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(54) Dielectric multimode resonator

(57) The present invention relates to a dielectric multimode resonator that comprises walls (2) enclosing a resonator cavity (3), and a resonator element (4, 4', 4") made of dielectric material and disposed in the resonator cavity (3). The resonator element (4, 4', 4'') comprises a plurality of at least three leg portions (8, 8'', 8a, 8b) extending towards the walls (2) and an annularly closed portion (5, 5') circumscribing an opening (7) and disposed spaced from the walls (2). The leg portions (8, 8", 8a, 8b) form projections extending from the annularly closed portion (5, 5') from different locations spaced in the circumferential direction of the annularly closed portion (5, 5'), such that each two adjacent leg portions (8, 8'', 8a, 8b) are separated in the circumferential direction by a section of the annularly closed portion (5, 5').

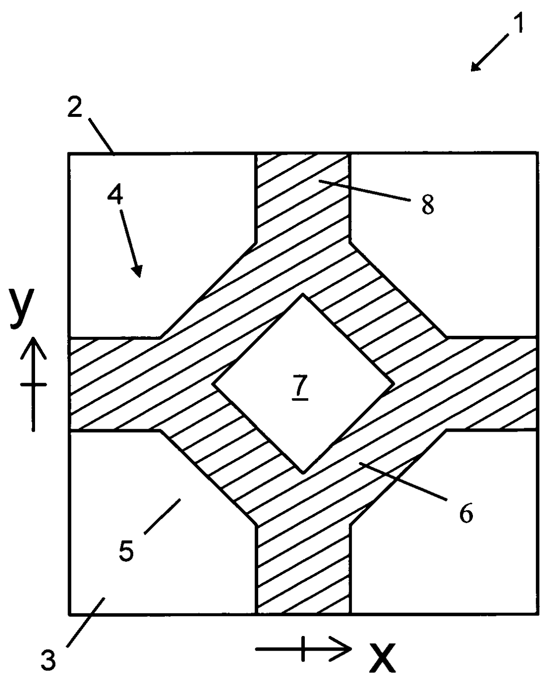


FIG. 1b

EP 1 962 370 A1

Description

[0001] The present invention relates to a dielectric multimode resonator comprising walls enclosing a resonator cavity, and a resonator element made of dielectric material and disposed in the resonator cavity, wherein the resonator element comprises a plurality of leg portions extending towards 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] 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.

[0004] 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.

[0005] 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).

[0006] Furthermore, dual mode operation was achieved by utilizing a cross-shaped resonator element, i.e. an element comprising two dielectric rods arranged perpendicular to each other. 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.

[0007] 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.

[0008] 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.

[0009] 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 cuboidal 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.

[0010] Therefore, to avoid ambiguities, it is more convenient to include the direction of propagation into the mode designation. For example, in a cuboidal 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".

[0011] 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 permittivity 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.

[0012] 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.

[0013] US 6,278,344 discloses a triple mode dielectric resonator with a planar cross-shaped resonator element having its leg portions connected to the sidewalls of the enclosure in which the resonator element is disposed. In addition to the above-described pseudo TM110 modes, the resonator element also supports a pseudo TM111 mode to achieve triple mode operation. A through bore may be provided in the center of the cross 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] US 5,880,650 describes a multimode dielectric resonator including a resonator element essentially having the shape of a polygon or of two perpendicular, crossed polygons. A polygon may have a central through bore.

[0015] WO 2004/066430 describes a dielectric multimode resonator device with an essentially cross-shaped resonator element supporting two perpendicular TE01δ modes and two perpendicular TM01δ modes. Protrusion portions are provided to upper and lower portions of the cross-shaped resonator element. Therefore, the effective dielectric constant of the portion where the dielectric flux of the even mode of the TE coupling modes passes is made different from that of the portion where the dielectric flux of the odd mode of the TE coupling mode passes. Additionally, a protrusion portion is provided to an intermediate layer portion of the resonator element. Therefore, the effective dielectric constant of the portion where the dielectric flux of the even mode of the TM coupling modes passes is almost equal to that of the portion where the dielectric flux of the odd mode of the TM coupling mode passes.

[0016] US 6,518,857 relates to a dielectric multimode resonator apparatus which is configured such that a TM mode and a TE mode are transformed into multiplex modes. In this apparatus, a dielectric resonator element is configured of a plate-like TM mode dielectric resonator element portion and a TE mode dielectric resonator element portion protruding therefrom in the vertical direction, for example in a spherical shape.

[0017] US 6,650,208 describes a TE dual mode dielectric resonator filter having two dual mode dielectric resonators which are constructed in a similar manner. Each of the dual mode dielectric resonators includes a cross-shaped resonator element made of low loss dielectric material, for example ceramic, with a dielectric constant between 36 and 45. Both resonator elements are attached with a distance between them on a planar interior surface of the cavity of an enclosure formed from a conductive material, for example metal. One of the dual mode dielectric resonators includes an input connector that is adapted to receive RF signals for processing by the filter, and the other dual mode dielectric resonator includes an output connector to provide a filter output signal.

[0018] EP 1 014 474 relates to a dielectric multimode resonator having a resonator element comprising a block-shaped central portions and a plurality of 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.

[0019] EP 1 122 807 relates to a dielectric multimode resonator having an essentially block-shaped resonator element supporting three fundamental TE01δ modes.

[0020] All above mentioned prior art dielectric multimode resonators have disadvantages. Taking the number of resonance modes supported as a measure, the dielectric resonators are relatively heavy and bulky, in particular for mobile communications systems. Further, increasing the number of resonance modes supported regularly yields resonator elements with a rather complex design and construction, so that manufacturing of these dielectric resonators is relatively expensive. Also, it is difficult to adapt the prior art resonators for use with different frequencies, and tuning of the prior art resonators is difficult and complex.

[0021] It is an object of the present invention to provide a dielectric multimode resonator, and in particular a dielectric TE multimode resonator, which is adapted to overcome the above mentioned disadvantages.

[0022] 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.

[0023] The dielectric multimode resonator comprises walls defining a resonator cavity enclosed by the walls. For example, the resonator cavity can have a (circularly or elliptically) cylindrical, cuboidal or cubical shape or the shape of a right prism with a polygonal base having three or more sides. In general, the walls consist of or comprise, e.g. in the form of a coating, a conductive material, such as a metal material.

[0024] 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. The resonator element comprises an annularly closed portion, i.e. a loop-shaped portion defining and completely surrounding an opening region or through bore. The annularly closed portion can have any shape, such as e.g. circular, oval, rectangular or polygonal, and it can have a planar or curved configuration and may or may not be rotationally symmetric. The annularly closed portion of the resonator element is disposed spaced from the walls. At least three leg portions, i.e. branches or arms, extend from different locations on the annularly closed portion, e.g. from the perimeter. Each of these leg portions constitutes a projection extending away from the annularly closed portion, and preferably is an elongate or rod-shaped or bar-shaped straight or curved portion of the resonator element. The leg portions are arranged to extend from different locations on the annularly closed portion such that the leg portions are spaced in the circumferential direction of the annularly closed portion. In this way, each two leg portions adjacent in the circumferential direction of the annularly closed portion are separated in this direction by a section of the annularly closed portion. This section can be regarded as an interconnection section interconnecting the respective two adjacent leg portions.

[0025] With other words, the structure of the resonator element could also be described as comprising at least three inner branches connected in series to form an annularly closed or loop-shaped central portion, and at least three outer branches extending from the central portion. Each outer branch is connected to the central portion at an interconnection region between two adjacent inner branches.

[0026] The dielectric multimode resonator according to the present invention has the advantage of providing a plurality of independently usable resonance modes, guided by the resonator element generally along the direction of extension of the outer and inner branches (i.e. guided resonance modes with the electric field extending along the direction of extension of the outer and inner branches), with a resonator element that is simple in construction and requires a relatively small amount of dielectric material for its production. In this way, manufacturing of the dielectric elements is facilitated and their volume and weight is reduced as compared to prior art resonator elements supporting a comparable number of resonance modes. Importantly, in addition to guided resonance modes involving the leg portions, such as e.g. resonance modes in which the electric field is guided into the annularly closed portion via one leg portion and guided out of the annularly closed portion via another leg portion and comparable to the resonance modes utilized for filter purposes in prior art dielectric resonators with a resonator element comprising one dielectric rod or at least two perpendicular dielectric rods, the dielectric multimode resonator according to the present invention advantageously also supports a mode in which the electric field is only dominant, i.e. concentrated, in and guided by the annularly closed portion in a closed loop and which is comparable to the TE01δ mode discussed above and can be referred to as "ring mode".

[0027] Further, by suitably choosing the dimensions, shape, orientation and relative arrangement of the annularly closed portion and the leg portions (the outer and inner branches), 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, the resonator element of the present invention additionally includes the plurality of inner branches that can be utilized advantageously in order to improve control of the above-described ring mode and/or the other resonance modes supported by the element, e.g. setting the resonance frequency or employing a particular resonance mode excitation scheme by utilizing the presence of the various inner branches. For these purposes, the resonance frequency of the ring mode may or may not lie in the region of the resonance frequencies of the other resonance modes used for actual filter operation. In general, due to the individual branches being spatially essentially separated, it is advantageously possible to individually choose the design and construction characteristics of each branch, such as its length, width and height. Furthermore, it is possible to provide coupling and tuning mechanisms selectively only acting upon or interacting with a particular branch (or group of branches) or mode.

[0028] 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.

[0029] In a preferred embodiment, one set of guided orthogonal resonance modes supported by the present resonator element includes the above-described ring mode as a first resonance mode. Accordingly, in the first resonance mode the electric field is concentrated, i.e. only dominant and preferably only present, in and guided by the annularly closed portion and extends in a closed loop within the annularly closed portion following its circumferential direction. With other words, while a small amount of the electric field may be present in the leg portions, the electric field lines are essentially confined or concentrated in the annularly closed portion and follow the course of this portion. 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.

[0030] In this embodiment, the set of orthogonal resonance modes further includes one or more second resonance modes in which the electric field is only dominant in and guided by at least a part of the annularly closed portion in the circumferential direction thereof and at least two of the plurality of leg portions. In this second mode or these second modes, within the annularly closed portion the electric field is only dominant and preferably only present in a first contiguous circumferential section and a second contiguous circumferential section. The circumferential direction of extension of the electric field in the first contiguous circumferential section is oppositely directed to the circumferential direction of extension of the electric field in the second contiguous circumferential section. Further, each of the first and the second contiguous circumferential section terminates at both of its ends at a leg portion in which electric field is guided. With other words, each end of the two contiguous sections is disposed at a location at which a leg portion is connected to the annularly closed portion. Thus, each contiguous section consists of one or more adjacent inner branches. The two contiguous sections may be entirely separated from each other by intermediate inner branches, or they may be directly interconnected at only one or at both ends, i.e. each pair of facing ends of the two contiguous sections may or may not be directly interconnected. If two ends of the two contiguous sections are directly interconnected, they are evidently associated with a common leg portion. In case the two contiguous sections are directly interconnected at both ends, they form a closed loop and the electric field is concentrated and guided in the entire annularly closed portion, and each pair of directly interconnected ends is associated with a common leg portion. In case the two contiguous sections are directly interconnected at one end only, within the annularly closed portion the electric field is only present in a contiguous part of the annularly closed portion, and the two ends, that are not directly interconnected, are associated with separate leg portions. Finally, in case the two contiguous sections are not directly interconnected at all, within the annularly closed portion the electric field is only present in two separate contiguous parts of the annularly closed portion, and each of the four ends of the two contiguous sections is associated with a separate leg portion.

[0031] The above condition of two contiguous sections is equivalent to the condition that when circulating the annularly closed portion clockwisely one will observe exactly two reversals of the circumferential direction of extension of the electric field. Evidently, since the circumferential direction of extension of the electric field is the same throughout each of the two contiguous sections, such a reversal of the direction of the electric field is only possible at a location or region at which one or more leg portions are connected to and extend from the annularly closed portion, because the reversal requires that the electric field is guided out of or into the annularly closed portion at this location or region.

[0032] Thus, in case of the electric field being present within the annularly closed portion not only in the first and second contiguous section defined above, i.e. in case of more than two of such reversals of direction, the electric field is necessarily guided into the annularly closed portion via leg portions that are separated in both circumferential directions of the annularly closed portion by leg portions via which the electric field is guided out of the annularly closed portion. Accordingly, there are always several spaced apart and distinct regions in which the electric field is guided into the annularly closed portion and several spaced apart and distinct regions in which the electric field is guided out of the annularly closed portion. By contrast, in case of the electric field being present within the annularly closed portion only in the first and second contiguous section defined above, i.e. in case of exactly two reversal of the direction of the electric field, the electric field is generally guided into the annularly closed portion in only one region of the element and is guided out of the annularly closed portion in only one region of the element, wherein these two regions are distinct from each other. Each region comprises a part of the annularly closed portion including one pair of facing ends of the first and second contiguous section and one or more leg portions, and within the annularly closed portion the electric field is guided within the first and the second contiguous section. In other words, the second resonance modes are characterized by an electric field configuration in which the electric field is guided into the resonator element via one or more leg portions in a particular region of the element, is guided along the annularly closed portion, and is guided out of the element via one or more leg portions in a non-overlapping different particular region of the element. In this regard, the second resonance modes resemble the pseudo TM110 modes described above for the case of a resonator element consisting of a dielectric rod or a plurality of perpendicular dielectric rods.

[0033] Depending on the arrangement and number of the leg portions involved in supporting a particular second resonance mode, the electric field may be dominant in the entire annularly closed portion or only in a part thereof, e.g. in the part forming the shortest path between two leg portions.

[0034] In this embodiment, the leg portions and the annularly closed portion are further arranged, e.g. by choosing suitable material, dimensions such as width and/or length, shape and relative positions of the individual leg portions and the annularly closed portion or individual sections or branches thereof, such that the central frequencies of the first resonance mode and the at least one 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%. In this context it should be noted, that the resonator element may of course also support further resonance modes with a field configuration as described for the at least one second resonance mode and with a resonance frequency outside the pass band. However, it is only decisive that the resonator element supports at least one second resonance mode with a central frequency in the indicated range. In case of more than one second resonance mode, it may also be advantageous to arrange the leg portions and the annularly closed portion such that only the central frequencies of two or more of the second resonance modes are within the same pass band of the dielectric multimode resonator, i.e. such that the first resonance mode does not contribute to this pass band. This can be an advantage in cases in which it is desired to avoid additional measures to achieve temperature compensation. However, also in this case, the inner branches may be used to achieve second resonance modes having the desired characteristics.

[0035] The dielectric multimode resonator according to this preferred embodiment has the advantage of providing, in the form of the first resonance mode, an additional independent usable resonance mode as compared to a dielectric resonator with a resonator element comprising one dielectric rod or at least two perpendicular dielectric rods without significantly increasing the complexity of and the amount of dielectric material required for the resonator element.

[0036] In a preferred embodiment, the plurality of leg portions includes one or more pairs of leg portions in which the electric field is guided in one of the at least one second resonance mode with the electric field being oppositely directed in the two leg portions relative to the annularly closed portion, and which are spaced apart by 180° in the circumferential direction of the annularly closed portion.

[0037] In one embodiment, the resonator element comprises exactly four leg portions. As will be described in more detail below, such a resonator element supports four guided orthogonal resonance modes, so that the resonator element, depending on the resonance frequencies chosen for the individual resonance modes, provides for a dielectric dual, triple or quadruple mode resonator.

[0038] In an alternative embodiment, the resonator element comprises exactly three leg portions or more than four leg portions, such as e.g. exactly five, exactly six, exactly seven or exactly eight leg portions. It can be generally shown that the number of guided orthogonal resonance modes is equal to the number of leg portions. In this regard, it should be noted that guided orthogonal resonance mode in the sense of the present application are resonance modes in which the electric field is guided along the general direction of extension of the various branches of the resonator element. Of course, there may also be orthogonal resonance modes in which the electric field e.g. extends around the cross-sectional circumference of a particular branch. However, while such resonance modes may also be utilized, they are not specifically considered here. Thus, the number of orthogonal resonance modes that can be utilized for filter operation increases with the number of leg portions provided. However, the larger the number of leg portions, the more difficult the manufacture and tuning of the resonator element and the more bulky the resonator element itself becomes and the more dielectric material is needed. Therefore, while more than eight leg portions might be suitable for particular applications, in most cases there will be less than nine leg portions with the number as small as possible when taking the number of required orthogonal resonance modes into consideration. In general, it is possible that all of the above guided orthogonal resonance modes are tuned to similar frequencies within a common pass band. However, advantageous filter properties are already obtained when only some of the available modes are utilized. Such arrangement also has the advantage that less restrictions on the construction of the resonator element are imposed, thereby facilitating manufacture.

[0039] In a further embodiment, the resonator element comprises three leg portions, such that the plurality of orthogonal resonance modes supported by the resonator element includes at least two of the above-defined second resonance modes. In one of these second resonance modes, in addition to the first and the second contiguous section of the annularly closed portion the electric field is also dominant in and guided by the three leg portions. The first and the second contiguous section are interconnected at one of the three leg portions in which leg portion the electric field is oppositely directed relative to the annularly closed portion as compared to the other two of the three leg portions. The plurality of orthogonal resonance modes supported by the resonator element also includes a further second resonance mode in which the electric field is only dominant in and guided by the entire annularly closed portion and two of the three leg portions. In the latter second resonance mode, the electric field is guided into the annularly closed portion via one of the two leg portions and guided out of the annularly closed portion via the other of the two leg portions. The leg portions and the annularly closed portion are arranged, e.g. by choosing suitable material, dimensions, shape and relative positions of the individual leg portions and the annularly closed portion, such that the central frequencies of the two second resonance modes are within the same pass band of the dielectric multimode resonator as the central frequency of the first resonance mode, and preferably lie in the range indicated above. It should be noted that the resonator element of this embodiment preferably includes only the three leg portions, but that it may also include additional leg portions. Thus, since such a resonator element supports two second resonance modes in addition to the first resonance mode, the resonator element provides for at least triple mode operation of the dielectric resonator. A dielectric triple mode resonator is obtained if only three leg portions are present. With more leg portions, which are suitably arranged and constructed, more modes may be utilized.

[0040] In this embodiment, it is preferred that the three leg portions considered are spaced apart by 120° in the circumferential direction of the annularly closed portion. In this arrangement, the resonator element can be constructed to be symmetric with regard to rotations by 120°, which has the advantage that the two second resonance modes have identical central frequencies, so that only the resonance frequency of the first resonance mode has to be tuned.

[0041] In a further embodiment, the resonator element comprises four leg portions, such that the plurality of orthogonal resonance modes supported by the resonator element includes two of the second resonance modes defined above and a third resonance mode in which the electric field is dominant in the annularly closed portion and the four leg portions considered. Further, in the third resonance mode in each pair of non-adjacent leg portions of the four leg portions the electric field is identically directed relative to the annularly closed portion, and in one pair of non-adjacent leg portions of the four leg portions the electric field is oppositely directed relative to the annularly closed portion as compared to the other pair of non-adjacent leg portions of the four leg portions. In the two second resonance modes, the first and the second contiguous section are interconnected at both ends thereof at two non-adjacent of the four leg portions with the electric field being oppositely directed in the respective two non-adjacent leg portions relative to the annularly closed portion. In one of the two second resonance modes the electric field is only dominant in and guided by the annularly closed portion and two non-adjacent leg portions of the four leg portions, and in the other of the two second resonance modes the electric field is only dominant in and guided by the annularly closed portion and the other two non-adjacent leg portions of the four leg portions, i.e. in the case of the four leg portions being spaced by 90° and of a rotationally symmetric annularly closed portion, the field configuration of one of the two second resonance modes is identical to the field configuration of the other second resonance mode after rotation by 90°. In the latter case, the field configuration of the two second resonance modes resembles to some extent the field configuration of the pseudo TM110 modes supported by two perpendicular dielectric rods together forming a cross.

[0042] Again, the leg portions and the annularly closed portion are arranged, e.g. by choosing suitable material, dimensions, shape and relative positions of the individual leg portions and the annularly closed portion, such that the central frequency of the third resonance mode is within the same pass band of the dielectric multimode resonator as the central frequencies of the first resonance mode and the two resonance modes of the at least one second resonance mode, and preferably such that these central frequencies lie in the range indicated above. It should be noted that the resonator element of this embodiment preferably includes only the four leg portions, but that it may also include additional leg portions. Thus, since such a resonator element supports a third resonance mode and two second resonance modes in addition to the first resonance mode, the resonator element provides for at least quadruple mode operation of the dielectric resonator. A dielectric quadruple mode resonator is obtained if only four leg portions are present. With more leg portions, which are suitably arranged and constructed, more modes may be utilized.

