.

[0070] Figure 14a shows a simplified branch model of the resonator 1 shown in Figures 11 and 12. The elongate leg portion 9b is electrically connected to the electrically conductive top wall 2 and the elongate leg portions 9a, 9c and 9d are electrically connected to the electrically conductive bottom wall 3. All four elongate leg portions extend from central portion 8. In Figures 14b to 14d the distribution of the electric field (arrows) for a set of three fundamental orthogonal resonance modes is shown. Due to 120° rotational symmetry, the resonance frequencies of the two modes shown in Figures 14c and 14d are identical. In the mode shown in Figure 14b, the electric field extends in all four elongate leg portions 9a, 9b, 9c, 9d with the electric field extending in elongate leg portion 9b towards the central portion 8, splitting up evenly at central portion 8 and extending in each of elongate leg portions 9a, 9c, 9d away from central portion 8. The resonance frequency of this mode can be adapted by changing the dimensions of the resonator cavity and/or the dimensions of elongate leg portion 9b. In this regard, elongate leg portion 9b could even terminate spaced from top wall 2. Again, it should be noted that the direction of the electric field reverses within one oscillation period.

[0071] Figure 15a shows a simplified branch model of a dielectric resonator having a symmetric resonator element with each pair of elongate portions defining an angle of 109.47° between them. In Figures 15b to 15d the distribution of the electric field (arrows) for a set of three fundamental orthogonal resonance modes is shown. In each mode, the electric field extends towards the central portion 8 in two of the elongate leg portions 9a, 9b, 9c, 9d and extends away from the central portion 8 in the remaining two of the elongate leg portions 9a, 9b, 9c, 9d. Due to the particular symmetry of such a resonator element, the resonance frequencies of all three modes are identical. Again, it should be noted that the direction of the electric field reverses within one oscillation period.

Claims

1. Dielectric multimode resonator comprising

- a plurality of walls (2, 3, 4) enclosing a resonator cavity (6), wherein the plurality of walls (2, 3, 4) includes a first wall (2), an opposing second wall (3) and one third wall (4) or a plurality of third walls (4) extending between and connecting the first wall (2) and the second wall (3), and
- a resonator element (7) made of dielectric material and disposed in the resonator cavity (6), wherein the resonator element (7) comprises a central portion (8) spaced from the walls (2, 3, 4) and exactly four elongate leg portions (9a, 9b, 9c, 9d) extending longitudinally from the central portion (8) towards the walls (2, 3, 4), such that one (10) of the two longitudinal ends (10, 11) of each elongate leg portion (9a, 9b, 9c, 9d) is directly joined to the central portion (8) and the other longitudinal end (11) is connected to only one of the walls (2, 3, 4),

characterized in that one, two or three of the four elongate leg portions (9a, 9b, 9c, 9d) constitute a first set of elongate leg portions (9a, 9b, 9c, 9d) and the remaining elongate leg portion or portions (9a, 9b, 9c, 9d) constitute a second set of elongate leg portions (9a, 9b, 9c, 9d), and that all elongate leg portions (9a, 9b, 9c, 9d) included in the first set are connected to the same wall (2, 3, 4), all elongate leg portions (9a, 9b, 9c, 9d) included in the second set are connected to the same wall (2, 3, 4), and the elongate leg portions (9a, 9b, 9c, 9d) included in the first set are connected to a different wall (2, 3, 4) than the elongate leg portions (9a, 9b, 9c, 9d) included in the second set.

2. Dielectric multimode resonator according to claim 1, wherein the resonator cavity (6) has the shape of a right prism with a polygonal base having three or more sides with sharp or rounded corners, so that the plurality of walls (2, 3, 4) consists of the first wall (2), the second wall (3) and a number of third walls (4), which number is equal to the number of sides of the polygonal base of the right prism, wherein each third wall (4) extends between and connects the first wall (2) and the second wall (3).

3. Dielectric multimode resonator according to claim 2, wherein the resonator cavity (6) has a cuboidal shape with sharp or rounded edges, so that the plurality of walls (2, 3, 4) consists of six walls, each defining one side of the cuboidal resonator cavity, including four third walls (4) extending between and connecting the first wall (2) and the second wall (3).

4. Dielectric multimode resonator according to claim 1, wherein the resonator cavity (6) has a circularly or elliptically cylindrical shape with sharp or rounded edges, so that the plurality of walls (2, 3, 4) consists of three walls including one cylindrical third wall (4) extending between and connecting the first wall (2) and the second wall (3).

5. Dielectric multimode resonator according to any of the preceding claims, wherein the first and the second set of elongate leg portions (9a, 9b, 9c, 9d) are connected to opposing walls (2, 3, 4).

6. Dielectric multimode resonator according to claim 5, wherein at least one of the two opposing walls (2, 3, 4) to which the two sets of elongate leg portions (9a, 9b, 9c, 9d) are connected comprises a resilient portion which is adapted to exert a spring force on the resonator element (7) generating a clamping force for securing the resonator element (7) within the resonator cavity (6) and to accommodate expansion and contraction of the resonator element (7).

7. Dielectric multimode resonator according to any of claims 1 to 4, wherein the first and the second set of elongate leg portions (9a, 9b, 9c, 9d) are connected to adjacent walls (2, 3, 4).

8. Dielectric multimode resonator according to any of the preceding claims, wherein the longitudinal end (11) opposite the central portion (8) of at least one of the elongate leg portions (9a, 9b, 9c, 9d) is directly connected to the respective wall (2, 3, 4).

9. Dielectric multimode resonator according to any of the preceding claims, wherein the longitudinal end (11) opposite the central portion (8) of at least one of the elongate leg portions (9a, 9b, 9c, 9d) is connected to the respective wall (2, 3, 4) via an intermediate element (12) that is made of dielectric material having a dielectric constant that is smaller than that of the dielectric material of the resonator element (7).

10. Dielectric multimode resonator according to any of the preceding claims, wherein the maximum diameter of the central portion (8) is smaller than the length of the elongate leg portions (9a, 9b, 9c, 9d).

11. Dielectric multimode resonator according to any of the preceding claims, wherein at the central portion (8), each elongate leg portion (9a, 9b, 9c, 9d) is in direct contact with at least one adjacent elongate leg portion (9a, 9b, 9c, 9d).

12. Dielectric multimode resonator according to any of the preceding claims, wherein one (9a) of the elongate leg portions of the first set of elongate leg portions and one of the elongate leg portions (9d) of the second set of elongate leg portions together form a first elongate member (9a, 8, 9d), and the remaining two elongate leg portions (9b, 9c) together form a second elongate member (9b, 8, 9c), wherein the first and the second elongate member intersect each other and wherein the central portion (8) is the region of intersection of the two elongate members.

13. Dielectric multimode resonator according to any of claims 1 to 11, wherein the central portion (8) of the resonator element (7) is an elongate portion, and two of the elongate leg portions (9a, 9b, 9c, 9d) extend from one longitudinal end of the central portion (8) and the remaining two elongate leg portions (9a, 9b, 9c, 9d) extend from the other longitudinal end of the central portion (8).

14. Dielectric multimode resonator according to any of the preceding claims, wherein the resonator element (7) is planar, so that all elongate leg portions (9a, 9b, 9c, 9d) extend in a common plane.

15. Dielectric multimode resonator according to any of claims 1 to 13, wherein the first set of elongate leg portions extends in a first plane, and the second set of elongate leg portions extends in a second plane, wherein the first plane is perpendicular to the second plane.

16. Dielectric multimode resonator according to any of the preceding claims, wherein all elongate leg portions (9a, 9b, 9c, 9d) have the same shape and dimensions, or at least one of the leg portions (9a, 9b, 9c, 9d) has a different shape and/or different dimensions as compared to the other leg portions (9a, 9b, 9c, 9d).

17. Dielectric multimode resonator according to any of the preceding claims, wherein at least one of the elongate leg portions (9a, 9b, 9c, 9d) is straight and/or at least one of the elongate leg portions (9a, 9b, 9c, 9d) is curved and/or angled.

18. Dielectric multimode resonator according to any of the preceding claims, wherein the first set of elongate leg portions includes exactly one of the four elongate leg portions (9a, 9b, 9c, 9d) and the second set of elongate leg portions includes the remaining three elongate leg portions (9a, 9b, 9c, 9d).

19. Dielectric multimode resonator according to any of claims 1 to 17, wherein the first set of elongate leg portions includes exactly two of the four elongate leg portions (9a, 9b, 9c, 9d) and the second set of elongate leg portions includes the remaining two elongate leg portions (9a, 9b, 9c, 9d).