[0043] In this embodiment, it is preferred that the four leg portions in which the electric field is dominant in the third resonance mode are spaced apart by 90° in the circumferential direction of the annularly closed portion.

[0044] In a further preferred embodiment, the leg portions and the annularly closed portion are arranged such that the resonance modes in the plurality of orthogonal resonance modes are degenerated, i.e. have the same or substantially the same resonance frequency, such that the resonator element supports a set of non-orthogonal resonance modes, in each of which the electric field is dominant only in another pair of adjacent leg portions and in the section of the annularly closed portion interconnecting the respective pair of adjacent leg portions, wherein the number of non-orthogonal resonance modes in the set is equal to the number of leg portions. Thus, there is a non-orthogonal resonance mode with the above characteristics for each pair of adjacent leg portions. This set of non-orthogonal resonance modes is obtainable by superposition of the set of orthogonal resonance modes. For example, in the case of exactly four leg portions described above, the first orthogonal resonance mode, the two second orthogonal resonance modes, and the third orthogonal resonance mode would be degenerated so that four non-orthogonal resonance modes could be formed by superposition, wherein in each of the four non-orthogonal resonance modes the electric field is dominant only in a different pair of adjacent leg portions and the interconnecting section of the annularly closed portion.

[0045] In such a resonator element, the set of non-orthogonal resonance modes are essentially decoupled with respect to sections of the annularly closed portion and adjacently coupled by means of the leg portions. It is advantageous to provide an input coupling means for coupling electromagnetic energy into the resonator element, wherein the input coupling means is arranged to couple electromagnetic energy selectively and predominantly to a first section of the annularly closed portion interconnecting two adjacent leg portions, and/or to provide an output coupling means for coupling electromagnetic energy out of the resonator element, wherein the output coupling means is arranged to couple electromagnetic energy selectively and predominantly out of a second section of the annularly closed portion interconnecting two adjacent leg portions, wherein the second section is adjacent the first section. In this way, the non-orthogonal resonance modes are coupled in series. Thus, the dielectric resonator can be regarded as comprising a number of individual resonators connected in series between input and output. It is further advantageous if the leg portion between the first and the second section of the annularly closed portion is shorter than the remaining leg portions in order to decrease the coupling strength between the input mode and the output mode.

[0046] In the alternative, and also for non-degenerated orthogonal resonance modes, a further advantageous and preferred arrangement of input and output coupling means for coupling electromagnetic energy into and out of, respectively, the resonator element is possible. The input coupling means is arranged in such a manner that each of the plurality of orthogonal resonance modes is excited, and the output coupling means is arranged in such a manner that electromagnetic energy from each of the plurality of orthogonal resonance modes is received by the output coupling means. By means of this arrangement, the orthogonal resonance modes are coupled in parallel between the input coupling means and the output coupling means without cross-coupling between the individual modes. The same coupling arrangement could also be implemented with other sets of orthogonal modes if the input and output coupling means are arranged such that all modes of the set are excited and sensed. It also has to be noted that generally the number of achievable transmission zeros is limited by the number of resonators, and that in the case of maximum transmission zeros at finite frequencies a direct electromagnetic, i.e. capacitive or inductive, coupling between input and output node is required. Of course, it is possible that only some of the orthogonal resonance modes principally available are coupled in the above manner, whereas the remaining orthogonal resonance modes are shifted to different frequencies so that they are not excited during filter operation.

[0047] The input coupling means and the output coupling means are preferably inductive coupling means. The inductive input coupling means and the inductive output coupling means may e.g. comprise an electrically conductive rod, wire-shaped element or plate, and at least one of the input coupling means and the output coupling means is preferably arranged such that the distance between its 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.

[0048] It is also preferred that the dielectric multimode resonator comprises at least one frequency adjustment screw extending through a wall portion into the resonator cavity towards a region of the annularly closed portion in the middle between two leg portions and/or at least one coupling adjustment screw extending through a wall portion into the resonator cavity towards a region of the annularly closed portion in which a leg portion is connected to the annularly closed portion. In any case, such screws are arranged such that the distance between their terminal ends and the annularly closed portion can be adjusted.

[0049] In a preferred form of the dielectric multimode resonator, each leg portion connects the annularly closed portion with a wall portion, i.e. for each leg portion the end opposite the end connected to the annularly closed portion is connected to the walls, thereby establishing electrical connections between the walls and the leg portions. Such connection may be direct or via e.g. a dielectric shielding cavity provided between the electrically conductive portions of the walls and the leg portions. The resonator element may also be integrally formed in one piece with such a shielding cavity.

[0050] In the alternative, for at least one of the leg portions the end of the leg portion opposite the end connected to the annularly closed portion is spaced from the walls and/or for at least one of the leg portions the end of the leg portion opposite the end connected to the annularly closed portion is connected to a wall portion via a distance piece. Preferably, such distance pieces is 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.

[0051] In a preferred embodiment, the resonator element is planar such that it extends entirely in a plane. Such a resonator element is particularly easy to manufacture and to secure within the resonator cavity.

[0052] It is preferred that the leg portions are equally spaced in the circumferential direction of the annularly closed portion, and in particularly that the leg portions are symmetrically arranged around the annularly closed portion. For example, the resonator element may comprise an even number of leg portions and a planar annularly closed portion, wherein the leg portions are symmetrically arranged around the central portion, extend alternately to the two sides of the planar central portion and are arranged such that electrically the distance between the wall contacts of two adjacent leg portions and of two leg portions separated by one leg portion are equal.

[0053] In a preferred embodiment, the annularly closed portion has the shape of a polygon, in particular a regular polygon, with n sides and n vertices, wherein the resonator element comprises between three to n, preferably n, leg portions, each of which extends from a different vertex of the polygon. In an alternative preferred embodiment, one, more or all of the sections of the annularly closed portion interconnecting adjacent leg portions are curved, and more preferred the annularly closed portion is circular or oval.

[0054] The leg portions may be straight or the leg portions may be curved. It is also possible that some of the leg portions are straight and some of the leg portions are curved.

[0055] It may be advantageous if at least one of the leg portions has a different length and/or diameter as compared to the other leg portions. By choosing suitable lengths and/or widths of the leg portions, the central frequencies of the supported orthogonal resonance modes can be set.

[0056] It is also preferred that the entire resonator element is made of the same dielectric material, and in particular that the resonator element is integrally formed in one piece. This construction avoids internal surfaces at which electromagnetic energy may be reflected.

[0057] In a preferred embodiment, the walls include two opposing, e.g. planar and parallel, end wall portions and a sidewall extending between and connecting the end wall portions and comprising a (circularly or elliptically) cylindrical wall portion or four rectangularly arranged wall portions, and all leg portions are connected with the end opposite the end connected to the annularly closed portion only to the same wall portion. Such a construction has advantages with regard to mechanical stress which can develop in operation due to different coefficients of thermal expansion of the resonator element and the walls. This is particularly true, if a flexible wall portion is utilized.

[0058] The filter performance of the dielectric multimode resonator can be further increased by providing for support of a further resonance mode in the same pass band, which resonance mode is independent of the resonator element. For example, for a dielectric multimode resonator having walls including a base wall, a sidewall (e.g. circularly or elliptically cylindrical or rectangular) extending upwardly from the base wall and an upper cover wall closing the resonator cavity, an inner conductor or a dielectric rod electrically connected to the base wall and extending upwardly towards the upper cover wall through the opening of the annularly closed portion may be provided for this purpose. In case of the base wall and the upper cover wall being parallel and of the inner conductor or dielectric rod being a straight, elongate component, the resonator element, i.e. the annularly closed portion and the leg portion, preferably extends in a plane parallel to the base wall and the upper cover wall and perpendicular to the direction of extension of the inner conductor or dielectric rod. In the alternative, the resonator cavity may be dimensioned such that in addition to the plurality of orthogonal modes supported by the resonator element an air cavity resonance is supported in the resonator cavity, wherein the central frequency of the air cavity resonance is within the same pass band as the central frequencies of the plurality of orthogonal modes.

[0059] In a further preferred embodiment, the resonator element comprises at least one further annularly closed portion spaced from the walls and one leg portion extending from the at least one further annularly closed portion or a plurality of leg portions extending from different positions of the further at least one annularly closed portion towards the walls such that each two adjacent leg portions are separated in the circumferential direction by a section of the at least one further annularly closed portion, wherein all annularly closed portions have the same or essentially the same shape and wherein the annularly closed portions are interconnected such that they define a common interior space. With other words, the resonator element comprises a plurality of equally shaped annularly closed portions which can have any of the above structures and which are e.g. arranged and interconnected such that they have a common center. Preferably, each two annularly closed portions share at least one common leg portion and preferably exactly two common leg portions. Further, one or more of the leg portions may be common to different annularly closed portions. With such a construction, the number of supported resonance modes which can be arranged in the same pass band can be further increased.

[0060] 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.

[0061] In the following, the invention is explained in more detail for preferred embodiments with reference to the figures.

Figs. 1a and 1b schematically show a cross sectional side view and top view, respectively, of a dielectric multimode resonator according to the present invention.

Fig. 2	shows a simplified branch model of the dielectric resonator shown in Figures 1a and 1b.
Figs. 3a to 3d	show the distribution of the electric field in the resonator element of the dielectric multimode resonator of Figures 1a and 1b for a set of four fundamental orthogonal resonance modes supported by the resonator element (chain dotted lines indicate E-plane and H-plane symmetries).
Figs. 4a to 4b	show the distribution of the electric field in the resonator element of the dielectric multimode resonator of Figures 1a and 1b for a different set of four orthogonal resonance modes supported by the resonator element which can be derived from the set shown in Figures 3a to 3d by superposition (chain dotted lines indicate E-plane and H-plane symmetries).
Figs. 5a to 5b	show the distribution of the electric field in the resonator element of the dielectric multimode resonator of Figures 1a and 1b for a set of four non-orthogonal resonance modes supported by the resonator element which can be derived from the sets shown in Figures 3a to 3d and 4a to 4d by superposition.
Fig. 6	shows schematically a top view, side view and bottom view (from top to bottom) of a dielectric quadruple mode resonator including an input and output coupling means and a plurality of tuning screws.
Fig. 7	shows schematically a top view, side view and bottom view (from top to bottom) of the dielectric quadruple mode resonator of Figure 6 with an alternative arrangement of input and output connector.
Fig. 8	shows the node diagram for the four pole band pass resonator with cross coupling corresponding to Figures 6 and 7.
Fig. 9	shows a node diagram for an eight pole band pass resonator with cross couplings realized by connecting two resonators shown in Figure 8 in series and including a non-resonating node.
Fig. 10	shows the node diagram of Figure 9 with the non-resonating node being suppressed.
Fig. 11	shows schematically and in top view an embodiment of two quadruple mode resonators coupled in series.
Fig. 12	shows schematically and in top view another embodiment of two quadruple mode resonators coupled in series.
Fig. 13	shows a node diagram of a four pole band pass resonator in which four orthogonal modes are coupled in parallel.
Fig. 14	shows schematically a top view, side view and bottom view (from top to bottom) of a dielectric quadruple mode resonator including an input and output coupling means for parallel coupling of the four modes and a plurality of tuning screws.
Fig. 15	shows schematically an alternative input and output coupling means for parallel coupling of the four modes.
Fig. 16	shows a node diagram for an eight pole band pass resonator realized by connecting two resonators shown in Figures 13 to 15 in series.
Fig. 17	shows a node diagram for an eight pole band pass resonator realized by connecting two resonators shown in Figures 13 to 15 in series without direct input/output coupling and suppressing the non-resonating node.
Fig. 18	shows schematically and in top view, side view and bottom view an embodiment of two quadruple

mode resonators shown in Figures 13 to 15 coupled in series.

Fig. 19	shows schematically and in side view a further embodiment of two quadruple mode resonators shown in Figures 13 to 15 coupled in series.
Fig. 20	shows schematically and in side view a further embodiment of two quadruple mode resonators shown in Figures 13 to 15 coupled in series.
Fig. 21	shows a dielectric multimode resonator with a differently shaped center portion of the resonator element.
Fig. 22	shows dielectric multimode resonators with differently shaped enclosures.
Fig. 23	shows a dielectric multimode resonator with a shielding enclosure.
Figs. 24a and 24b	schematically show a cross sectional side view and top view, respectively, of a dielectric multimode resonator according to the present invention having a modified resonator element.
Figs. 25a to 25c	schematically show cross sectional side views and a top view, respectively, of a dielectric multimode resonator according to the present invention having a modified resonator element.
Figs. 26a to 26c	schematically show cross sectional side views and a top view, respectively, of a dielectric multimode resonator according to the present invention having a modified resonator element.
Figs. 27a to 27c	show examples of resonator elements with three, five and eight leg portions.
Figs. 28a to 28c	show the electric field configuration of three fundamental orthogonal modes in a resonator element having three leg portions.
Figs. 29a and 29b	show different possibilities for the planar arrangement of three leg portions.
Figs. 30a to 30e	show the distribution of the electric field in the resonator element for a set of five fundamental orthogonal resonance modes supported by a resonator element having five leg portions (chain dotted lines indicate E-plane and H-plane symmetries).
Figs. 31a to 31h	show the distribution of the electric field in the resonator element for a set of eight fundamental orthogonal resonance modes supported by a resonator element having eight leg portions (chain dotted lines indicate E-plane and H-plane symmetries).
Figs. 32a and 32b	show simplified branch models of dielectric resonators having three dimensional resonator elements.
Fig. 33	shows a further three dimensional resonator element.

[0062] In Figures 1a and 1b a cross sectional side view and top view, respectfully, of a dielectric multimode resonator 1 according to the present invention is shown schematically. The dielectric resonator 1 comprises walls 2 forming a cuboidal enclosure defining a resonator cavity 3. The walls 2 are, at least in part, electrically conductive. Inside the resonator cavity 3 a planar resonator element 4 made of dielectric material is disposed extending in the x-y-plane and electrically connected to the walls 2.

[0063] The resonator element 4 comprises an annularly closed center portion 5 consisting of four interconnected straight, elongate portions or inner branches 6 circumscribing an opening or through bore 7 in the center of the resonator element 4. The annularly closed center portion 5 has the shape of a regular polygon with the inner branches being connected in series at the vertices of the polygon. Further, the resonator element 4 comprises four leg portions or outer branches 8, each of which is connected with the annularly closed center portion 5 at locations in which two adjacent inner branches 6 are connected to each other, i.e. at the vertices of the polygonal shape of center portion 5. The leg portions 8 extend away from the center portion 5 towards the walls 2 and are electrically connected to the walls 2. The resonator element 4 is integrally constructed in one piece.

[0064] In Figure 2 a simplified branch model of the dielectric resonator 1 depicted in Figures 1a and 1b is shown. The leg portions or outer branches 8 are electrically connected to the electrically conductive walls 2 and are further connected to the inner branches 6 which are annularly connected, i.e. in a closed loop, to form the center portion 5.

[0065] In Figures 3a to 3d the distribution of the electric field (open arrows) for four fundamental orthogonal resonance modes supported by the resonator element 4 and guided along the general direction of extension of the outer branches 8 and inner branches 6 is illustrated. The chain dotted lines indicate E-plane and H-plane symmetries, since the branches 6 and 8 are symmetrically arranged. Due to the planar arrangement of the resonator element and its concentration of the electric fields, the depicted fundamental orthogonal modes can be designated as TE type. Therefore, instead of using the TM mode terminology, the modes can be better designated as TEz01δ (Fig. 3a), TEz101 (Fig. 3b), TEz011 (Fig. 3c) and TEz111 (Fig. 3d). In the TEz01δ mode shown in Fig. 3a, the electric field is confined in the center portion 5 and is not present in the leg portions 8. In the center portion 5, the electric field extends annularly in a closed loop. This mode corresponds to the mode supported by a dielectric puck. In the TEz101 mode shown in Fig. 3b and the TEz011 mode shown in Fig. 3c the electric field extends in one leg portion 8 towards the center portion 5, splits up at the interconnection point between the leg portion 8 and the center portion 5, extends along the inner branches 6 to either side of this interconnection point towards the opposite leg portion 8, is combined again at the beginning of this opposite leg portion 8 and extends along this opposite leg portion 8 away from the center portion 5. In Fig. 3b, the two left inner branches 6 constitute a first contiguous section of the center portion 5, and the two right inner branches 6 constitute a second contiguous section of the center portion 5. Similarly, In Fig. 3c, the two upper inner branches 6 constitute a first contiguous section of the center portion 5, and the two lower inner branches 6 constitute a second contiguous section of the center portion 5. In both Figures, the first and the second contiguous section are interconnected at both ends at a location at which a leg portion 8 guiding electric field is connected to the center portion 5. Each contiguous section is one half of the center portion 5. The electric field is guided into the center portion 5 via a leg portion 8 at one pair of interconnected ends of the two contiguous sections, is guided along the two contiguous sections to the opposite pair of interconnected ends, and is guided out of the center portion 5 via the leg portion 8 associated with the latter pair.

[0066] These modes correspond to the modes supported by crossed dielectric rods and designated above as pseudo TM110 modes. For each of them, the electric field reverses its circumferential direction of extension in the center portion 5 exactly twice when circulating the center portion 5. These modes are second resonance modes within the meaning of the above definition. In the TEz111 mode shown in Fig. 3d, the electric field extends in two opposing leg portions 8 towards the center portion 5, splits up at the interconnection points between these two leg portions 8 and the center portion 5, extends along the inner branches 6 to either side of the respective connection point towards the respective adjacent leg portion 8 and extends along these other two opposing leg portions 8 away from the center portion 5. This mode corresponds to the mode supported by crossed dielectric rods and designated above as pseudo TM111 mode. In this mode, the electric field changes its circumferential direction of extension in each two adjacent inner branches 6, so that the electric field is not only present in two contiguous sections of the center portion 5 with opposite circumferential orientation of the electric field. The electric field reverses its circumferential direction of extension in the center portion 5 at each of the four vertices.

[0067] In the dielectric multimode resonator 1, the above four fundamental orthogonal modes are simultaneously utilized to achieve quadruple mode operation. The resonator element 4 not only supports modes similar to the modes described in US 6,278,344, but also the TE01δ mode which is supported by the center portion 5. By suitably shaping and arranging the leg portions 8 and the center portion 5, the resonance or central frequencies of the four modes are set such that they lie within the same pass band of the dielectric resonator 1, i.e. that the four fundamental modes are resonating at a similar frequency to generate a common pass band. By setting the resonance frequencies accordingly, it is of course also possible to achieve triple mode or dual mode operation. The frequencies of the modes can be varied by e.g. suitable choice of the width and height of each inner branch 6 and leg portion 8.

[0068] If the TEz101 and TEz011 modes are degenerated (i.e. have the same resonance frequency), they can be superposed to result in the fields "TEz101+TEz011" as shown in Figure 4a and "TEz101-TEz011" as shown in Figure 4b. Further, if the TEz01δ and the TEz111 modes are degenerated, they can be superposed to result in the fields "TEz011-TEz01δ" as shown in Figure 4c and "TEz011+TEz01δ" as shown in Figure 4d. These four modes shown in Figures 4a to 4d represent an alternative set of orthogonal modes supported by the resonator element 4. The fields of the modes included in this set show cross diagonal E-plane and H-plane symmetry. Therefore the patterns can be achieved if corresponding cross diagonal symmetry of the resonator element 4 is given, even if no symmetry is present with respect to the x- and y-axes.

[0069] With the electric fields shown in Figures 4a to 4d, another set of non-orthogonal modes can be obtained by superposition. Therefore, all four modes should have similar resonance frequencies. The resulting set of non-orthogonal modes is depicted in Figures 5a to 5d. As can be seen from the figures, for each mode in this set, the electric field distribution is concentrated in a different pair of two adjacent leg portions 8 and the inner branch 6 connecting the respective two leg portions 8. Thus, in the ideal case in which the electric field does not penetrate into other portions of the resonator element 4, the non-orthogonal modes are decoupled with respect to the inner branches 6, but are coupled adjacently in pairs by the leg portions 8.

[0070] For the case depicted in Figure 5, a preferred coupling and tuning arrangement for the dielectric multimode resonator 1 can be provided. Figure 6 schematically shows a top view, side view and bottom view (from top to bottom) of a dielectric quadruple mode resonator 1 including an input and output coupling means 9 and a plurality of tuning screws 10 and 11.

[0071] The input and output coupling means 9 comprises an input connector 12, an output connector 13 and a conductive coupling plate 14 electrically connected to the input connector 12 and the output connector 13. The plate 14 comprises a input portion 14a and an output portion 14b. The plate 14 is arranged such that the input portion 14a is located beneath only one of the inner branches 6 of the center portion, so that it essentially can only excite this inner branch 6, and that the output portion 14b is located only beneath one of the adjacent inner branches 6, so that it essentially can only interact with this inner branch 6. Further, the electrical connections between the input connector 12 and the plate 14 and between the output connector 13 and the plate 14 are arranged and constructed such that coupling to additional portions of the resonator element 4 is avoided. The two portions 14a, 14b of the plate 14 are separated by an intermediate lowered plate section or other electrical connection that substantially avoids coupling to the resonator element 4. Figure 7 shows a dielectric multimode resonator 1 identical to the resonator shown in Figure 6 with the exception that the input connector 12 and the output connector 13 are arranged beneath the plate 14 and the resonator element 4. an alternative arrangement of the connectors from the bottom side is shown.

[0072] In any case, the coupling plate 14 constitutes an inductive coupling. Preferably, it is adjustable - primarily in its width and distance to the dielectric resonator element - to render the coupling strength adjustable. Electromagnetic energy is only coupled to one of the four inner branches 6, and thus to only one of the non-orthogonal modes shown in Figures 5a to 5d. The electromagnetic energy is then coupled in series from one mode to the next via the overlapping fields at the leg portions 8 common to two adjacent modes until the output mode is reached. The node diagram for the resulting four pole band pass filter is shown in Figure 8. Nodes 0 and 5 represent the input and output, nodes 1 to 4 represent the individual modes or resonators, and the connecting lines represent the couplings. The overlapping of the fields generate couplings M12, M23, M34 and M14. Coupling M14 is depicted as a dashed line. As can be seen from Figure 8, a cascaded quadruplet and - with negative coupling sign - transmission zeros in the transfer function of the dielectric resonator are created. The couplings can be set by suitably choosing the dimensions (primarily the width, height and length) of the leg portions 8. It should be noted that the inner branches 6 have to be adjusted as well to keep the resonance frequencies constant. Since M14 should generally be smaller than the other coupling coefficients, the leg portion responsible for coupling M14 is constructed shorter than the other leg portions as shown in Figures 6 and 7.

[0073] The frequencies and couplings can be adjusted by means of frequency tuning screws 10 and coupling tuning screws 11 shown in Figures 6 and 7. The tuning screws extend through the wall portion over the resonator element 4 and can be moved further into or out of the resonator cavity. The screws 10 disposed over the inner branches 6 mainly decrease the frequency of the mode corresponding to the respective inner branch 6. The screws 11 disposed over the intersection of a leg portion and the center portion 5 mainly affect the corresponding coupling but also the frequencies of the involved modes.

[0074] By coupling two of the quadruple mode resonators 1 shown in Figure 8 in series, an eight pole band pass resonator can be realized. In Figure 9, the corresponding node diagram is shown. The output node 5 of Figure 8 is now in the center and acts as the input node of the second quadruple mode resonator 1. Node 5 could be interpreted with the "nonresonating node model" as introduced in S. Amari, U. Rosenberg, J. Bornemann, "Singlets, cascaded singlets, and the nonresonating node model for advanced modular design of elliptic filters", IEEE Microwave Wireless Comp. Letters, Volume 2, 14 May 2004, pages 237-239. For determining the coupling coefficients and resonance frequencies such a nonresonating node could be included into a standard design by the node insertion method as described in H. C. Bell, "Cascaded Singlets Realized by Node Insertions", IEEE MTT-Symposium, 2005. Furthermore the nonresonating node can also be suppressed as described in that publication. The resulting node diagram for the eight pole band pass resonator is shown in Figure 9.

[0075] In Figures 11 and 12, two embodiments of coupled dielectric resonators 1 are shown. In Figure 11 the coupling between the modes of node 4 and node 6 of Figure 10 is achieved by using two interconnected inductive coupling loops 15 with a coaxial line extending through an opening 16 in the wall separating the two dielectric resonators 1. The coupling loop arrangement 15 could be interpreted as the nonresonating node 5. In Figure 12, the coupling between the similar modes - which are represented by nodes 4 and 5 of Figure 10 - is achieved by interaction of their magnetic fields due to the presence of a coupling aperture 17 in the wall separating the two dielectric resonators 1.

[0076] In Figure 13, the node diagram of another implementation of a four pole band pass resonator using the resonator structure shown in Figures 1 to 5 is shown. This implementation is based on the arrangement of a "canonical transversal array" as introduced in R. J. Cameron, "Advanced coupling matrix synthesis techniques for microwave filters", IEEE Transactions on Microwave Theory and Techniques, Volume 51, No. 1, Jan. 2003, pages 1-10. Instead of coupling the modes or individual resonators one to each other as has been described with reference to Figures 6 to 12 to obtain the conventional series connection, the modes or individual resonators are coupled parallel to each other between the input connector 12 and the output connector 13 without couplings between the modes. As discussed in the publication, transmission zeros can be realized in the "canonical transversal array" just by suitable choice of the input/output coupling values and resonance frequencies of the modes, i.e. without making use of cross coupling. Generally the number of achievable transmission zeros is limited by the number of resonators. In the case of maximum transmission zeros at finite frequencies a direct coupling between input and output node is required and is shown in Figure 13.

[0077] Because the modes utilized for this coupling arrangement must not show cross coupling, the set of guided orthogonal modes shown in Figure 3 are used for the layout of the band pass resonator shown in Figure 13. The parallel coupling of all four modes requires an input coupling arrangement by means of which all four modes are excited simultaneously. A possible embodiment for such a dielectric resonator is depicted in Figure 14. Input and output coupling is effected by means of a coupling plate arrangement 14' which comprises an input portion 14a' electrically connected to the input connector 12 and an output portion 14b' electrically connected to the output connector 13. The input portion 14a' is located beneath all inner branches 6 and leg portions 8 of the half of the resonator element 4 closest to the input connector 12, and the output portion 14b' is located beneath all inner branches 6 and leg portions 8 of the half of the resonator element 4 closest to the output connector 13, i.e. the portions 14a' and 14b' of the coupling plate arrangement 14' essentially have the shape of one half of the resonator element 4. Thus, as required for parallel coupling, the portions 14a' and 14b' of the coupling plate arrangement 14' inductively interact with all four orthogonal modes of Figure 3.

[0078] The coupling effected by the input portion 14a' of the coupling plate arrangement 14' can be described by five coupling coefficients k1 to k5 corresponding to the coupling to the five branches 6 and 8 of the respective half of the resonator element 4. The coupling coefficients k1 to k5 and their correlation with the different sections of the resonator element 4 are shown in the lower part of Figure 14. Each coupling coefficient k1 to k5 can be adjusted by varying the shape and dimensions (primarily the width and length) of the respective portion of input portion 14a' of coupling plate arrangement 14' and its distance to the resonator element 4. In a linear model, the resulting overall coupling coefficients to the four orthogonal modes of the resonator can be expressed as follows:

$$
\begin{aligned}
k(TEz01\delta) &= k2 - k3 \\
k(TEz101) &= k1 + k2 - k3 - k4 \\
k(TEz011) &= k2 + k3 + k5 \\
k(TEz111) &= -k1 - k2 - k3 - k4 - k5.
\end{aligned}
$$

[0079] Therefore by a suitable choice of k1 to k5 the coupling to the orthogonal modes can be individually set to the required values.

[0080] In Figure 15 an alternative embodiment 14" of the coupling plate arrangement is shown, which has a simpler shape. The input portion 14a" and the output portion 14b " are straight. Each coupling coefficient for a particular mode is then a nonlinear function of the individual coupling coefficients, i.e. k(TEz*) = f(t_TEz*, k1, k2, k3, k4, k5).

[0081] As shown in Figure 14, the frequencies can be tuned by using nine tuning screws 10' at locations with different influences on the modes. In a simplified linear model, the resulting frequency change Δf of the modes is proportional to a linear combination of the penetration lengths t1 to t9 of the nine screws 10':

$$
\begin{aligned}
\Delta f(TEz01\delta) &\sim t1 + t2 + t3 + t4 + t9 \\
\Delta f(TEz101) &\sim t1 + t2 + t3 + t4 + t5 + t7 + t9 \\
\Delta f(TEz011) &\sim t1 + t2 + t3 + t4 + t6 + t8 + t9 \\
\Delta f(TEz111) &\sim t1 + t2 + t3 + t4 + t5 + t6 + t7 + t8
\end{aligned}
$$

[0082] Actually, each individual screw 10' has a slightly different influence on each mode. Especially screw No. 9 will have a stronger influence on mode TEz01δ and a weak influence on mode TEz111. More precisely, each frequency shift shows a more general nonlinear functional relationship with the individual screw penetration lengths, i.e. Δf(TEz*) = f(TEz*, t1, t2, t3, t4, t5, t6, t7, t8).

[0083] By connecting two of the dielectric resonators shown in Figures 13 to 15 in series, an eight pole resonator with the node diagram shown in Figure 16 can be constructed. This topology can be interpreted as a "cascaded transversal array". The non-resonating node 5 can again be suppressed to result in a node diagram as shown in Figure 17. It should be noted that the direct input/output coupling was neglected. Therefore, only six finite transmission zeros can be achieved instead of the maximum number of eight. However, usually even six finite transmission zeros are more than required for current applications.

[0084] In Figure 18, an embodiment of two quadruple mode resonators 1 shown in Figures 13 to 15 coupled in series is schematically shown in side view. Similar to the case shown in Figure 11, the coupling between the dielectric resonators 1 is achieved by using two interconnected inductive coupling loops 15' with a coaxial line extending through an opening 16' in the wall separating the two dielectric resonators 1. As shown in Figure 19, the two dielectric resonators 1 may also be disposed on top of each other. Furthermore, a coupling aperture 17' instead of wire coupling may be utilized for coupling of the dielectric resonators 1 (see Figure 20).

[0085] Figure 21 shows a dielectric multimode resonator 1' in which the inner branches 6' are not straight but curved, so that the center portion 5' of resonator element 4' has a circular outer circumference. The opening 7' defined by the annularly closed center portion 5' is star-shaped. Further, the width and thickness of the branches are different as compared to Figure 1.

[0086] Figure 22 shows dielectric multimode resonators 1'' and 1''' having differently shaped enclosures. It has to be noted that their shape has influence on the frequency of the eigenmodes.

[0087] The dielectric multimode resonator may also be realized by producing the resonator element 4 together with a dielectric shielding enclosure 18 integrally in one piece from a single block (see Figure 23).

[0088] Figures 24a and 24b show a cross sectional side view and top view, respectively, of a dielectric multimode resonator with a resonator element 4" which is modified as compared to the resonator element 4 shown in the previous figures. The resonator element 4" has a center portion 5 identical to the center portion of the resonator element 4 of the previous embodiments, but differs in that the leg portions 8" are shorter than the leg portions 8 so that their terminal ends are spaced from the four side walls of the enclosure. The resonator element 4'' can be supported in the resonator cavity by means of suitable prior art techniques, such as e.g. the support structure used for dielectric pucks. Due to the gap between the leg portions 8'' and the walls, the TEz101, TEz011, TEz111 are shifted to higher frequencies as compared to leg portions in electrical contact with the walls. It is also possible that some of the leg portions of a resonator element are constructed like the leg portions 8 of the previous embodiments, and only some of the leg portions are shorter and are constructed like the leg portions 8" shown in Figures 24a and 24b. Thus, it is also possible to provide such a resonator element with four leg portions, two of which, spaced 180° apart, are shorter so that they do not contact the walls. This structure can be suitable to support dual mode operation with TEz01δ, TEz011 as fundamental orthogonal modes, since the modes TEz101 and TEz111 are shifted to higher frequencies.

[0089] Instead of a planar arrangement of the resonator element 4, 4', 4'', the leg portions may also be angled with respect to a planar center portion. In Figures 25a to 25c, two side views and a top view of a dielectric multimode resonator comprising such a resonator element is shown. The resonator element comprises a center portion 5 identical to the previous center portions. However, one pair of opposing leg portions 8a is at an angle of 90° relative to the plane of the center portion 5, and the leg portions 8a extend toward the bottom wall 20a and are in contact with the bottom wall 20a. The other pair of opposing leg portions 8b is at an angle of 90° relative to the plane of the center portion 5, and the leg portions 8b extend toward the top wall 20b and are in contact with the top wall 20b. Depending on the application, other angles could also hold advantages. In any case, such a design of the resonator element has advantages with regard to mechanical stress, in particular if a flexible top wall and/or bottom wall is provided. It is also possible to provide a resonator element in which all four leg portions extend in the same direction, i.e. having four leg portions 8a at an angle of 90° relative to the plane of the center portion 5 and extending toward e.g. the bottom wall 20a into contact with the bottom wall 20a. This is shown in Figures 26a to 26c. This design holds similar advantages, in particular if a suitable flexible connection to the bottom wall is considered. It is to be noted that the resonator of Figures 25a to 25c has a TEz111 mode which tends to shift to lower frequencies, while the resonator of Figures 26a to 26c has a TEz111 mode which tends to shift to higher frequencies as compared to the planar arrangement when similar dimensions are considered.

[0090] In the previous figures, embodiments of the resonator element with four leg portions have been shown. However, it is possible to use any number of leg portions greater than three in order to achieve multimode operation in an advantageous manner. In Figures 27a to 27c, examples of resonator elements with three, five and eight leg portions 8 symmetrically arranged about a circular center portion 5 of the resonator element 4 are shown. As shown in Figures 28a to 28c for a resonator element with three leg portions 8, the circular center portions 5 of Figures 27a to 27c consist of a number of interconnected curved inner branches 6 equal to the number of leg portions 8. For the case of three leg portions spaced by 120° about a circular center portion, the symmetry already entails that two of the three guided orthogonal modes have identical frequencies. In addition, the resonator element supports the mode in which the electric field is guided in the center portion. With respect to Figure 27c, it should be noted that an arrangement of the leg portions 8 in which the leg portions 8 are alternatingly oriented to extend towards the top wall and the bottom wall, respectively, provides the advantage of shifting the resonance frequency of a mode similar to the mode depicted in Figure 31g, which mode has a high resonance frequency in the planar arrangement, to a lower value. In the mode shown in Figure 31g, the orientation of the electric field in the leg portions 8 with respect to the annularly closed portion 5 alternates from leg portion 8 to leg portion 9. Thus, by arranging the leg portions as in Figure 27c, the electric field is generally guided through the resonator element from the top to the bottom thereof (or vice versa). The same advantage may be achieved for resonator elements having other numbers of leg portions and by orienting leg portions 8 with different directions of extension of the electric field differently.

[0091] Figures 28a to 28c show the electric field distribution of the three fundamental orthogonal modes supported by this resonator element with three leg portions. In the resonance mode shown in Figure 28a, the electric field is only present in the upper two inner branches 6. These two inner branches, in one of which the electric field is extending clockwisely and in the other of which the electric field is extending counter-clockwisely, constitute a first contiguous section and a second contiguous sections, respectively, in the sense of the above definition. The two contiguous sections 6 are interconnected at their upper ends at a location 21 at which the upper leg portion 8 is connected to the center portion 5. In contrast to the case of four leg portions 8 described with reference to Figures 3a to 3d, the other ends of the two contiguous sections 6 are not interconnected, so that no or essentially no electric field is present in the lower inner branch 6. Rather, each of these two ends of the two contiguous sections 6 are connected to a respective leg portion 8, namely to the lower left leg portion 8 and the lower right leg portion 8, respectively. In these two leg portions 8, the electric field is oppositely directed relative to the center portion 5 as compared to the upper leg portion 8 associated with the interconnected ends of the two contiguous sections 6 (at location 21). Further, when completely circulating the center portion 5 in a particular direction, one encounters exactly two reversals of the circumferential direction of the electric field in the center portion 5. The same is true for the resonance mode shown in Figure 28b. However, in this resonance mode the electric field is present in the entire center portion with the upper two inner branches constituting a first contiguous section and the lower inner branch 6 constituting a second contiguous section in the sense of the above definition. In contrast to Figure 28a, the two contiguous sections are interconnected at both pairs of facing ends of the contiguous sections at two locations 21. At each of these two locations 21, a leg portion 8, namely the lower left and the lower right leg portion 8, guiding electric field is connected to the center portion. In the upper leg portion 8 no or essentially no electric field is present. These two resonance modes are second resonance modes within the meaning of the above definition, whereas the resonance mode shown in Figure 28c is the first resonance mode within the meaning of the above definition. In Figure 28a, the electric field is guided essentially from a lower region or the lower part of the resonator element 4 to a distinct upper region or its upper part as viewed in Figure 28a, and in Figure 28b, the electric field is guided essentially from a lower left region or the left part of the resonator element 4 to a distinct lower right region or its right part as viewed in Figure 28b. These two modes therefore resemble the field configuration of the pseudo TM110 modes described above for a cross shaped dielectric element.

[0092] Thus, triple mode operation is supported. For example, the circularly cylindrical enclosure or housing has a diameter of 50 mm and a height of 30 mm, the dielectric material of the resonator element has a relative permittivity of 42, and the annularly closed center portion has an outer diameter of 37.5 mm, an inner diameter of 17.5 mm and a thickness of 7.3 mm. The three leg portions also have a thickness of 7.3 mm, and the width of the leg portions is to be determined to achieve the desired triple mode operation. The parameters of the center portion are already chosen such that the TE mode guided by it has a central frequency of 2 GHz. In order to adjust the remaining two modes to this frequency, the width of the leg portions is varied in field simulations between e.g. 4 and 6 mm. In this way, it can be determined that a width of about 5 mm yields the desired result of all three modes having a central frequency of about 2 GHz. The "ring mode" is affected by the width variation to a minor degree only.

[0093] Further possibilities of a planar resonator element with three leg portions are shown in Figures 29a and 29b, in which the leg portions 8 are asymmetrically arranged about the center portion 5 of the resonator element 4, which center portions 5 consists of three inner branches 6 connected in series. Due to this asymmetry, the first two modes do not automatically have the same central frequencies, so that these frequencies also have to be adjusted with respect to each other by a suitable choice of e.g. the dimensions and shape of the individual branches.

[0094] Figures 30a to 30e schematically show the electric field distribution of the five fundamental orthogonal modes supported by a resonator element having five leg portions and a polygonal center portion with five inner branches and five vertices to which the leg portions are connected. The resonator element shows rotational and mirror symmetry. The expressions next to the inner branches and the leg portions indicate, in relative terms, the electric field strength in the respective inner branch or leg portion. In the expressions, "μ" and "v" are variables having values that depend on the particular geometry.

[0095] In Figure 30a, the electric field extends clockwisely in a contiguous section of the center portion consisting of the two inner branches on the left of the plane designated with H and counter-clockwisely in a contiguous section consisting of the two inner branches on the right of the plane designated with H. No or essentially no electric field is present in the lowermost inner branch. In this connection it should be noted that no electric field is only present in this inner branch in the case of complete symmetry. As soon as there is any deviation from symmetry, some electric field will also be guided in the lowermost inner branch. The two contiguous sections, which are contiguous sections within the meaning of the above definition, are interconnected at their upper ends at the location at which the uppermost leg portion is connected to the center portion. The opposite ends of the left and the right contiguous section are connected to the lower left leg portion and the lower right leg portion, respectively. In the two lowermost leg portions the electric field extends oppositely relative to the center portions as compared to the upper three leg portions. Thus, the electric field is essentially guided from a lower region of the resonator element to a distinct upper region.

[0096] In Figure 30d, the electric field extends clockwisely in a contiguous section of the center portion consisting of the upper left, the upper right and the lower right inner branch and counter clockwisely in a contiguous section consisting of the lower left and the lowermost inner branch. The two contiguous sections, which are contiguous sections within the meaning of the above definition, are interconnected at both pairs of facing ends at the locations at which the upper left and the lower right leg portion are connected to the center portion. In the two left leg portions the electric field is oppositely directed relative to the center portion as compared to the two right leg portions, wherein no or essentially no electric field is present in the uppermost leg portion (however, the above explanations with regard to a deviation from symmetry also apply in this case). Thus, the electric field is essentially guided from a left region of the resonator element to a distinct right region.