20. Dielectric multimode resonator according to claim 19, wherein the elongate leg portions (9a, 9b, 9c, 9d) and the central portion (8) are arranged and constructed such that the resonator element (7) supports a plurality of orthogonal resonance modes including

- a first resonance mode in which the electric field is only dominant in and guided in one elongate leg portion (9b) of the first set of elongate leg portions (9a, 9b), one elongate leg portion (9c) of the second set of elongate leg portions (9c, 9d), and at least a part of the central portion (8), wherein, relative to the central portion (8), the electric field in one (9b) of the elongate leg portions (9b, 9c) is oppositely directed as compared to the other elongate leg portion (9c),
- a second resonance mode in which the electric field is only dominant in and guided in one elongate leg portion (9a) of the first set of elongate leg portions (9a, 9b), one elongate leg portion (9d) of the second set of elongate leg portions (9c, 9d), and at least a part of the central portion (8), wherein these two elongate leg portions (9a, 9d) are different from the elongate leg portions (9b, 9c) in which the electric field is guided in the first resonance mode, and wherein, relative to the central portion (8), the electric field in one of the elongate leg portions (9a) is oppositely directed as compared to the other elongate leg portion (9d), and
- a third resonance mode in which the electric field is dominant in and guided in the entire resonator element (7), wherein in each two non-adjacent elongate leg portions (9a, 9b, 9c, 9d) the electric field is identically directed relative to the central portion (8), and the electric field is oppositely directed relative to the central portion (8) in the two groups of non-adjacent elongate leg portions (9a, 9b, 9c, 9d), and such that

the resonance frequencies of the first resonance mode and the second resonance mode are within the same pass band of the dielectric multimode resonator.

21. Dielectric multimode resonator according to claim 20, wherein the elongate leg portions (9a, 9b, 9c, 9d) and the central portion (8) are arranged and constructed such that the resonance frequencies of the first resonance mode, the second resonance mode and the third resonance mode are within the same pass band of the dielectric multimode resonator.

22. Dielectric multimode resonator according to any of the preceding claims, further comprising an input coupling means for coupling electromagnetic energy into the resonator element (7) and/or an output coupling means for coupling electromagnetic energy out of the resonator element (7).

23. Dielectric multimode resonator according to claim 22, wherein the input coupling means and/or the output coupling means is an inductive coupling means.

24. Dielectric multimode resonator according to claim 23, wherein the inductive input coupling means and/or the inductive output coupling means comprises an electrically conductive rod, wire-shaped element or plate.

25. Dielectric multimode resonator according to claim 24, wherein the inductive input coupling means and/or the inductive output coupling means is arranged such that the distance between its rod, wire-shaped element or plate and the resonator element (7) and/or its width is adjustable.

26. Dielectric multimode resonator according to any of the preceding claims, further comprising at least one frequency or coupling adjustment screw extending through a wall (2, 3, 4) into the resonator cavity (6) towards the resonator element (7), wherein the distance between the terminal ends of the tuning screws and the resonator element (7) can be adjusted.

27. Dielectric multimode resonator according to any of the preceding claims, wherein a through bore is provided in the central portion (8) of the resonator element (7).

28. Dielectric multimode resonator according to any of the preceding claims, wherein at least one bore is provided in a portion of a wall (2, 3, 4) to which a longitudinal end (11) of one of the elongate leg portions (9a, 9b, 9c, 9d) is connected, which bore extends longitudinally into the elongate leg portion (9a, 9b, 9c, 9d), and wherein the dielectric multimode resonator (1) further comprises at least one frequency or coupling adjustment screw extending through such a bore in a wall (2, 3, 4) into the bore provided longitudinally in the respective elongate leg portion (9a, 9b, 9c, 9d), wherein the extension of the tuning screw into the bore in the elongate leg portion (9a, 9b, 9c, 9d) can be modified to thereby adjust the resonator element.

29. Microwave filter comprising a plurality of coupled resonators including at least one of the dielectric resonators (1) according to any of claims 1 to 28, wherein the coupling to and/or from the at least one dielectric resonator (1) to the adjacent resonators is effected by means of coupling loops and/or coupling apertures.