[0097] The two resonance modes depicted in Figures 30a and 30d are second resonance modes in the sense of the above definition.

[0098] In Figure 30c, the electric field is only dominant or concentrated in and guided by the center portion. This resonance mode is the first resonance mode in the sense of the above definition.

[0099] In the resonance modes depicted in Figures 30b and 30e the electric field is guided into the center portions via pairs of leg portions between which leg portions are located via which the electric field is guided out of the center portion. Therefore, there is no single region from which the electric field is guided to a single distinctly different region.

[0100] Figures 31a to 31h schematically show the electric field distribution of the eight fundamental orthogonal modes supported by a resonator element having eight leg portions and a polygonal center portion with eight inner branches and eight vertices to which the leg portions are connected. Again, the resonator element shows rotational and mirror symmetry and the expressions next to the inner branches and the leg portions indicate the electric field strength in the respective inner branch or leg portion.

[0101] In Figure 31a, the electric field extends clockwisely in a contiguous section of the center portion consisting of the four inner branches on the left of the plane designated with H and counter-clockwisely in a contiguous section consisting of the four inner branches on the right of the plane designated with H. The two contiguous sections, which are contiguous sections within the meaning of the above definition, are interconnected at both pairs of facing ends at the locations at which the uppermost and the lowermost leg portion are connected to the center portion. In the three leg portions beneath the plane designated with E the electric field is oppositely directed relative to the center portion as compared to the three leg portions above the plane designated with E. No or essentially no electric field is present in the two leg portions extending in the plane designated with E (however, the above explanations with regard to a deviation from symmetry also apply in this case). Thus, the electric field is essentially guided from a lower region of the resonator element to a distinct upper region.

[0102] In the resonance mode shown in Figure 31b, the electric field configuration is identical to the one of Figure 31a rotated clockwisely by 90°.

[0103] The two resonance modes depicted in Figures 31a and 31b are second resonance modes in the sense of the above definition.

[0104] In Figure 31h, the electric field is only dominant or concentrated in and guided by the center portion. This resonance mode is the first resonance mode in the sense of the above definition.

[0105] The resonance modes depicted in Figures 31c to 31g the electric field is guided into the center portions via pairs of leg portions between which leg portions are located via which the electric field is guided out of the center portion. Therefore, there is no single region from which the electric field is guided to a single distinctly different region.

[0106] Figures 32a and 32b show in a simplified branch model view resonator elements having two (Figure 32a) and three (Figure 32b) planar annularly closed portions 5 of the type shown in Figures 1 and 2 and which are interconnected at vertices to have a common center 22 and extend in planes perpendicular to each other. In Figure 32a the two planes intersect at a line connecting two opposite vertices of the annularly closed portions 5 and the common center 22, and in Figure 32b the three planes intersect at the common center 22. Each two annularly closed portions are interconnected at exactly two vertices and share exactly two common leg portions. These resonator elements can support sextuple mode operation and octuple mode operation, respectively. A further three dimensional resonator element, which is a three dimensional extension of a planar resonator element with three leg portions is shown in Figure 33. Each two annularly closed portions are interconnected such that they share exactly on common inner branch and the two leg portions between which this inner branch extends. Together, the three interconnected annularly closed portions have the shape of a tetrahedron. In general, in three dimensional constructs including a plurality of annularly closed portions, the annularly closed portions may be arranged outside the space enclosed by the annularly closed portions (such as in Figure 33), or they may be arranged to intersect each other at the common center.

Claims

1. Dielectric multimode resonator comprising

- walls (2) enclosing a resonator cavity (3), and
- a resonator element (4, 4', 4") made of dielectric material and disposed in the resonator cavity (3),

wherein the resonator element (4, 4', 4") comprises a plurality of at least three leg portions (8, 8", 8a, 8b) extending towards the walls (2),
characterized in that the resonator element (4, 4', 4'') further comprises an annularly closed portion (5, 5') circumscribing an opening (7) and disposed spaced from the walls (2), wherein the leg portions (8, 8' ' , 8a, 8b) form projections extending from the annularly closed portion (5, 5') from different locations spaced in the circumferential direction of the annularly closed portion (5, 5'), such that each two adjacent leg portions (8, 8'', 8a, 8b) are separated in the circumferential direction by a section of the annularly closed portion (5, 5').

2. Dielectric multimode resonator according to claim 1, wherein the leg portions (8, 8", 8a, 8b) and the annularly closed portion (5, 5') are arranged such that

- the resonator element (4, 4', 4'') supports a plurality of orthogonal resonance modes including
- a first resonance mode in which the electric field is only dominant in and guided in a closed loop by the annularly closed portion (5, 5') in the circumferential direction thereof, and
- at least one second resonance mode in which the electric field is only dominant in and guided by at least a part of the annularly closed portion (5, 5') in the circumferential direction thereof and at least two of the leg portions (8, 8", 8a, 8b) in such a manner that within the annularly closed portion (5, 5') the electric field is only dominant in a first contiguous circumferential section and a second contiguous circumferential section, wherein the circumferential direction of extension of the electric field in the first contiguous circumferential section is oppositely directed to the circumferential direction of extension of the electric field in the second contiguous circumferential section, and wherein each of the first and the second contiguous circumferential section terminates at both of its ends at a leg portion (8, 8'', 8a, 8b) in which electric field is guided, and
- the frequencies of the first resonance mode and the at least one second resonance mode are within the same pass band of the dielectric multimode resonator.

3. Dielectric multimode resonator according to claim 1 or claim 2, wherein the plurality of leg portions (8, 8", 8a, 8b) includes a pair of leg portions in which the electric field is guided in one of the at least one second resonance mode with the electric field being oppositely directed in the two leg portions relative to the annularly closed portion (5, 5'), and which are spaced apart by 180° with regard to the annularly closed portion (5, 5').

4. Dielectric multimode resonator according to any of the preceding claims, wherein the resonator element (4, 4', 4'') comprises exactly four leg portions.

5. Dielectric multimode resonator according to any of claim 1 to 3, wherein the resonator element (4, 4', 4'') comprises exactly three leg portions (8) or more than four leg portions (8, 8'', 8a, 8b).

6. Dielectric multimode resonator according to claim 2, wherein the resonator element (4) comprises three leg portions (8), such that the plurality of orthogonal resonance modes supported by the resonator element includes

- a second resonance mode in which the electric field is dominant in and guided by the three leg portions (8), wherein the first and the second contiguous section are interconnected at one of the three leg portions (8) in which leg portion (8) the electric field is oppositely directed relative to the annularly closed portion (5) as compared to the other two of the three leg portions (8), and
- a second resonance mode in which the electric field is only dominant in and guided by the entire annularly closed portion (5) and two of the three leg portions (8), wherein the electric field is guided into the annularly closed portion (5) via one of the two leg portions (8) and guided out of the annularly closed portion (5) via the other of the two leg portions (8),

wherein the leg portions (8) of the resonator element (4) and the annularly closed portion (5) are arranged such that the central frequencies of the two second resonance modes and of the first resonance mode are within the same pass band of the dielectric multimode resonator.

7. Dielectric multimode resonator according to claim 6, wherein the three leg portions (8) are spaced apart by 120° with regard to the annularly closed portion (5).

8. Dielectric multimode resonator according to claim 6 or claim 7, wherein the resonator element (4) comprises exactly three leg portions (8).

9. Dielectric multimode resonator according to claim 2 or claim 3, wherein the resonator element (4, 4', 4") comprises four leg portions (8, 8", 8a, 8b), such that the plurality of orthogonal resonance modes supported by the resonator element includes

- two second resonance modes in which the first and the second contiguous section are interconnected at both ends thereof at two non-adjacent of the four leg portions (8, 8'', 8a, 8b) with the electric field being oppositely directed in the respective two non-adjacent leg portions relative to the annularly closed portion (5, 5'), wherein in one of the two second resonance modes the electric field is only dominant in and guided by the annularly closed portion (5, 5') and two non-adjacent leg portions of the four leg portions (8, 8'', 8a, 8b), and in the other of the two second resonance modes the electric field is only dominant in and guided by the annularly closed portion (5, 5') and the other two non-adjacent leg portions of the four leg portions (8, 8'', 8a, 8b), and
- a third resonance mode in which the electric field is dominant in the annularly closed portion (5, 5') and the four leg portions (8, 8'', 8a, 8b), wherein in each pair of non-adjacent leg portions of the four leg portions (8, 8'', 8a, 8b) the electric field is identically directed relative to the annularly closed portion (5, 5'), and the electric field is oppositely directed relative to the annularly closed portion (5, 5') in the two pairs of non-adjacent leg portions of the four leg portions (8, 8", 8a, 8b),

wherein the material, the dimensions, the shape and the relative positions of the individual leg portions (8, 8'', 8a, 8b) and the annularly closed portion (5, 5') are chosen such that the central frequency of the third resonance mode is within the same pass band of the dielectric multimode resonator as the central frequencies of the first resonance mode and the two resonance modes of the at least one second resonance mode.

10. Dielectric multimode resonator according to claim 9, wherein the four leg portions (8, 8'', 8a, 8b) in which the electric field is dominant in the third resonance mode are spaced apart by 90° with regard to the annularly closed portion (5, 5').

11. Dielectric multimode resonator according to claim 10, wherein the resonator element (4, 4', 4'') comprises exactly four leg portions (8, 8'', 8a, 8b).

12. Dielectric multimode resonator according to any of the preceding claims, wherein the leg portions (8, 8'', 8a, 8b) and the annularly closed portion (5, 5') are arranged such that the resonance modes in the plurality of orthogonal resonance modes are degenerated, such that the resonator element (4, 4', 4") supports a set of non-orthogonal resonance modes, in each of which the electric field is dominant only in a different pair of adjacent leg portions and the respective interconnecting section of the annularly closed portion (5, 5'), wherein the number of non-orthogonal resonance modes in the set is equal to the number of leg portions (8, 8", 8a, 8b).

13. Dielectric multimode resonator according to claim 12, further comprising

- an input coupling means (12, 14a) for coupling electromagnetic energy into the resonator element (4, 4', 4''), wherein the input coupling means (12, 14a) is arranged to couple electromagnetic energy selectively and predominantly to a first section of the annularly closed portion (5, 5') interconnecting two adjacent leg portions (8, 8'', 8a, 8b), and/or
- an output coupling means (12, 14b) for coupling electromagnetic energy out of the resonator element (4, 4', 4''), wherein the output coupling means (12, 14b) is arranged to couple electromagnetic energy selectively and predominantly out of a second section of the annularly closed portion (5, 5') interconnecting two adjacent leg portions (8, 8", 8a, 8b), wherein the second section is adjacent the first section,

such that the non-orthogonal resonance modes are coupled in series.

14. Dielectric multimode resonator according to claim 13, wherein the leg portion (8, 8'', 8a, 8b) between the first and the second section of the annularly closed portion (5, 5') is shorter than the remaining leg portions (8, 8", 8a, 8b) .

15. Dielectric multimode resonator according to any of claims 1 to 12, further comprising

- an input coupling means (12, 14a', 14a'') for coupling electromagnetic energy into the resonator element (5, 5') in such a manner that each of the plurality of orthogonal resonance modes is excited, and/or
- an output coupling means (12, 14b', 14b'') for coupling electromagnetic energy out of the resonator element (5, 5') in such a manner that electromagnetic energy from each of the plurality of orthogonal resonance modes is received by the output coupling means (12, 14b', 14b"),

so that the orthogonal resonance modes are coupled in parallel between the input coupling means (12, 14a', 14a") and the output coupling means (12, 14b', 14b'').

16. Dielectric multimode resonator according to claim 15, further comprising a direct electromagnetic connection between the input coupling means (12, 14a', 14a") and the output coupling means (12, 14b', 14b'').

17. Dielectric multimode resonator according to any of claims 13 to 16, wherein the input coupling means (12, 14a, 14a', 14a'') and the output coupling means (12, 14b, 14b', 14b'') are inductive coupling means.

18. Dielectric multimode resonator according to claim 17, wherein the inductive input coupling means (12, 14a, 14a', 14a") and the inductive output coupling means (12, 14b, 14b', 14b'') comprise an electrically conductive rod, wire-shaped element or plate.

19. Dielectric multimode resonator according to claim 18, wherein at least one of the input coupling means (12, 14a, 14a', 14a'') and the output coupling means (12, 14b, 14b', 14b'') is arranged such that the distance between its wire or belt and the resonator element (4, 4', 4'') and/or its width is adjustable.

20. Dielectric multimode resonator according to any of the preceding claims, further comprising at least one frequency adjustment screw (10, 10') extending through a wall portion (2) into the resonator cavity (3) towards a region of the annularly closed portion (5, 5') in the middle between two leg portions (8, 8'', 8a, 8b), wherein the distance between the terminal ends of the tuning screws (10, 10') and the annularly closed portion (5, 5') can be adjusted, and/or at least one coupling adjustment screw (11) extending through a wall portion (2) into the resonator cavity (3) towards a region of the annularly closed portion (5, 5') in which a leg portion (8, 8", 8a, 8b) is connected to the annularly closed portion (5, 5'), wherein the distance between the terminal ends of the tuning screws (11) and the annularly closed portion (5, 5') can be adjusted.

21. Dielectric multimode resonator according to any of the preceding claims, wherein each leg portion (8, 8'', 8a, 8b) connects the annularly closed portion (5, 5') with a wall portion (2).

22. Dielectric multimode resonator according to any of claims 1 to 20, wherein for at least one of the leg portions (8, 8'', 8a, 8b) the end of the leg portion (8, 8'', 8a, 8b) opposite the end connected to the annularly closed portion (5, 5') is spaced from the walls (2) and/or wherein for at least one of the leg portions (8, 8", 8a, 8b) the end of the leg portion (8, 8", 8a, 8b) opposite the end connected to the annularly closed portion (5, 5') is connected to a wall portion (2) via a distance piece made of ceramic material with a dielectric constant lower than the dielectric constant of the dielectric material of the resonator element (4, 4', 4'').

23. Dielectric multimode resonator according to any of the preceding claims, wherein the resonator element (4, 4', 4'') is planar such that it extends entirely in a plane.

24. Dielectric multimode resonator according to any of the preceding claims, wherein the leg portions (8, 8'', 8a, 8b) are equally spaced in the circumferential direction of the annularly closed portion (5, 5').

25. Dielectric multimode resonator according to claim 24,
wherein the leg portions (8, 8", 8a, 8b) are symmetrically arranged around the annularly closed portion (5, 5').

26. Dielectric multimode resonator according to any of the preceding claims, wherein the annularly closed portion (5, 5') has the shape of a polygon with n sides and n vertices, wherein the resonator element (4, 4', 4'') comprises n or less leg portions (8, 8'', 8a, 8b), each of which extends from a different vertex of the polygon.

27. Dielectric multimode resonator according to claim 26, wherein the polygon is a regular polygon.

28. Dielectric multimode resonator according to any of claims 1 to 25, wherein the annularly closed portion (5') is circular or oval.

29. Dielectric multimode resonator according to any of claims 1 to 25, wherein one, more or all of the sections (6) of the annularly closed portion (5, 5') interconnecting adjacent leg portions (8, 8'', 8a, 8b) are curved.

30. Dielectric multimode resonator according to any of the preceding claims, wherein the leg portions (8, 8'', 8a, 8b) are straight or the leg portions are curved.

31. Dielectric multimode resonator according to any of the preceding claims, wherein at least one of the leg portions (8, 8", 8a, 8b) has a different length and/or diameter as compared to the other leg portions (8, 8", 8a, 8b).

32. Dielectric multimode resonator according to any of the preceding claims, wherein the walls (2) include two opposing end wall portions and a sidewall extending between and connecting the end wall portions and comprising a cylindrical wall portion or four rectangularly arranged wall portions, and wherein all leg portions (8, 8", 8a, 8b) are connected with the end opposite the end connected to the annularly closed portion (5, 5') to the same wall portion only.

33. Dielectric multimode resonator according to any of the preceding claims, wherein the walls (2) include a base wall, a sidewall extending upwardly from the base wall and an upper cover wall closing the resonator cavity (3), and wherein an inner conductor or a dielectric rod is electrically connected to the base wall and extends upwardly towards the upper cover wall through the opening of the annularly closed portion and is arranged such that the central frequency of the respective resonance mode is within the same pass band as the central frequencies of the plurality of orthogonal modes.

34. Dielectric multimode resonator according to any of claims 1 to 32, wherein the resonator cavity (3) is dimensioned such that in addition to the plurality of orthogonal modes supported by the resonator element (4, 4', 4") an air cavity resonance is supported in the resonator cavity (3), wherein the central frequency of the air cavity resonance is within the same pass band as the central frequencies of the plurality of orthogonal modes.

35. Dielectric multimode resonator according to any of the preceding claims, wherein the resonator element (4, 4', 4") comprises at least one further annularly closed portion (5, 5') spaced from the walls (2) and a plurality of leg portions (8, 8'', 8a, 8b) extending from different positions of the further at least one annularly closed portion (5, 5') towards the walls (2), wherein all annularly closed portions (5, 5') have the same shape and wherein the annularly closed portions (5, 5') are interconnected such that they define a common interior space.

36. Microwave filter comprising a plurality of coupled resonators including at least one of the dielectric multimode resonators according to any of claims 1 to 35, wherein the coupling to and/or from the at least one dielectric multimode resonator to the adjacent resonators is effected by means of coupling loops (15, 15') and/or coupling apertures (17, 17').

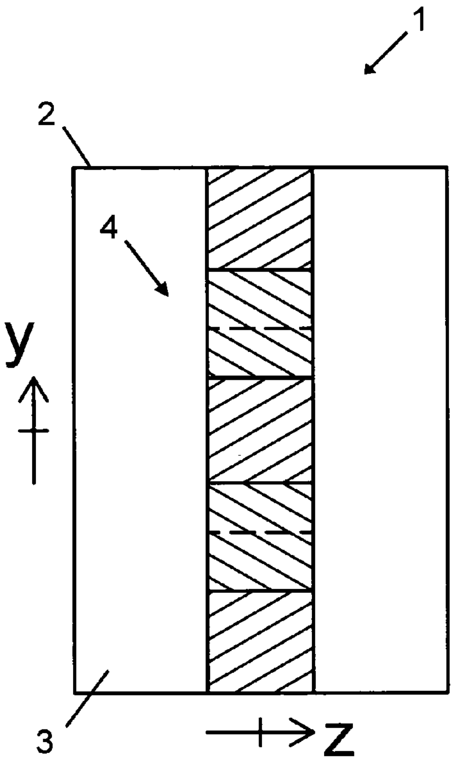


FIG. 1a

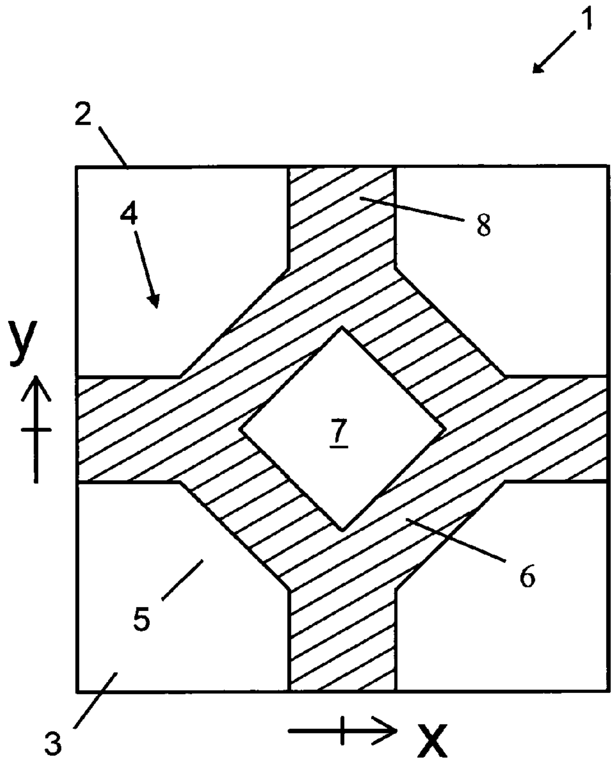


FIG. 1b

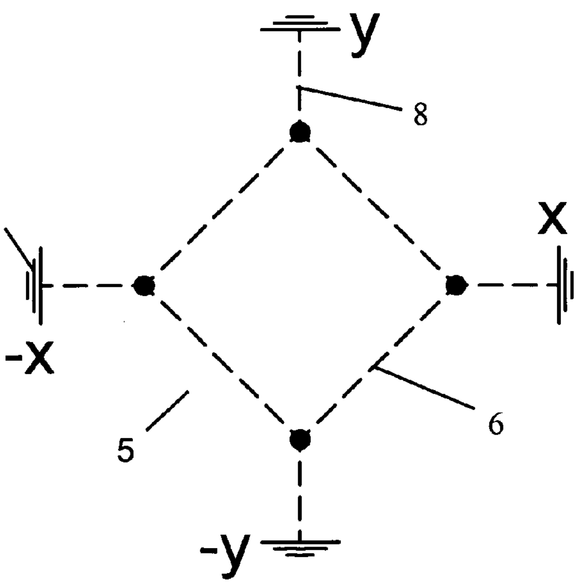


FIG. 2

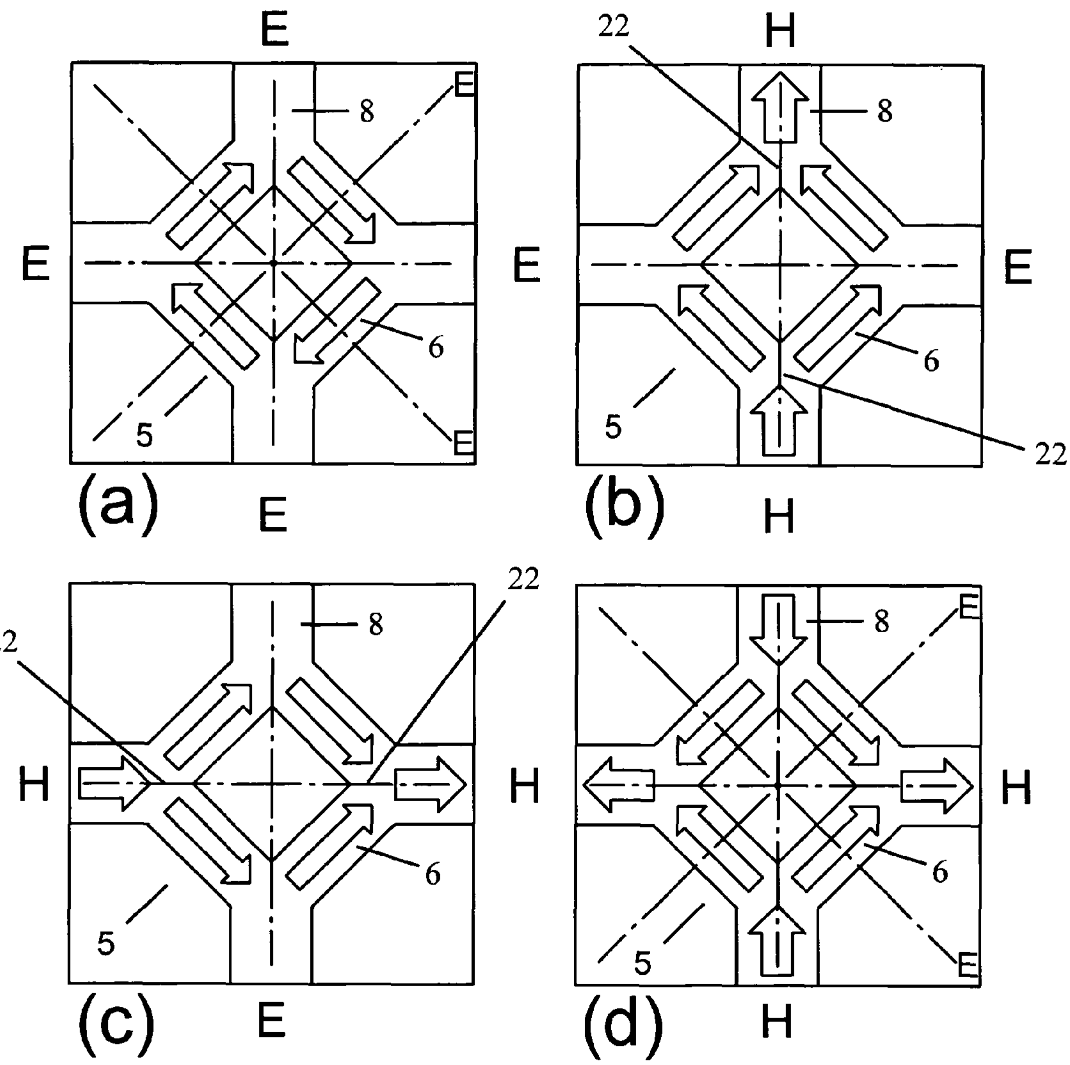


FIG. 3

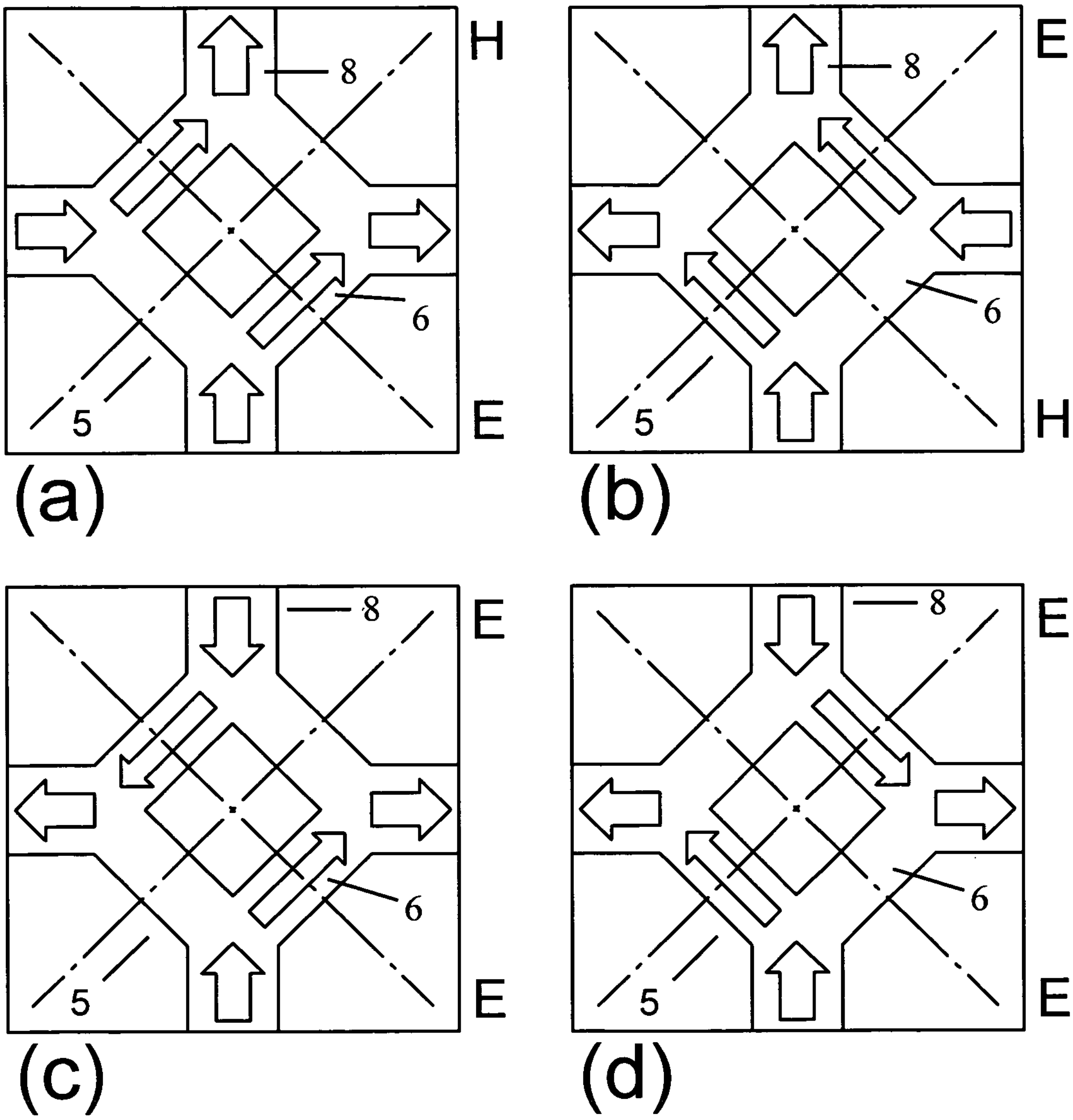


FIG. 4

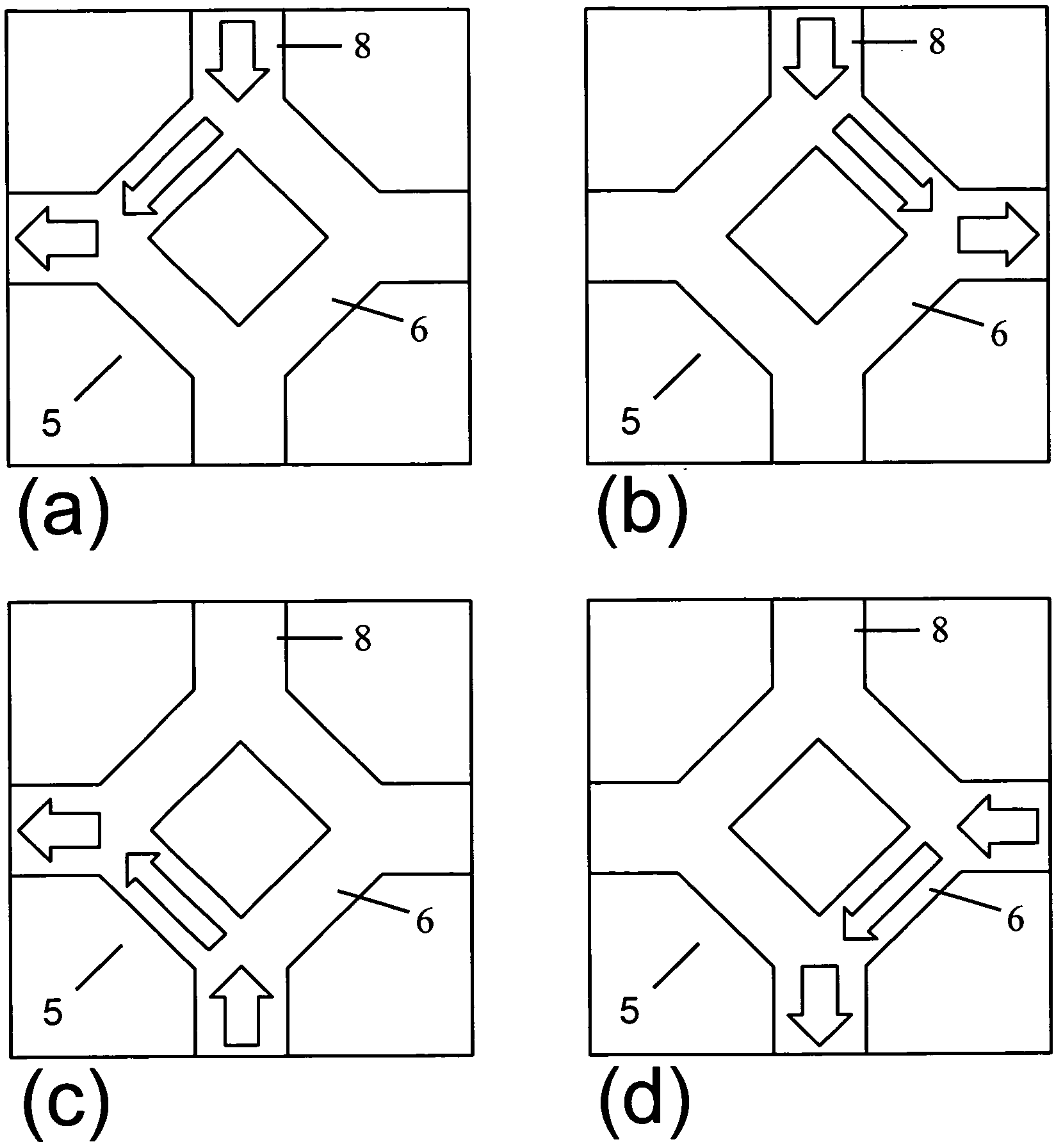


FIG. 5

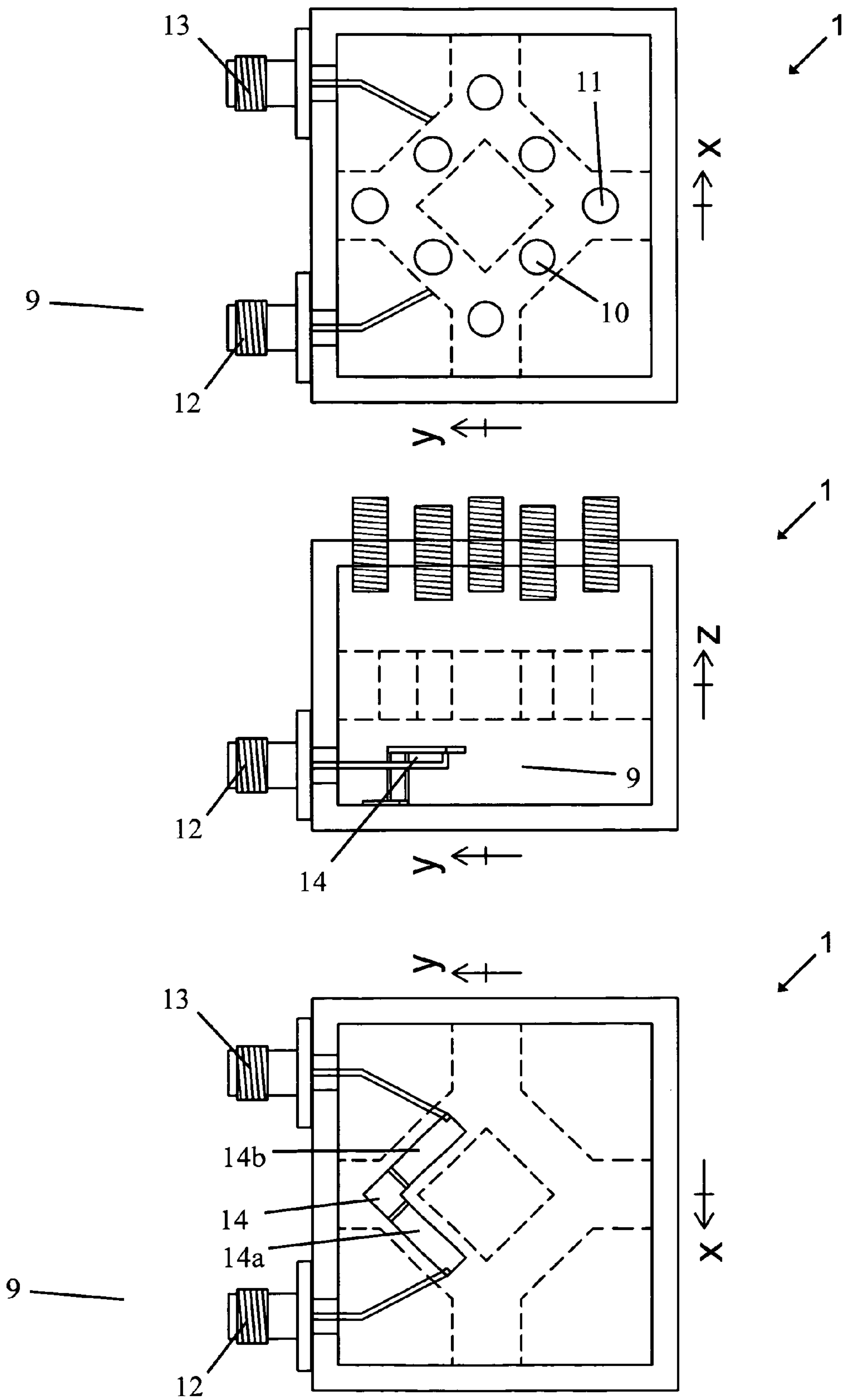


FIG. 6

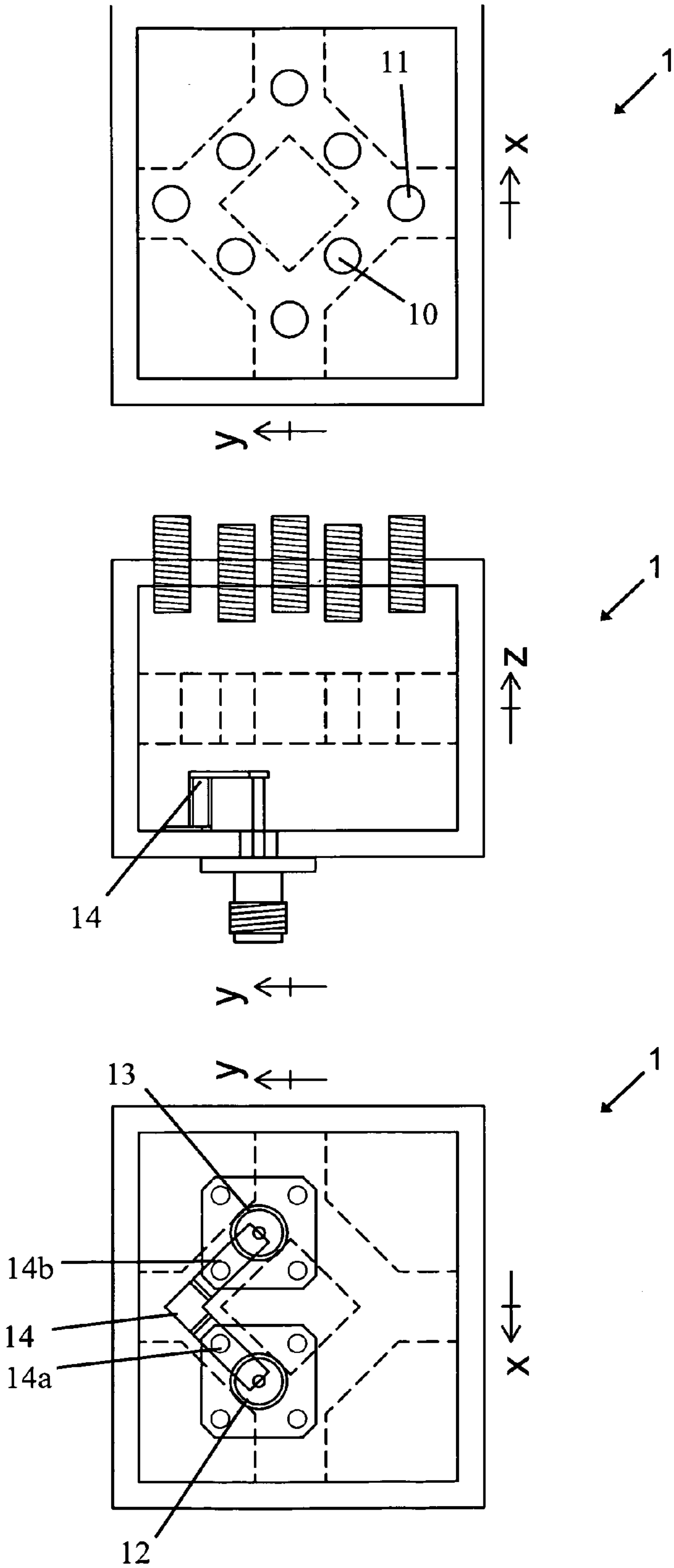


FIG. 7

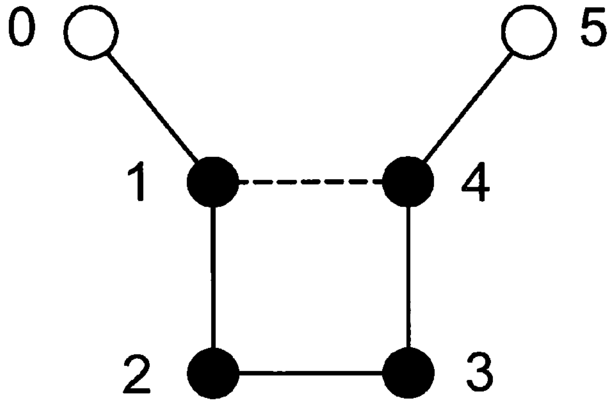


FIG. 8

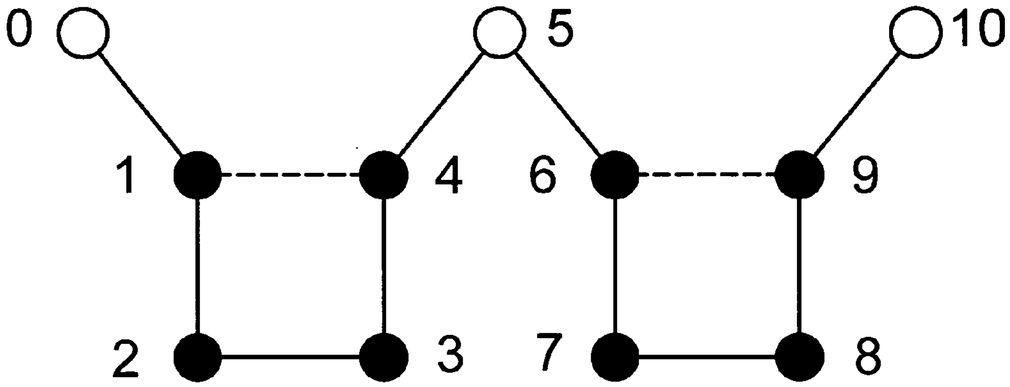


FIG. 9

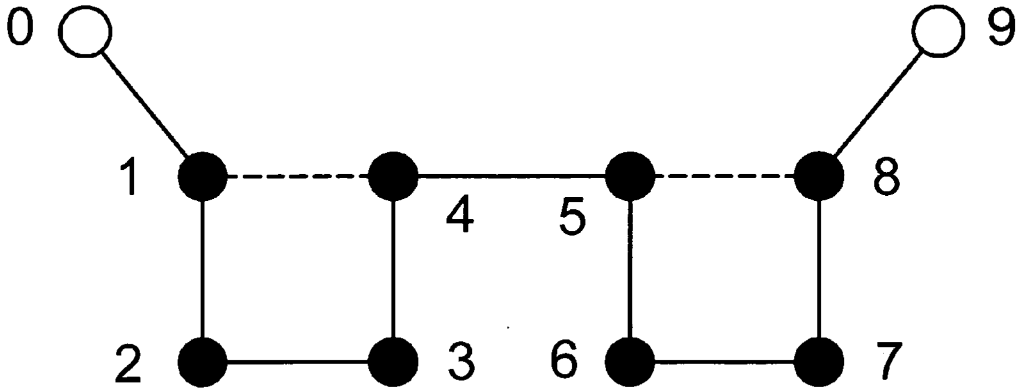
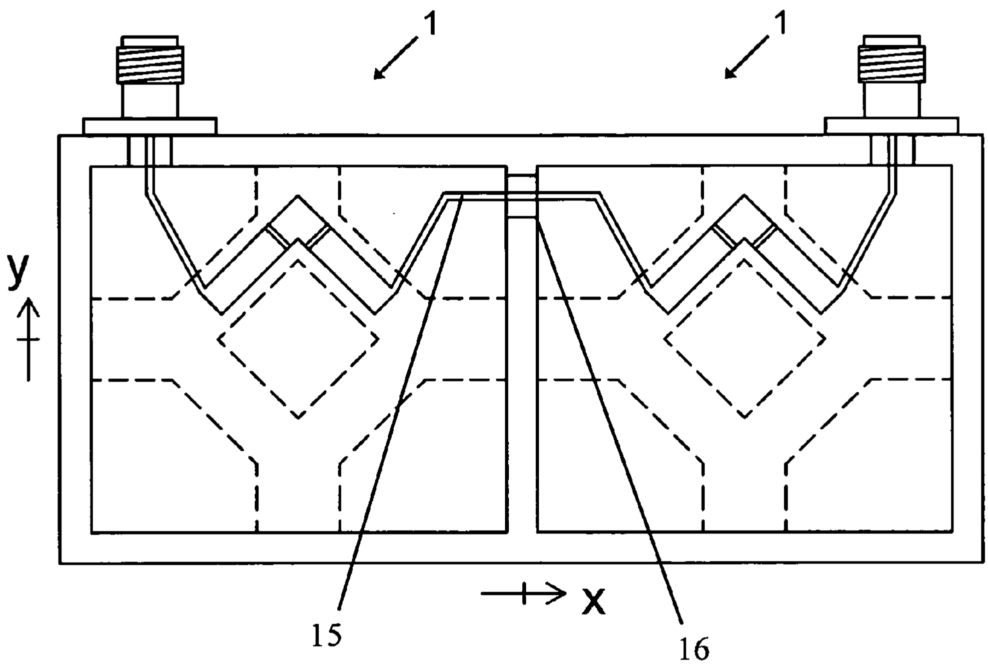