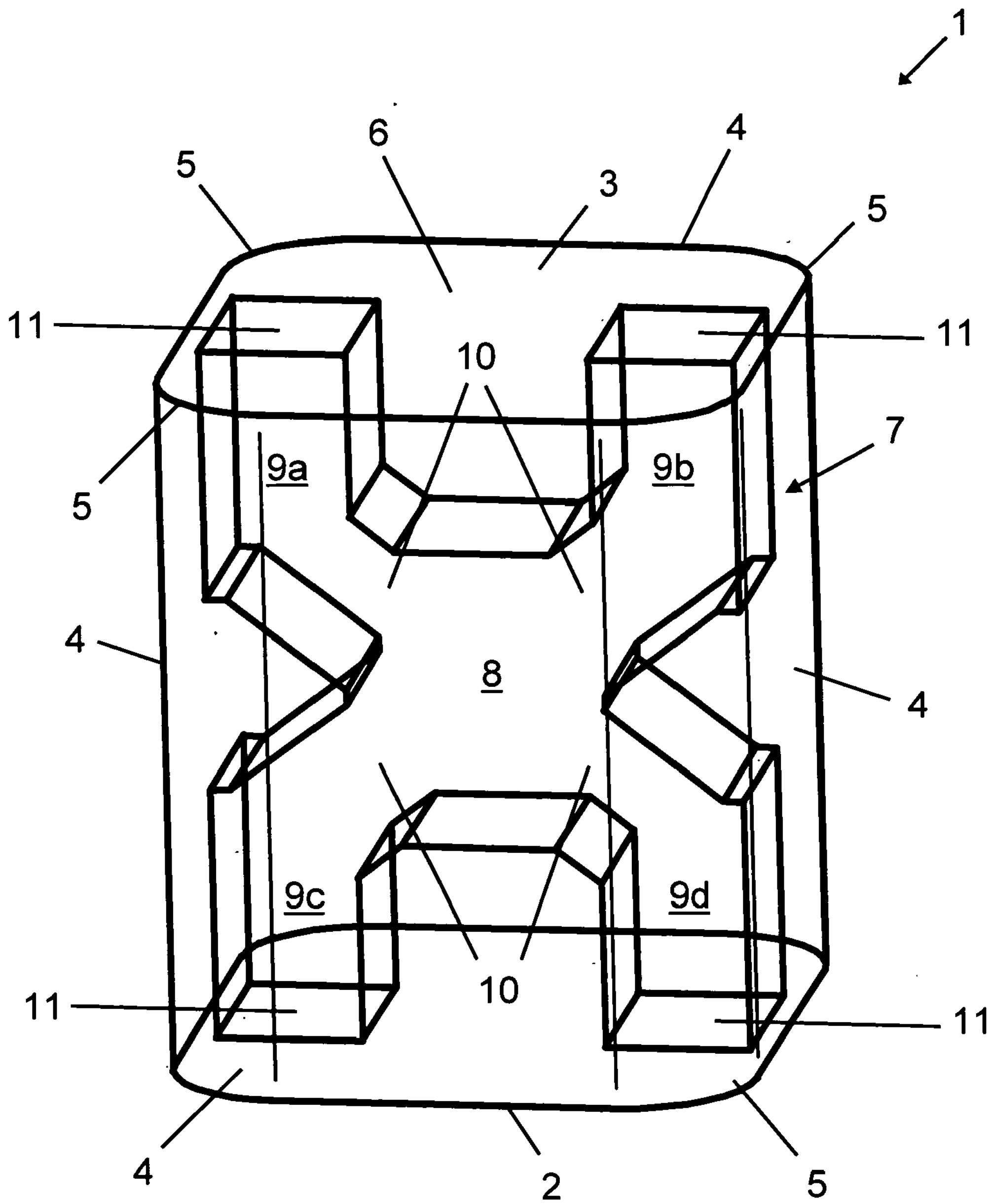

FIG. 1

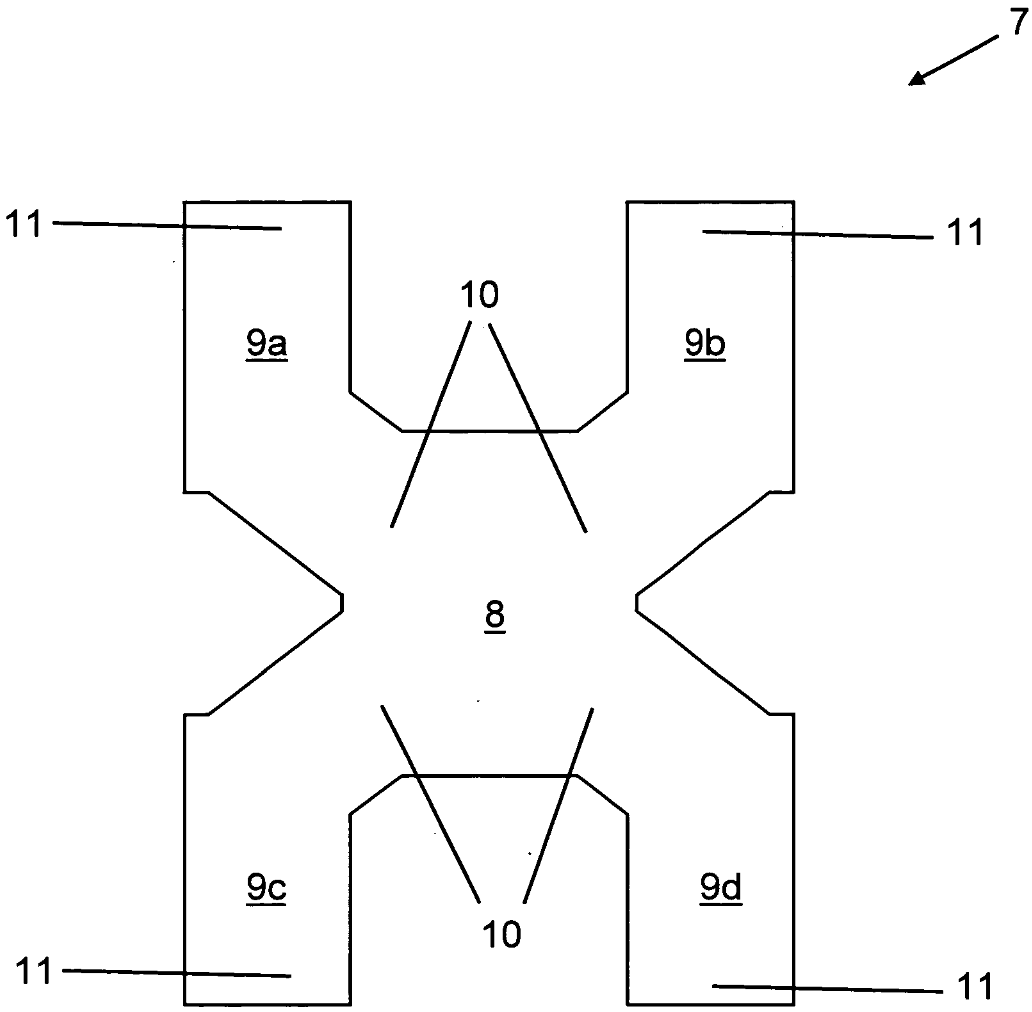

FIG. 2

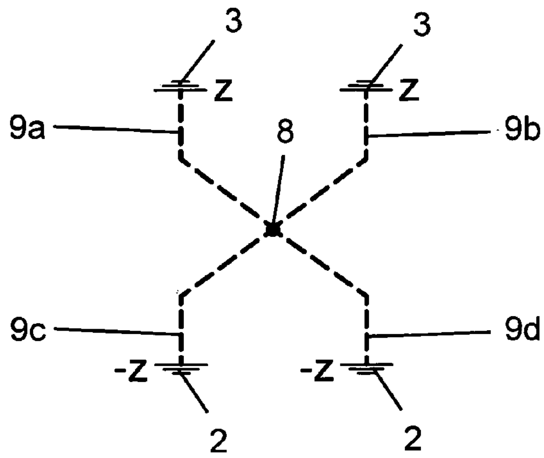

FIG. 3a

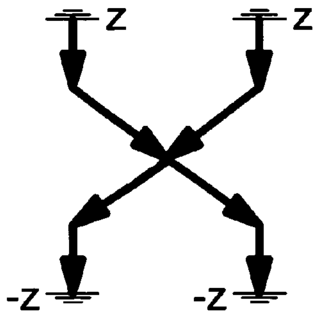

FIG. 3b

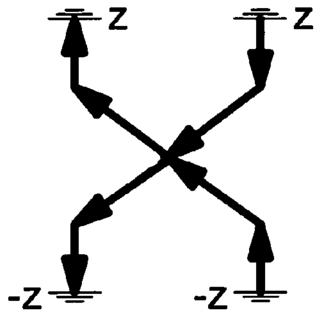

FIG. 3c

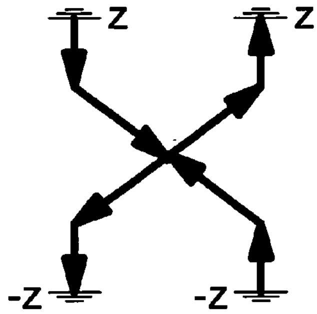

FIG. 3d

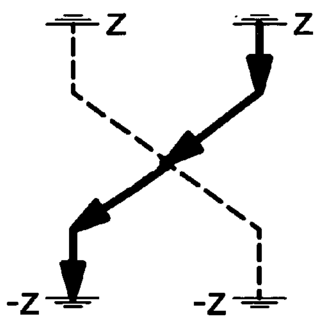

FIG. 3e

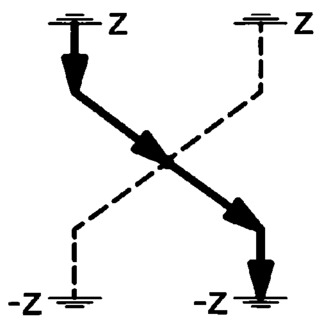

FIG. 3f

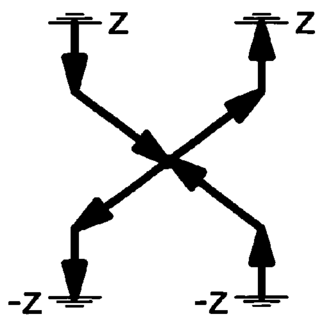

FIG. 3g

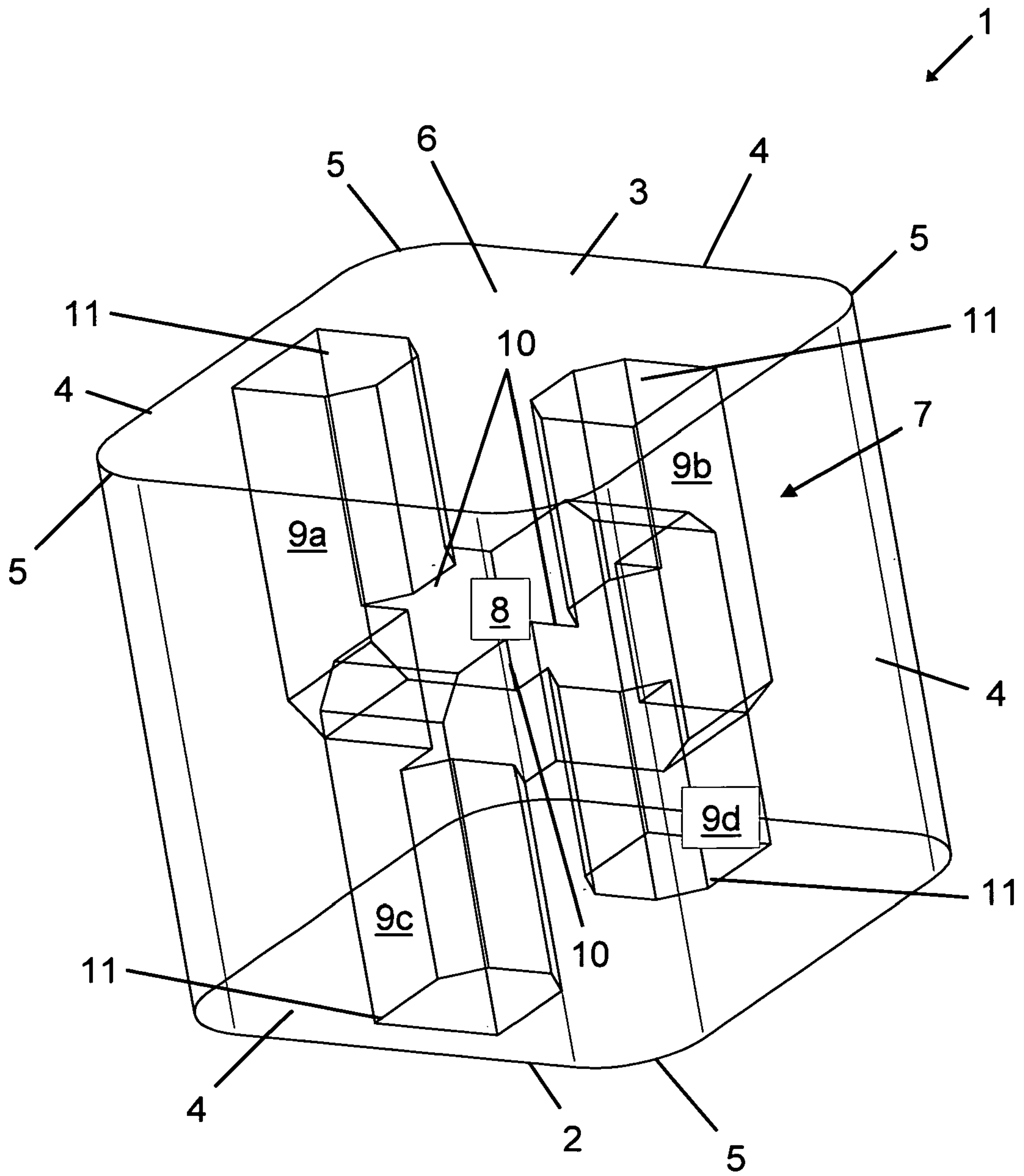

FIG. 4

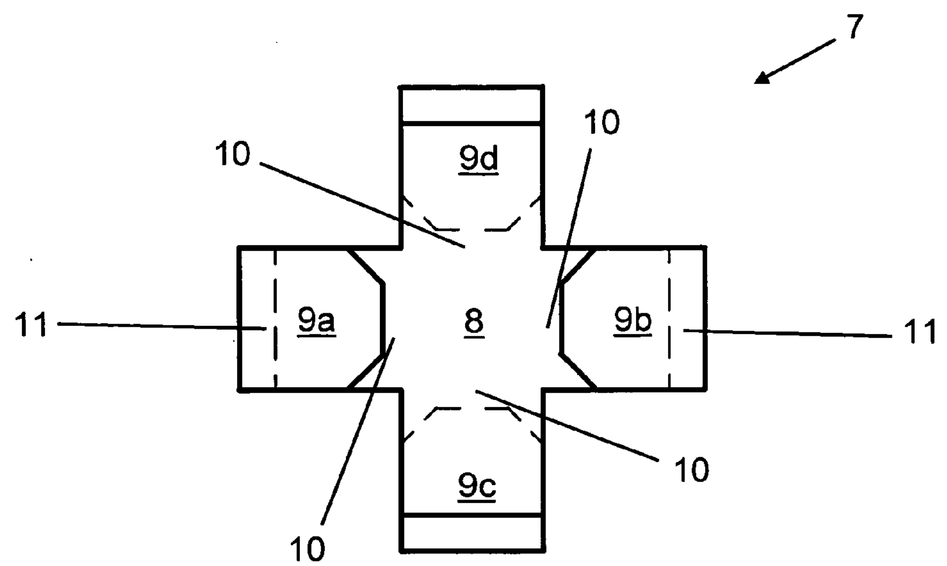

FIG. 5a

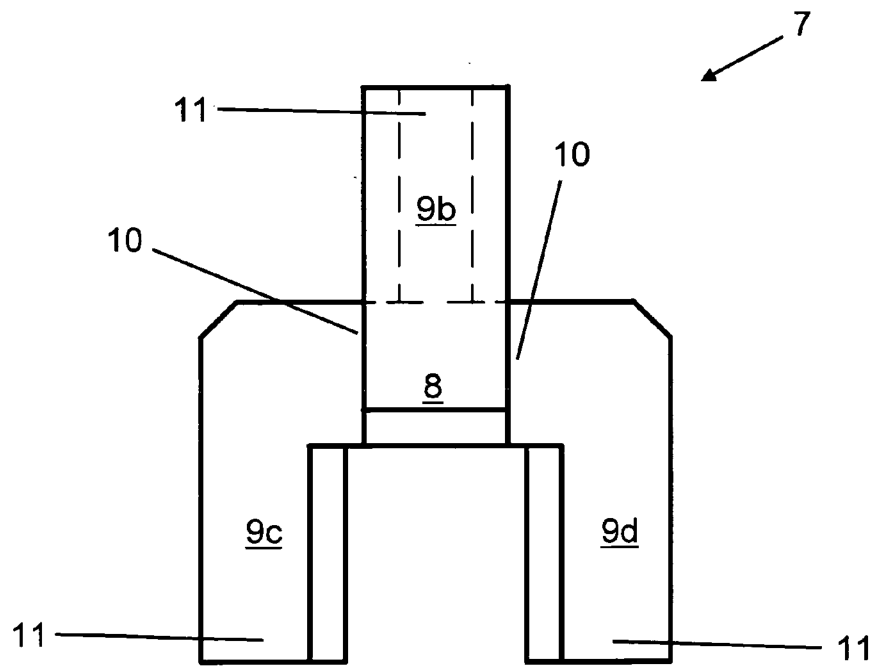

FIG. 5b

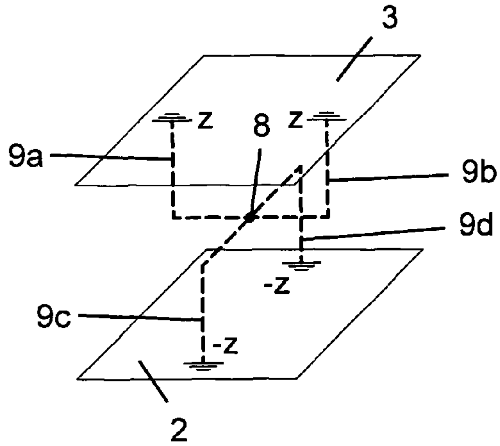

FIG. 6a

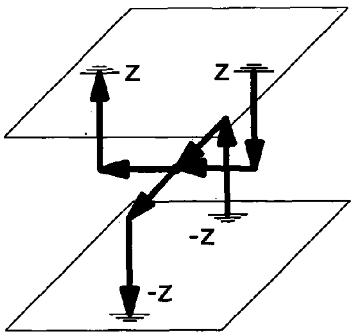