FIG. 10



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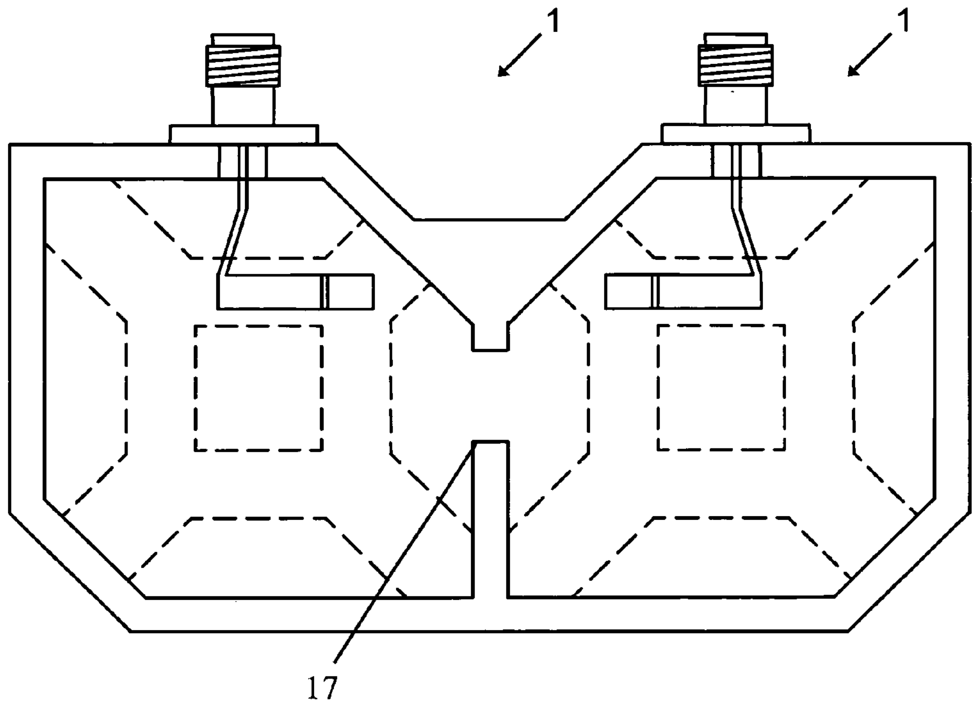

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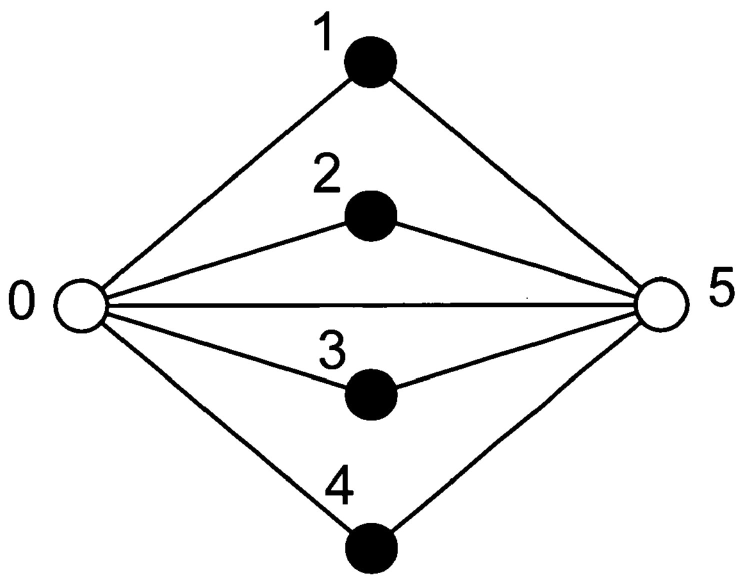

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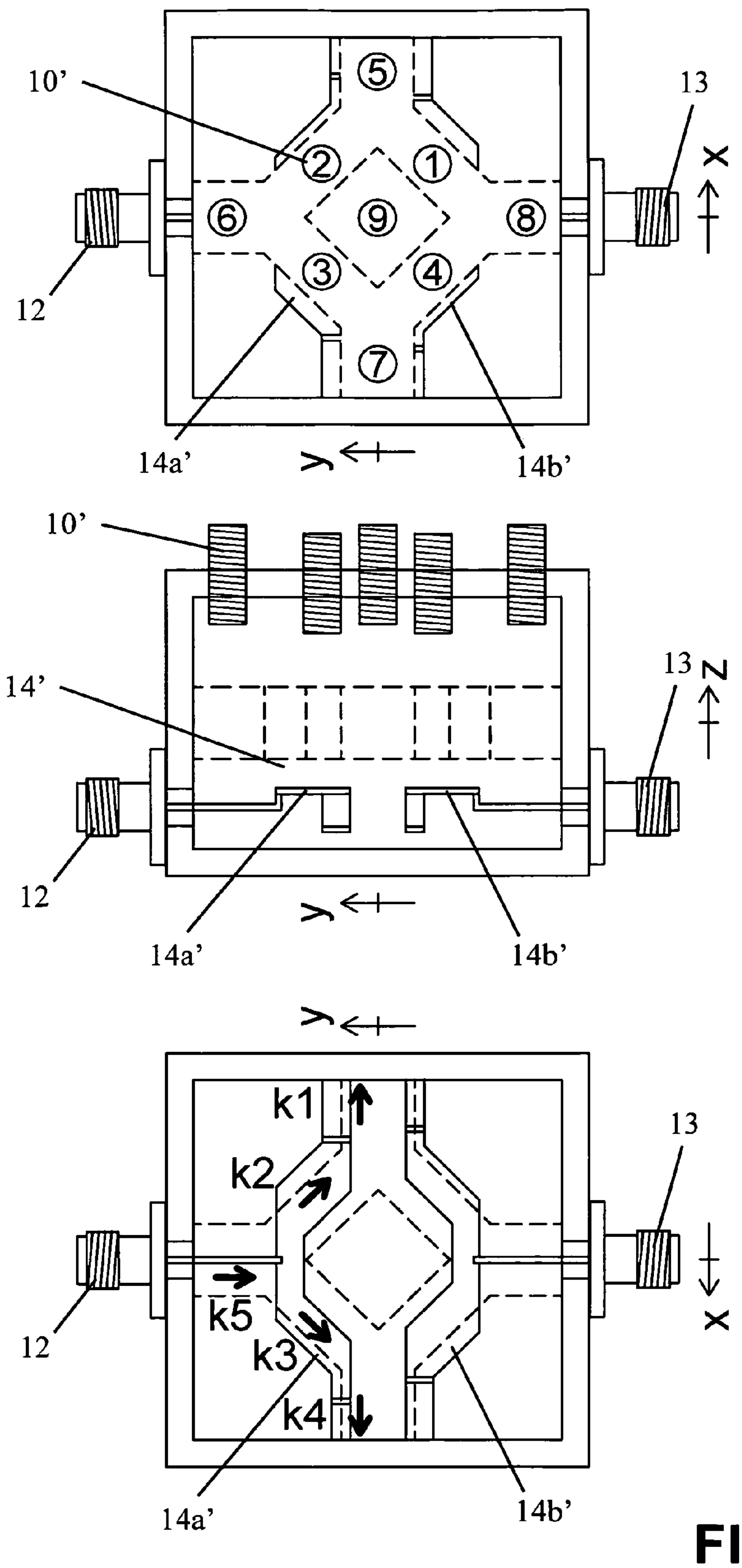

10'
13
x
⑤
②
①
⑥
⑨
⑧
③
④
⑦
12
14a'
y
14b'
10'
14'
13
z
12
y
14a'
14b'
y
k1
k2
13
k5
k3
k4
12
x
14a'
14b'

FIG. 14

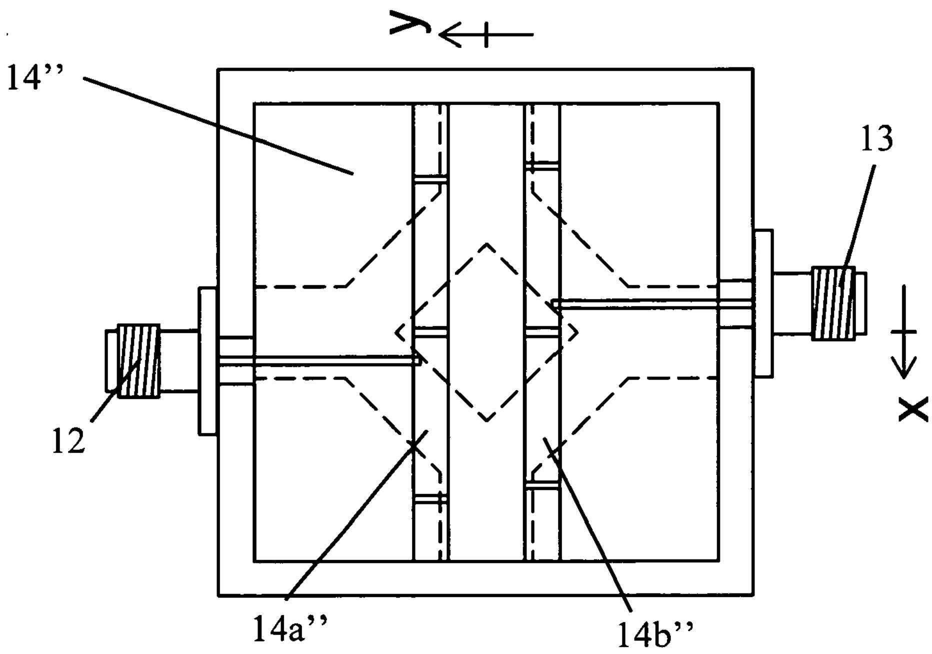
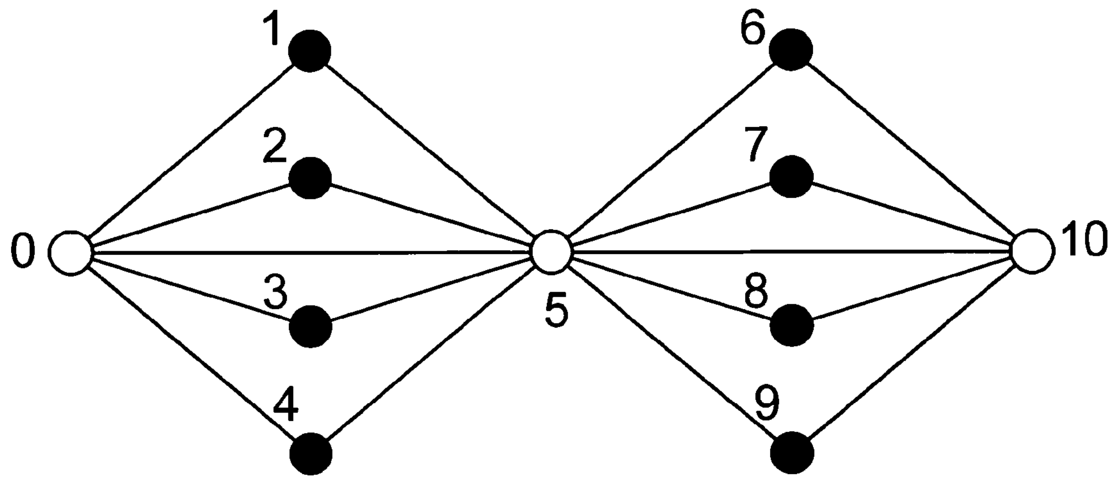


FIG. 15



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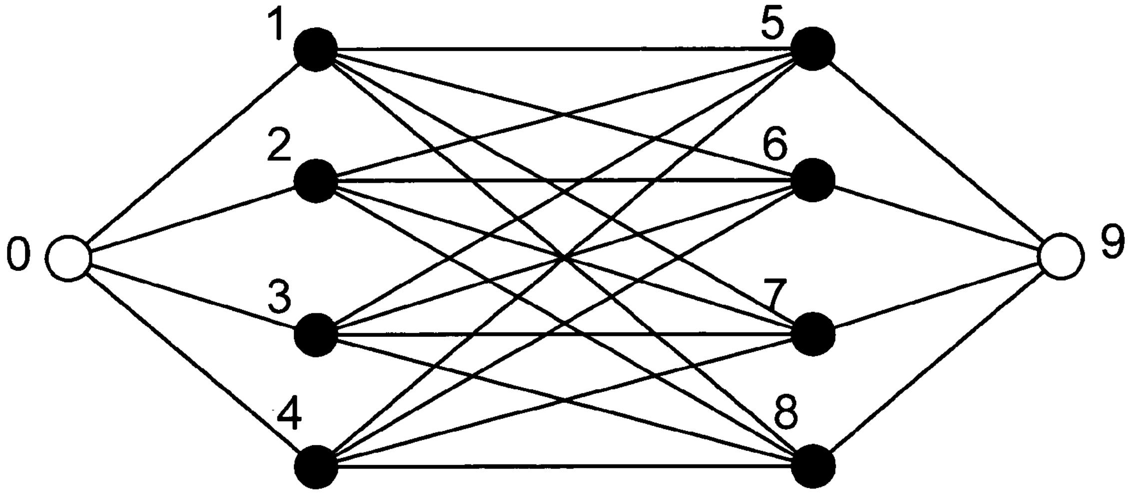


FIG. 17

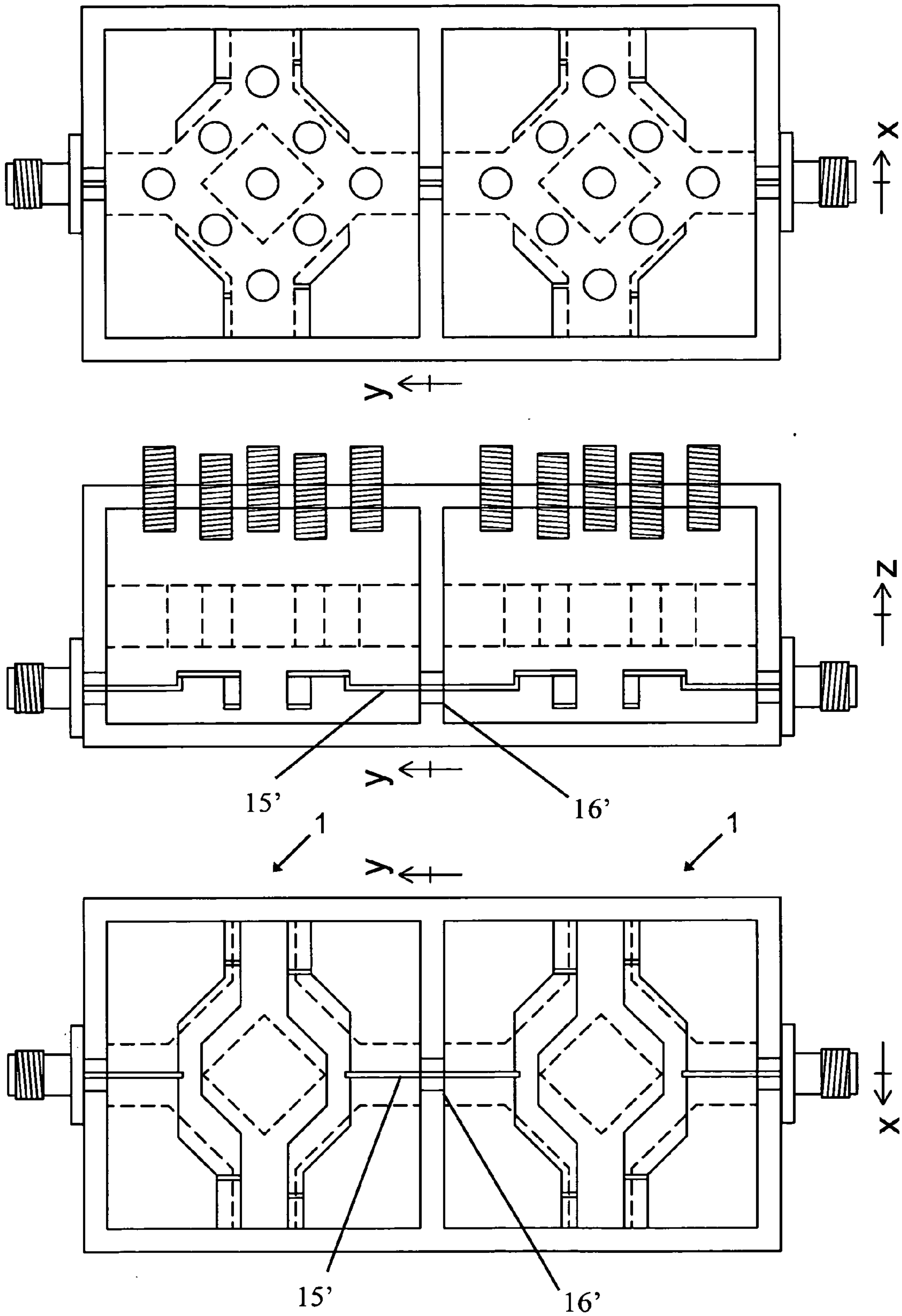


FIG. 18

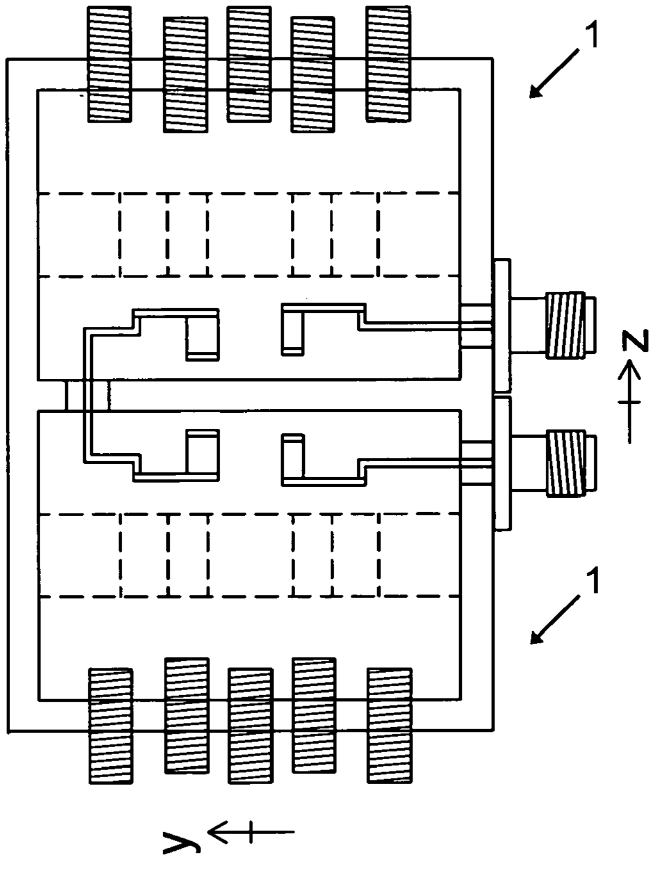


FIG. 19

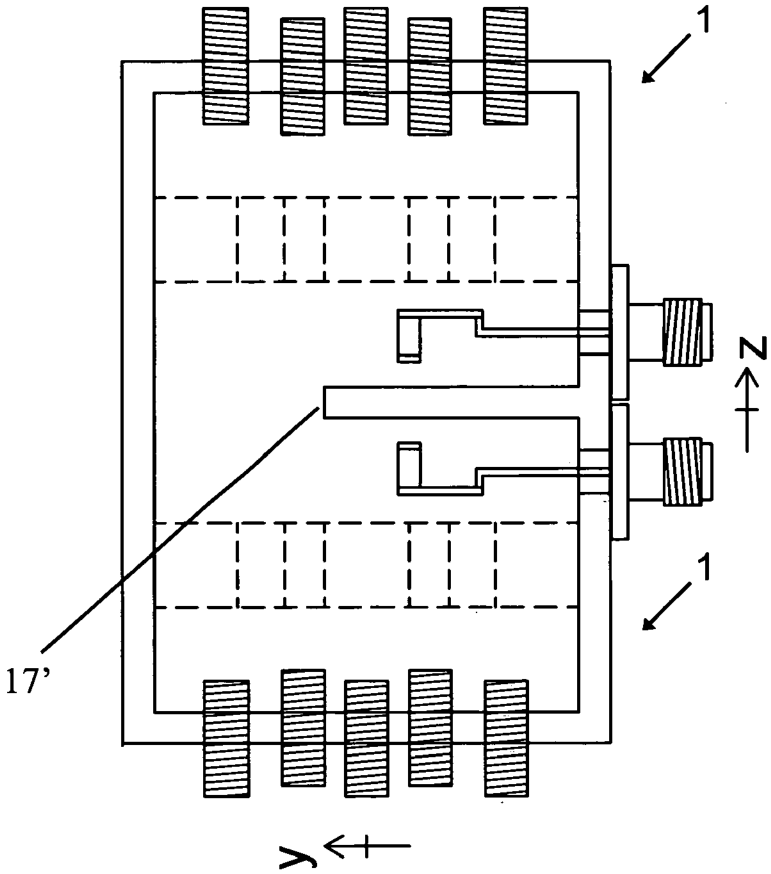


FIG. 20

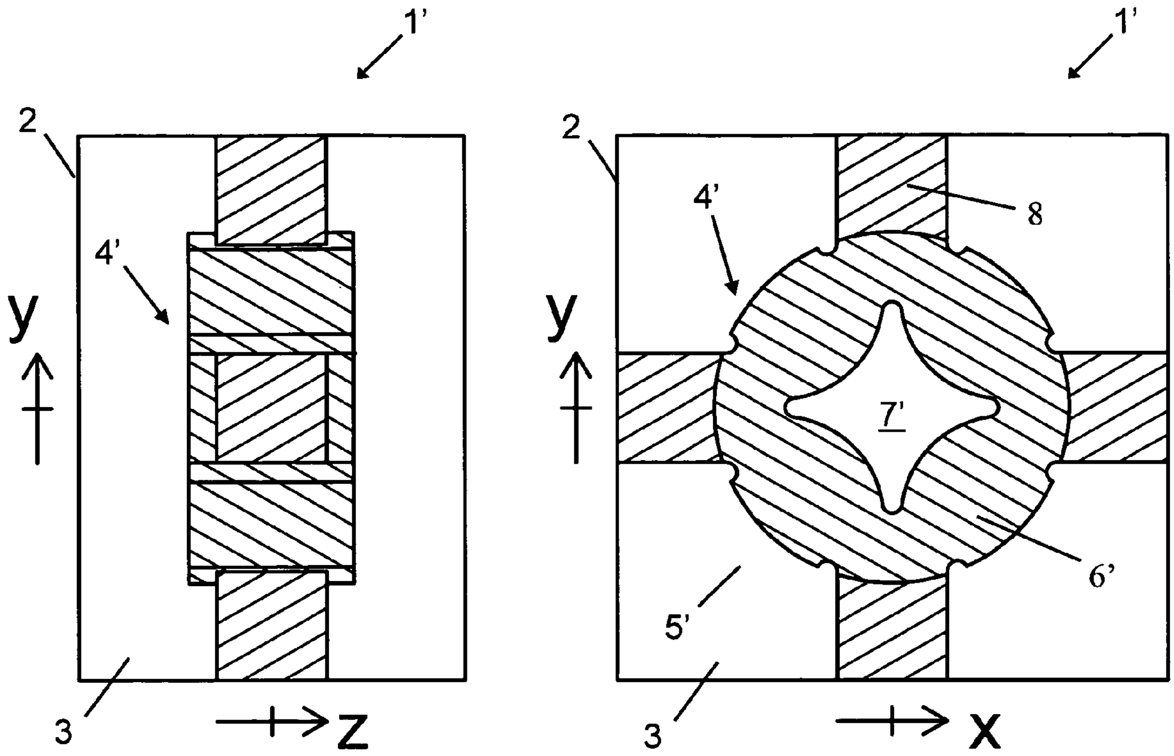


FIG. 21

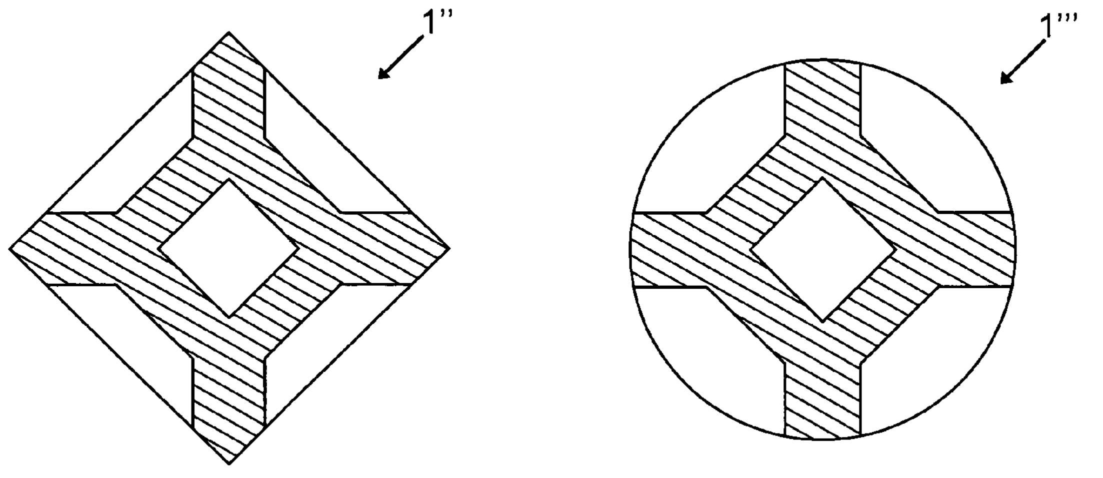


FIG. 22

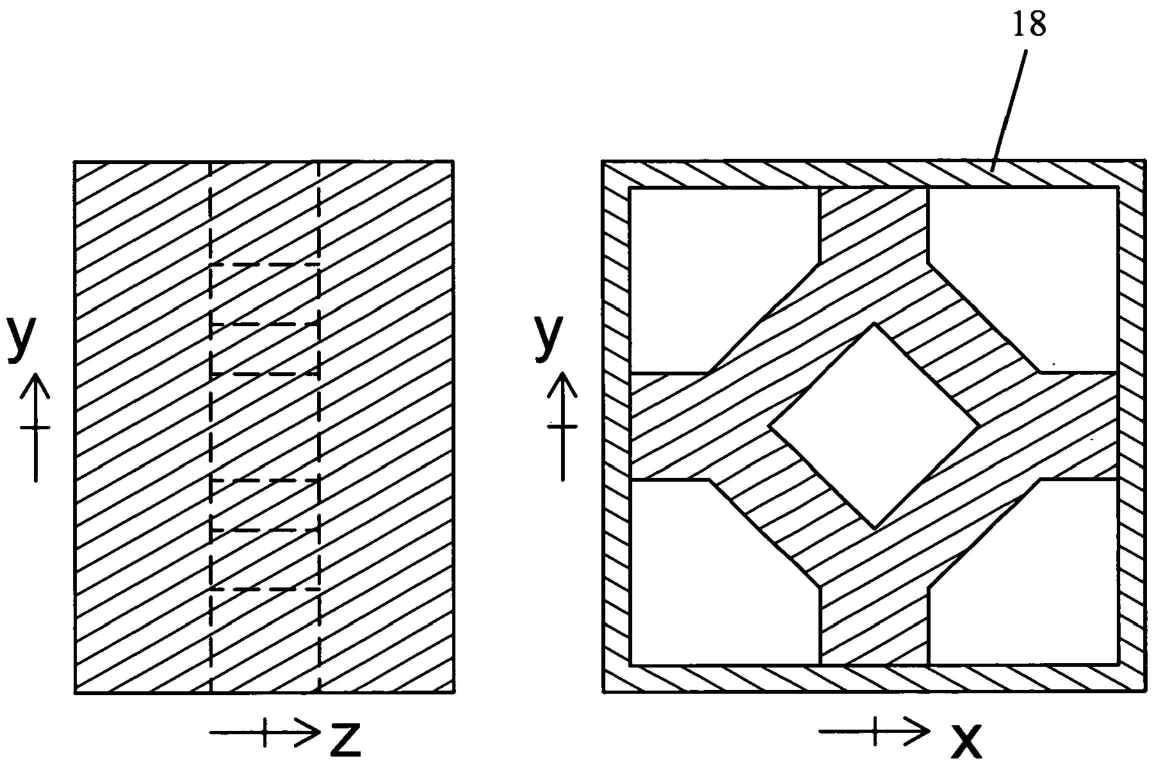


FIG. 23

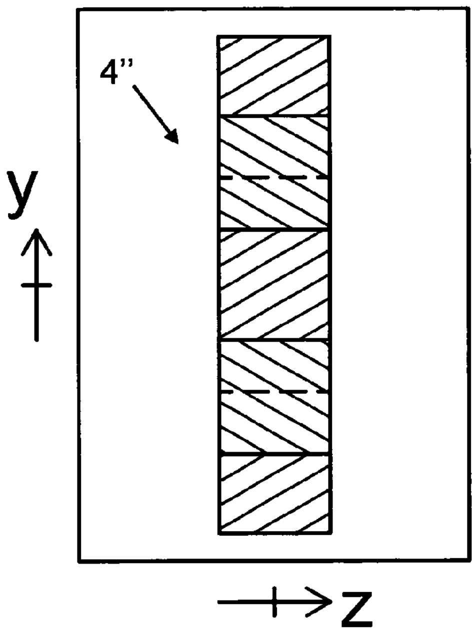


FIG. 24a

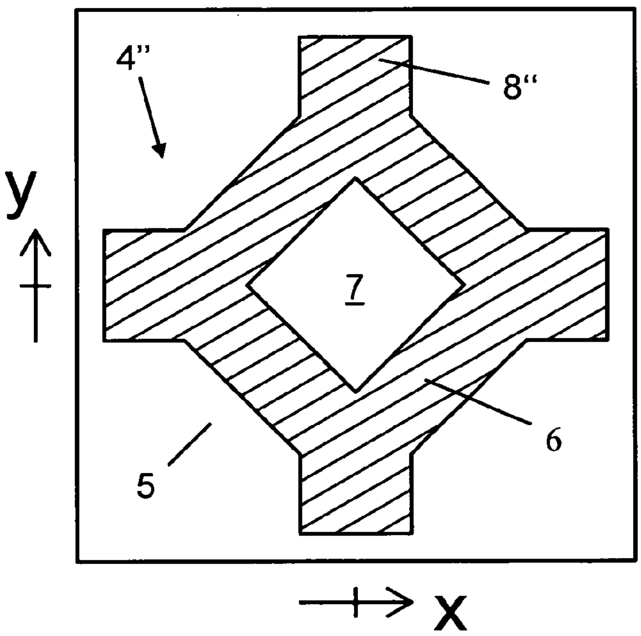


FIG. 24b

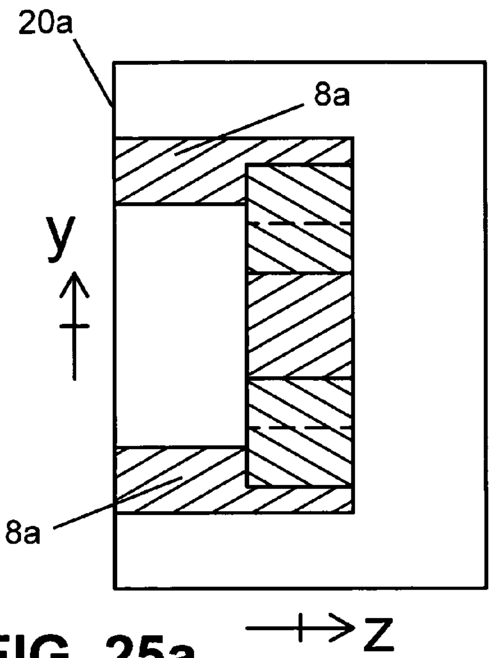


FIG. 25a

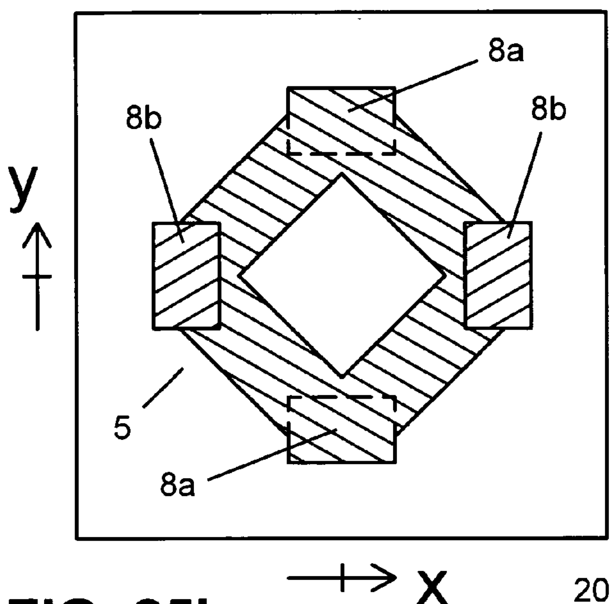


FIG. 25b

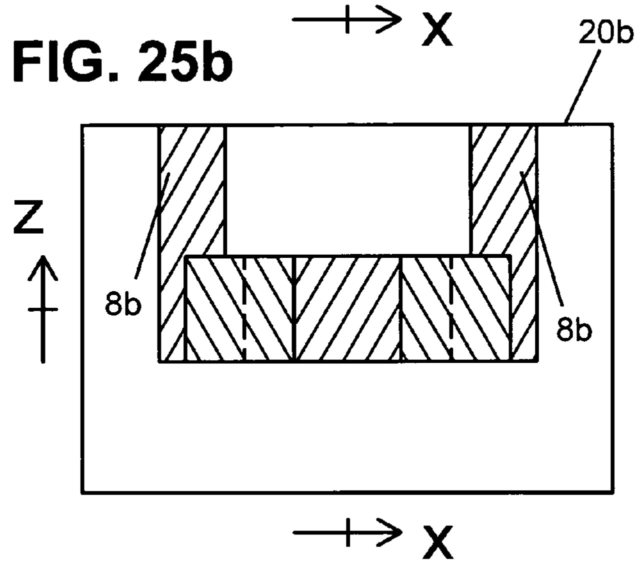


FIG. 25c

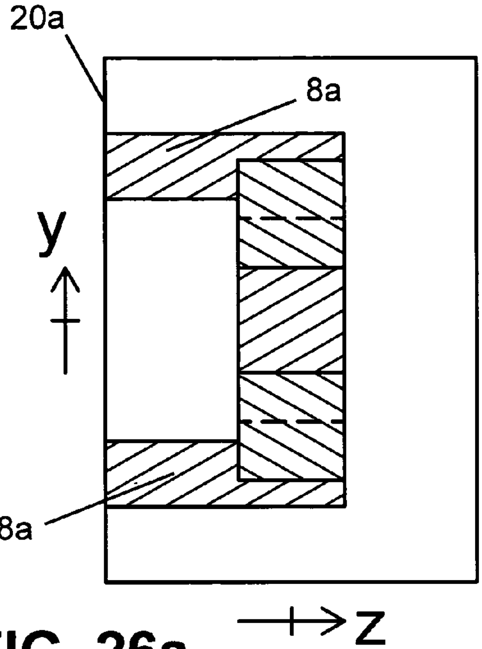


FIG. 26a

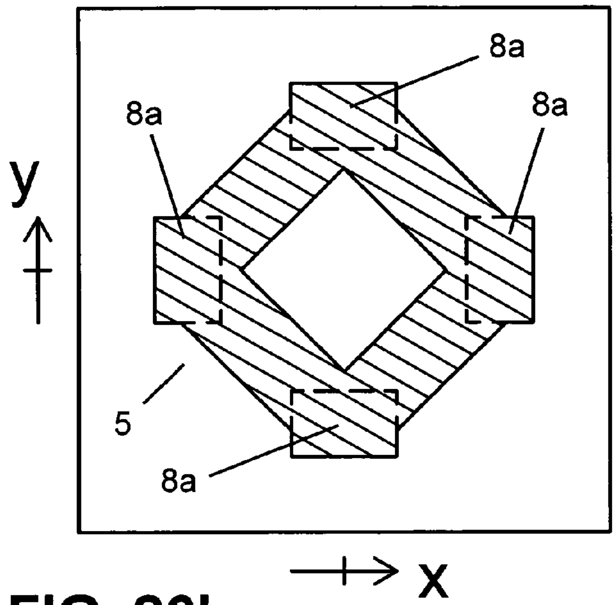


FIG. 26b

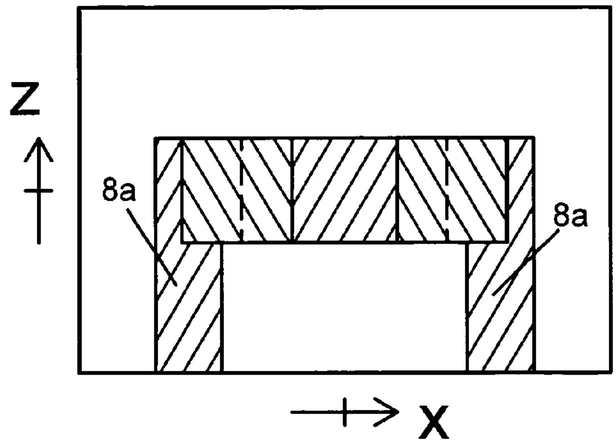


FIG. 26c

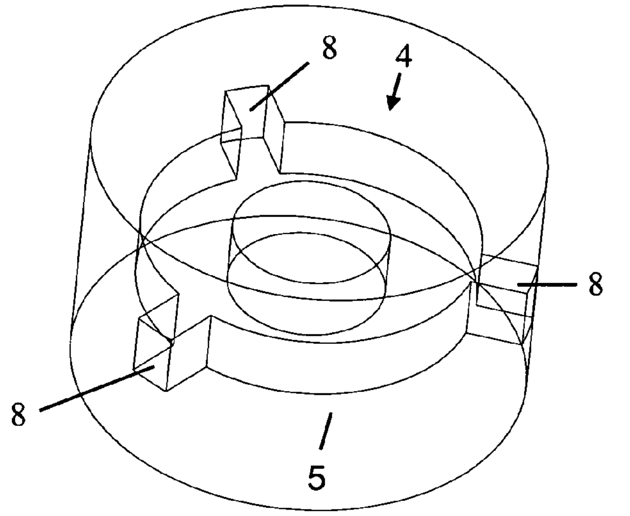


FIG. 27a

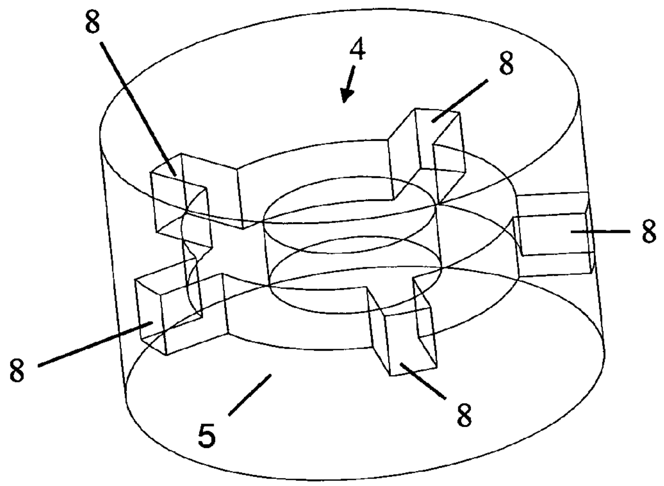


FIG. 27b

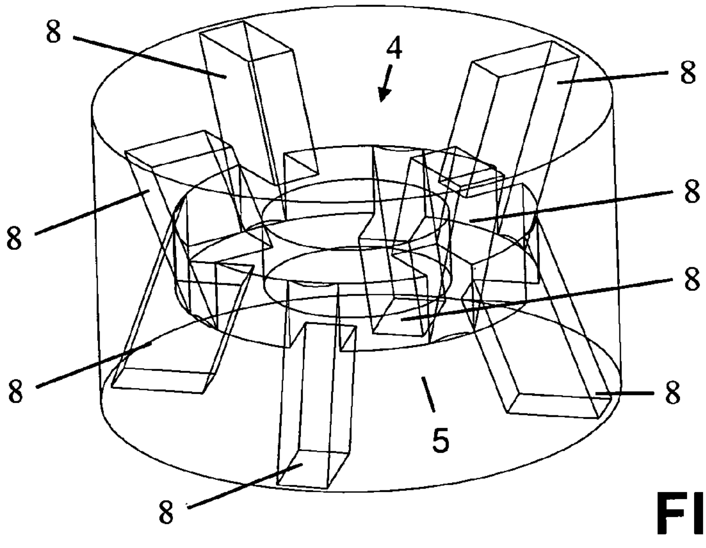
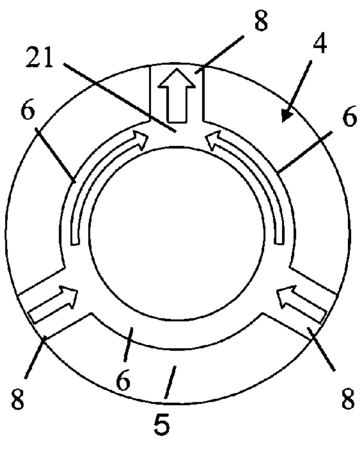
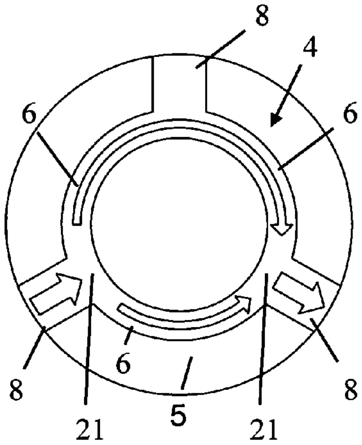


FIG. 27c





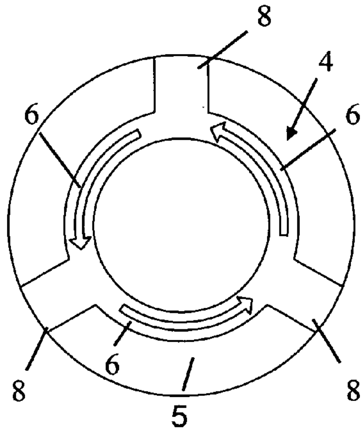
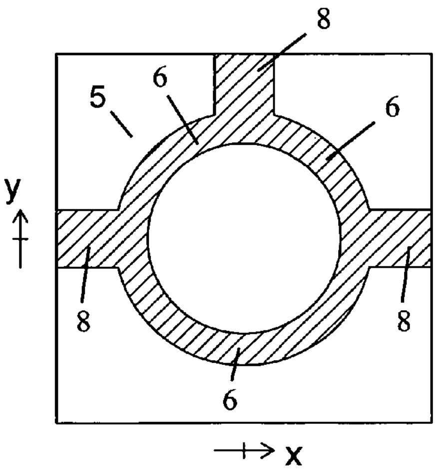


FIG. 28a

FIG. 28b

FIG. 28c



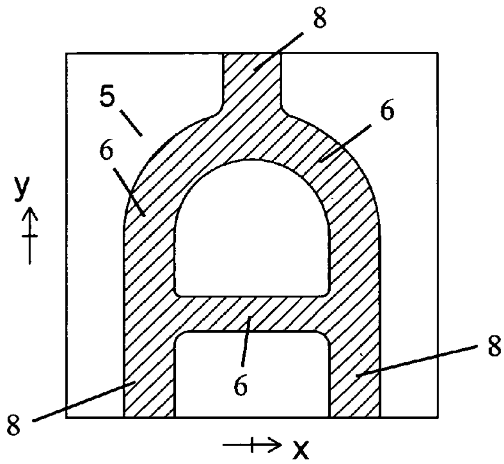


FIG. 29a

FIG. 29b

FIG. 30a

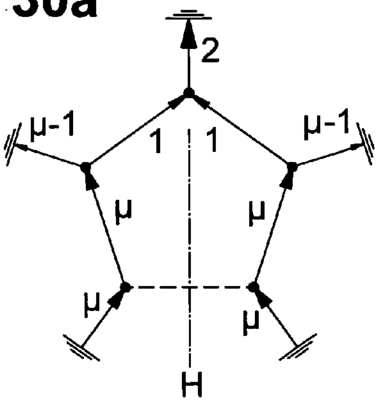
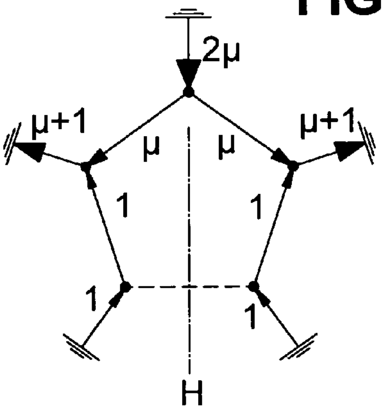


FIG. 30b



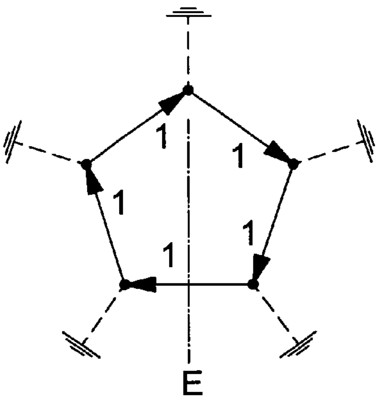


FIG. 30c

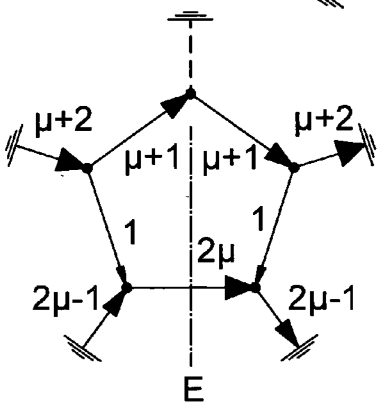


FIG. 30d

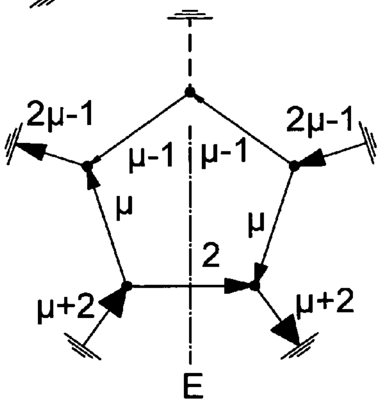


FIG. 30e

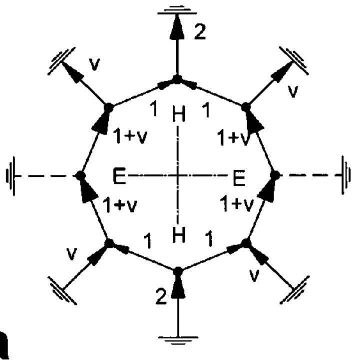