FIG. 6b

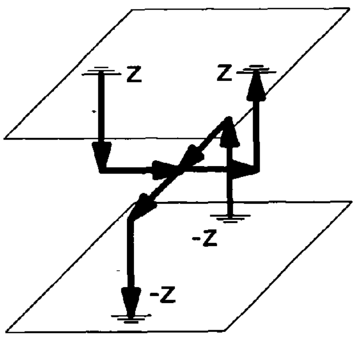

FIG. 6c

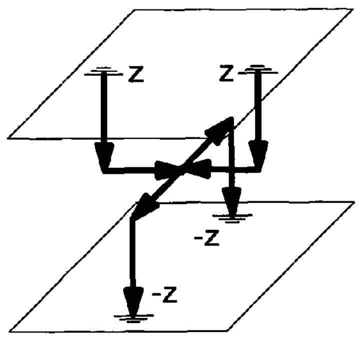

FIG. 6d

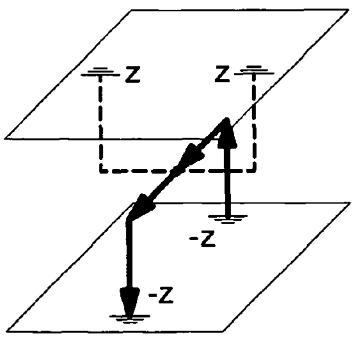

FIG. 6e

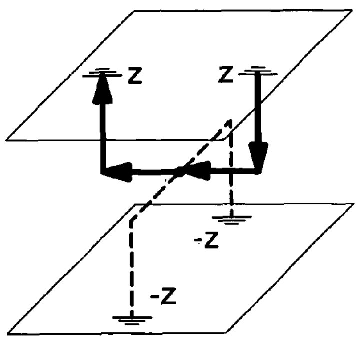

FIG. 6f

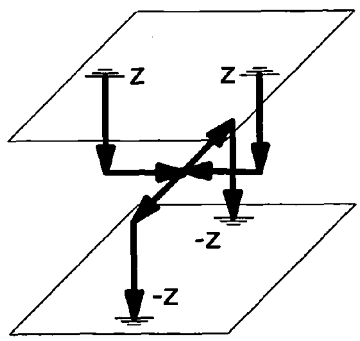

FIG. 6g

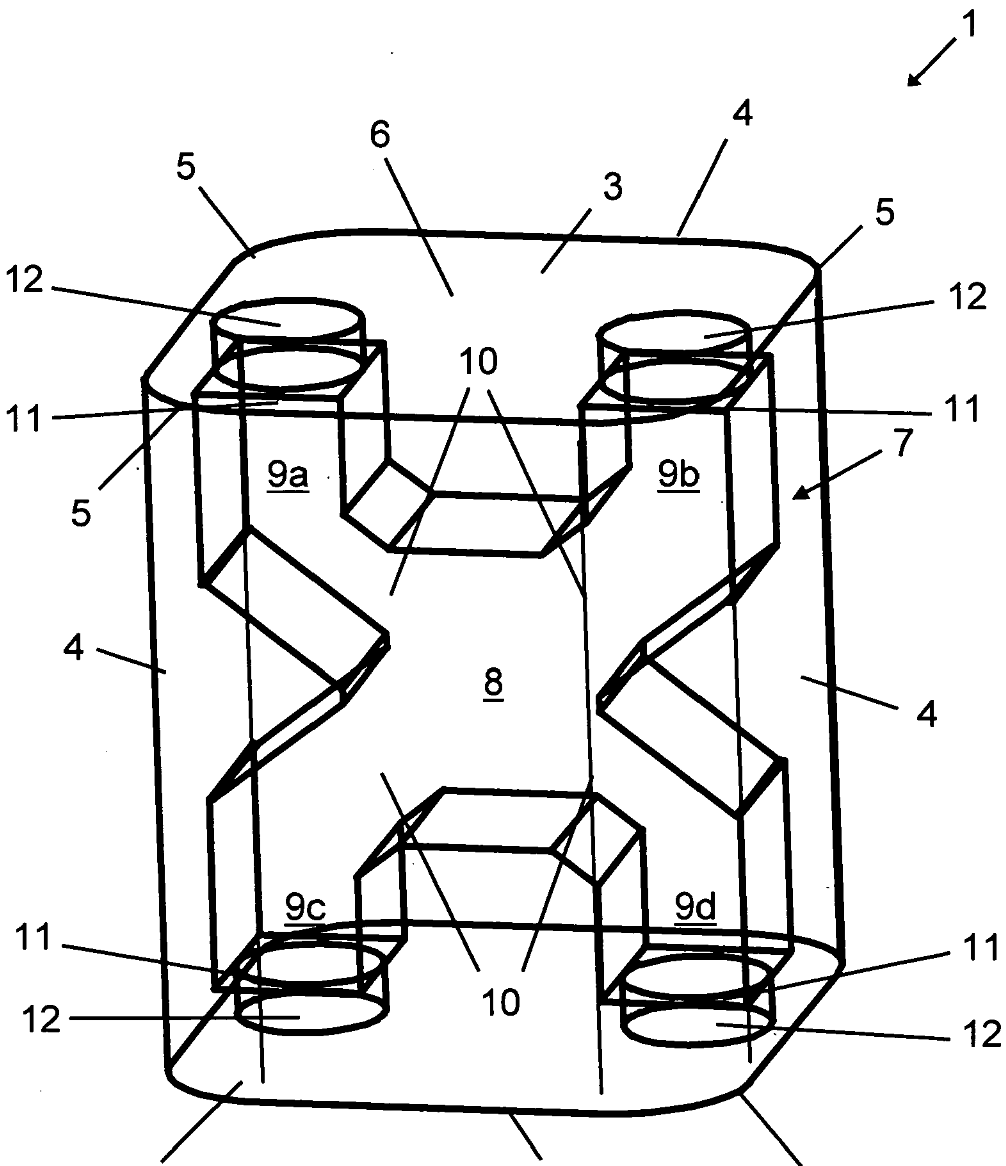

FIG. 7

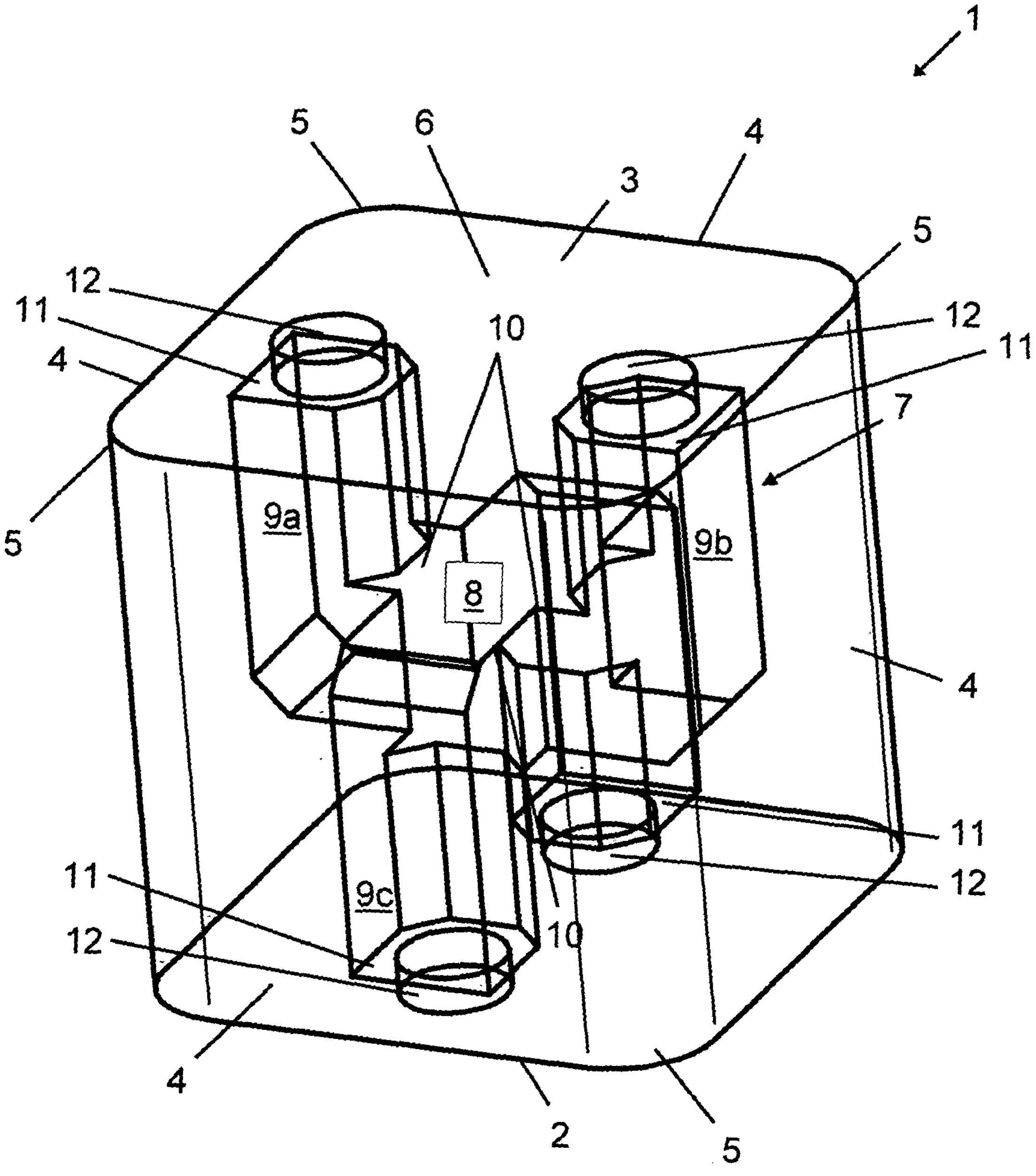

FIG. 8

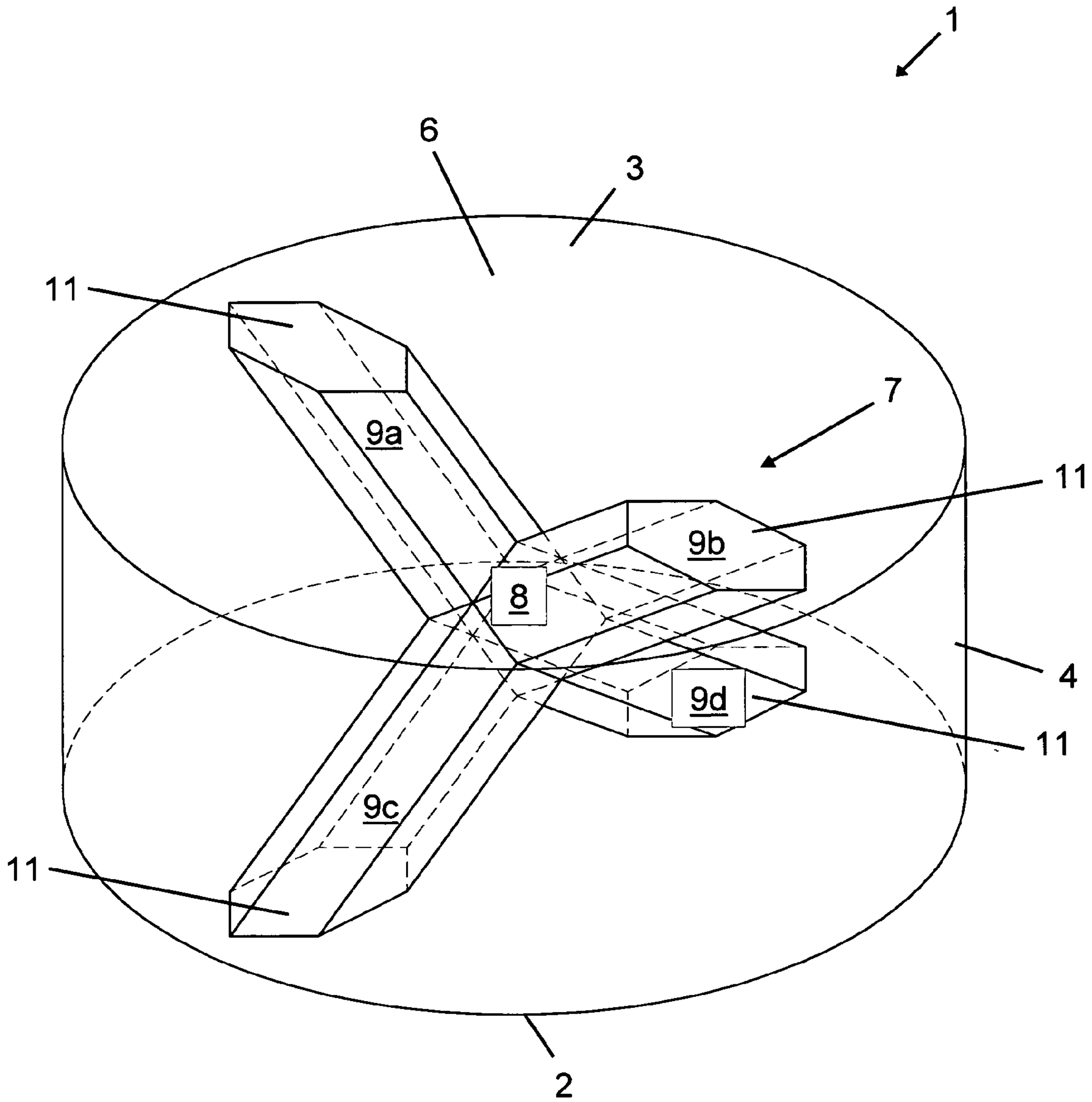

FIG. 9

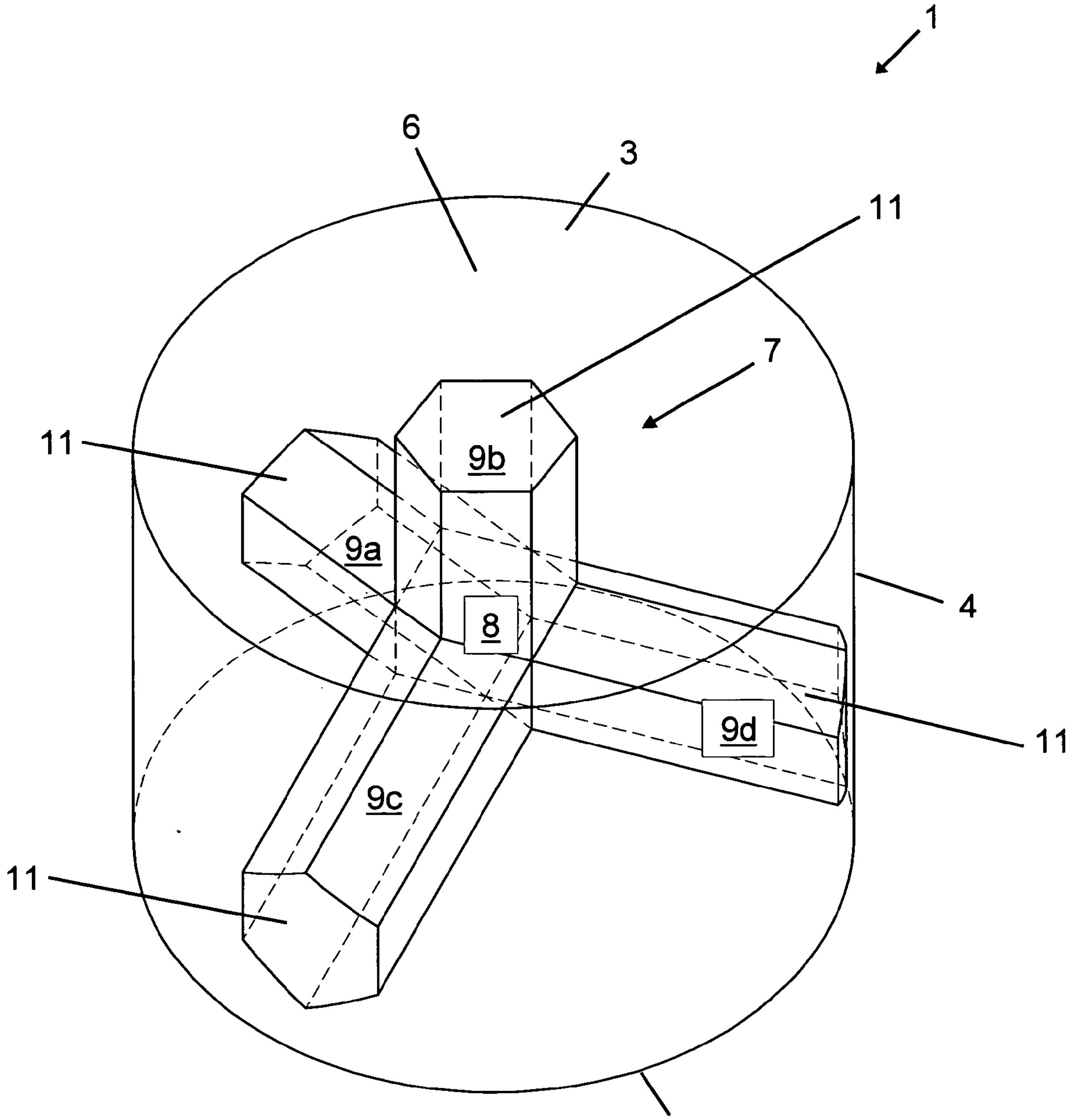

FIG. 10

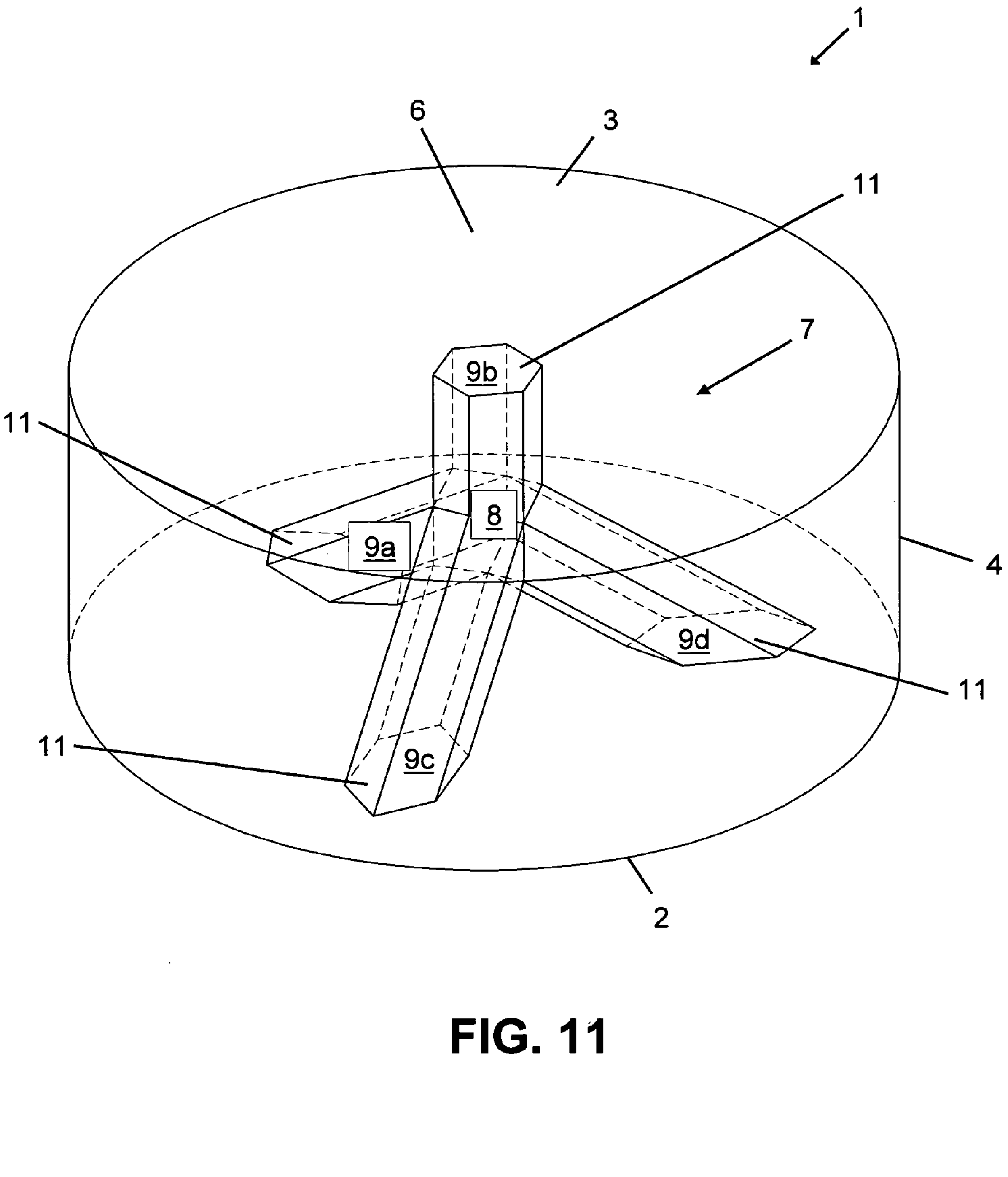

FIG. 11

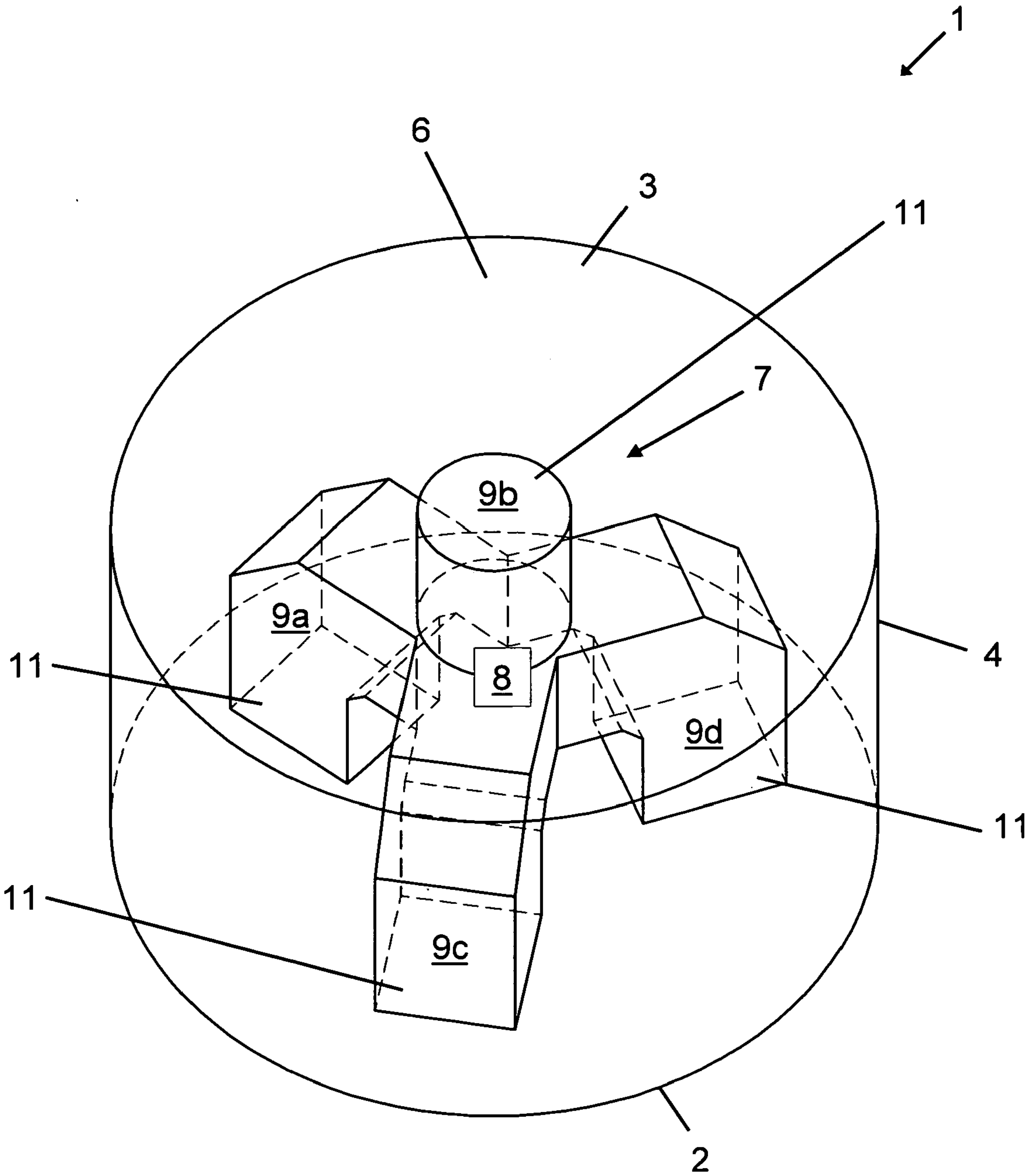

FIG. 12

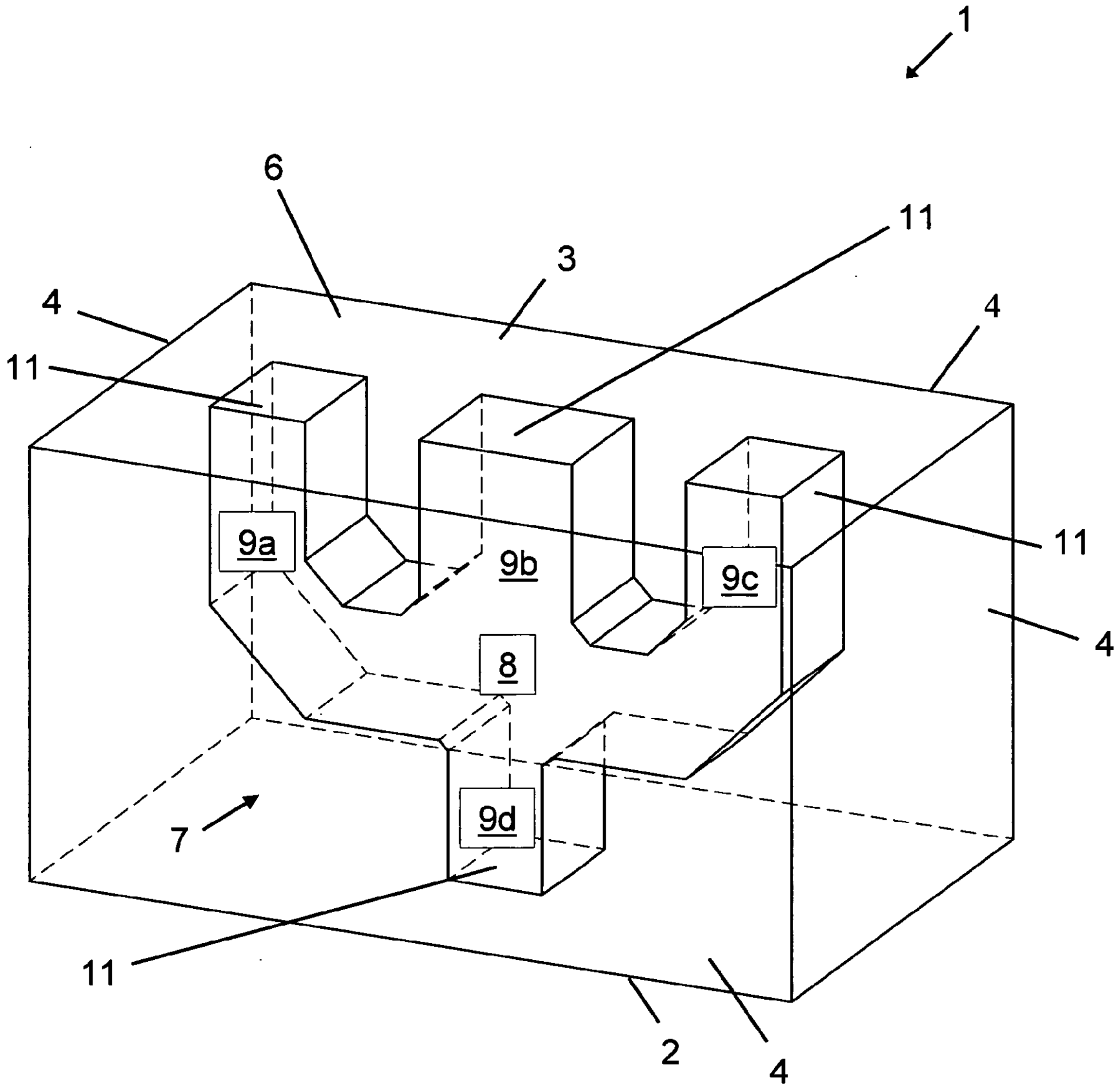

FIG. 13

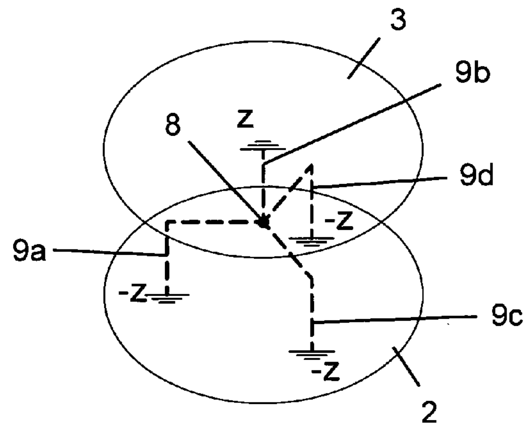

FIG. 14a

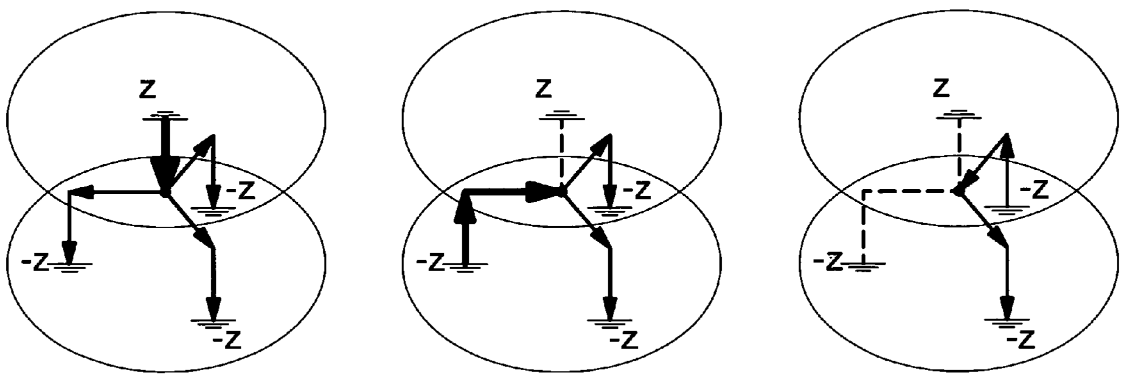

FIG. 14b FIG. 14c FIG. 14d

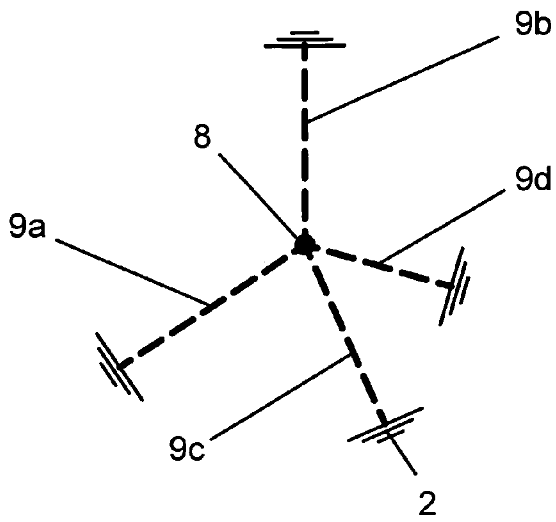

FIG. 15a

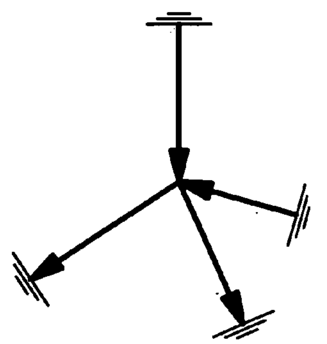

FIG. 15b

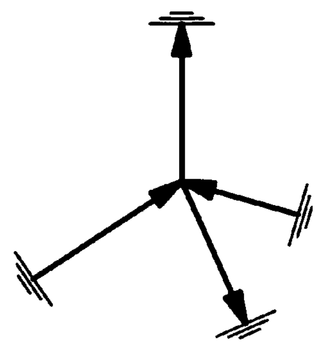

FIG. 15c

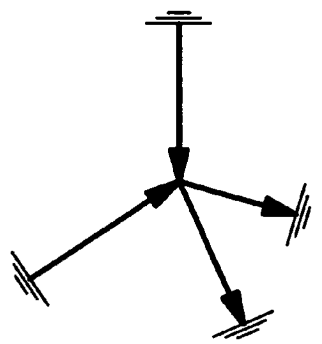

FIG. 15d

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 07 00 3578

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X,D	EP 1 014 474 A1 (MURATA MANUFACTURING CO [JP]) 28 June 2000 (2000-06-28) * column 6, line 19; figures 1,5-14 * -----	1	INV. H01P1/208 H01P7/10
A	WO 03/001683 A (REMEC OY [FI]; REMEC INC [US]; KARHU KIMMO KALERVO [FI] REMEC OY [FI];) 3 January 2003 (2003-01-03) * page 11; figures 1,10 * -----	1	
D,A	ISHIKAWA Y ET AL: "800 MHz high-power duplexer using TM dual mode dielectric resonators" MICROWAVE SYMPOSIUM DIGEST, 1992., IEEE MTT-S INTERNATIONAL ALBUQUERQUE, NM, USA 1-5 JUNE 1992, NEW YORK, NY, USA,IEEE, US, 1 June 1992 (1992-06-01), pages 1617-1620, XP010063153 ISBN: 0-7803-0611-2 * the whole document * -----	1	
D,A	US 6 278 344 B1 (KURISU TORU [JP] ET AL) 21 August 2001 (2001-08-21) * the whole document * -----	1	TECHNICAL FIELDS SEARCHED (IPC) H01P

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	20 June 2007	Ribbe, Jonas

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
....
& : member of the same patent family, corresponding document

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 07 00 3578

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

20-06-2007

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 1014474	A1	28-06-2000	CA	2302588	A1	11-03-1999
			CN	1269914	A	11-10-2000
			DE	69833662	T2	21-12-2006
			WO	9912225	A1	11-03-1999
			JP	3503482	B2	08-03-2004
			JP	11145705	A	28-05-1999
			NO	20001106	A	28-04-2000
			US	6507254	B1	14-01-2003
WO 03001683	A	03-01-2003	GB	2394366	A	21-04-2004
			US	2004135654	A1	15-07-2004
			US	2003043000	A1	06-03-2003
US 6278344	B1	21-08-2001	NONE			

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 6278344 B **[0012] [0012] [0013]**
- EP 1014474 A **[0014]**

Non-patent literature cited in the description

- **Y. KOBAYASHI ; S. YOSHIDA.** Bandpass filters using TM010 dielectric rod resonators. *Proc. IEEE MTT-Symposium,* 1978, 233-235 **[0007]**
- **Y. ISHIKAWA ; J. HATTORI ; M. ANDOH ; T. NISHIKAWA.** 800 MHz high power duplexer using TM dual mode dielectric resonators. *Proc. IEEE MTT-Symposium,* 1992, 1617-1620 **[0007]**
- **T. NISHIKAWA ; K. WAKINO ; H. WADA ; Y. ISHIKAWA.** 800 MHz band dielectric channel dropping filter using TM110 triple mode resonance. *Proc. IEEE MTT-Symposium,* 1985, 289-292 **[0010]**
- Theory and Design of microwave filters. **I.C. HUNTER.** IEE electromagnetic waves series. 2001, 314 **[0011]**
- **S. RAMO ; J.R. WHINNERY ; T. VAN DUZER.** Fields and waves in communication electronics. John Wiley & Sons, 1993, 494 **[0011]**