FIG. 31a

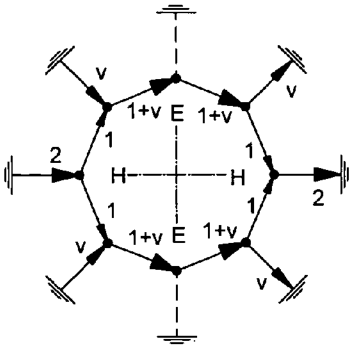


FIG. 31b

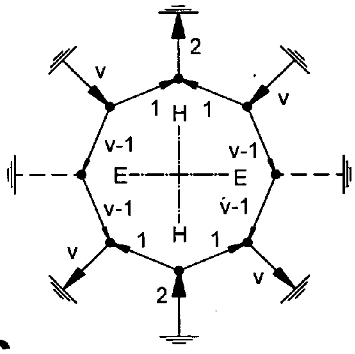


FIG. 31c

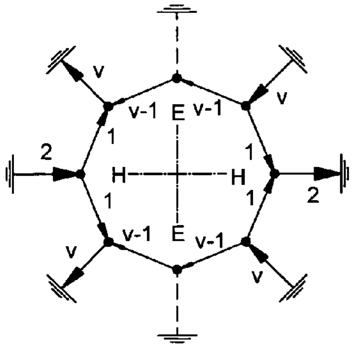


FIG. 31d

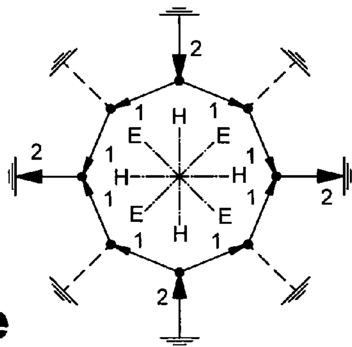


FIG. 31e

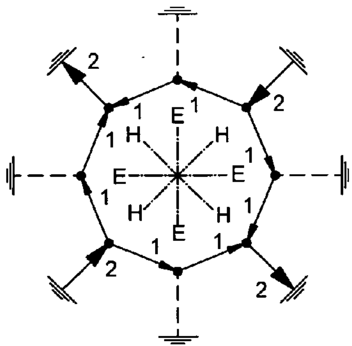


FIG. 31f

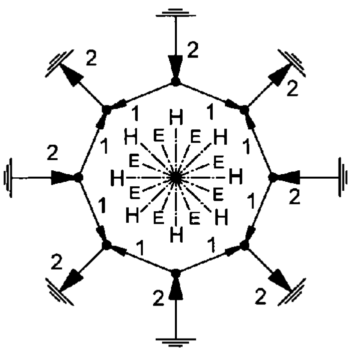


FIG. 31g

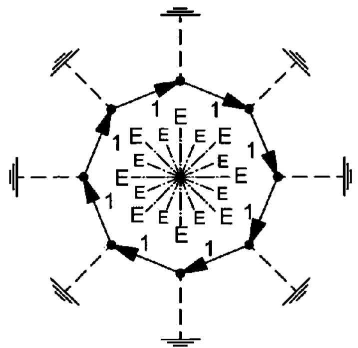


FIG. 31h

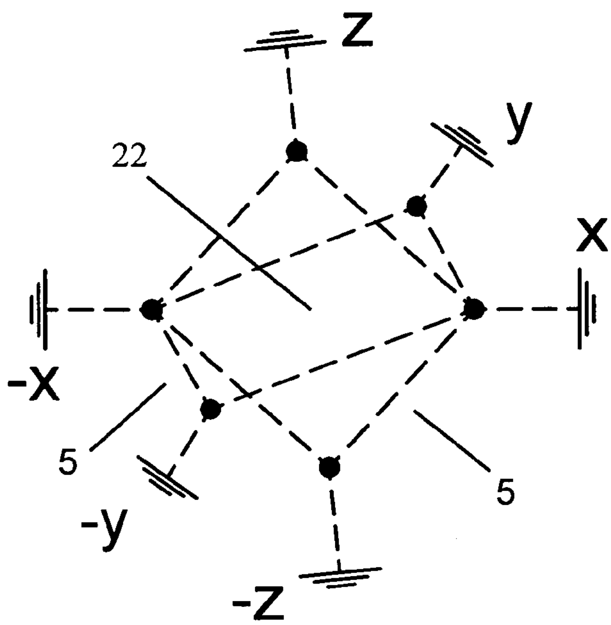


FIG. 32a

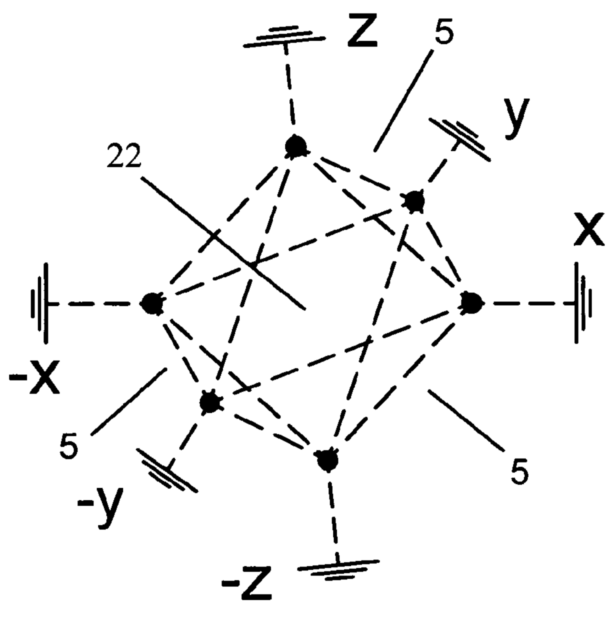


FIG. 32b

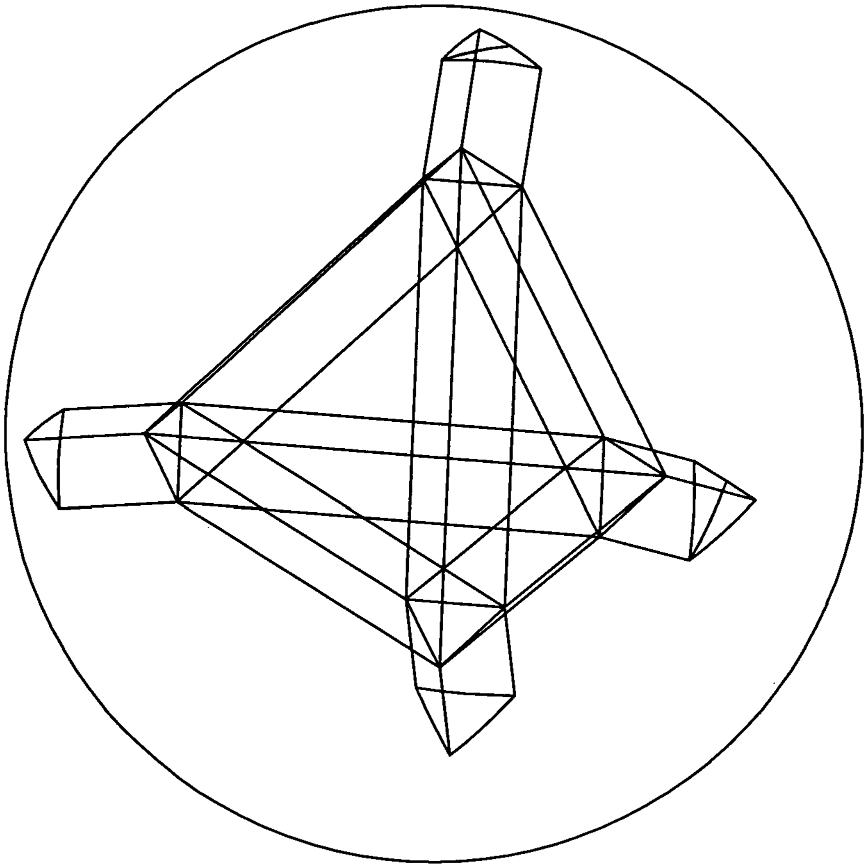


FIG. 33

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EUROPEAN SEARCH REPORT

Application Number
EP 07 00 3577

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	TABER R C ET AL: "MICROWAVE OSCILLATORS INCORPORATING CRYOGENIC SAPPHIRE DIELECTRIC RESONATORS" IEEE TRANSACTIONS ON ULTRASONICS, FERROELECTRICS AND FREQUENCY CONTROL, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 42, no. 1, January 1995 (1995-01), pages 111-119, XP000507512 ISSN: 0885-3010 * page 116, left-hand column, line 27 - right-hand column, line 6; figure 4 * -----	1,2,5, 15,17, 18,21, 23-25, 28-30, 32,34,36	INV. H01P7/10
X	US 2002/171509 A1 (ANDO MASAMICHI [JP] ET AL) 21 November 2002 (2002-11-21) * paragraph [0030]; figure 5a * -----	1	
X	EP 1 014 473 A1 (MURATA MANUFACTURING CO [JP]) 28 June 2000 (2000-06-28) * paragraphs [0028], [0037]; figures 5,14 * -----	1	
			TECHNICAL FIELDS SEARCHED (IPC)
A	EP 0 742 603 A1 (ALCATEL NV [NL] CIT ALCATEL [FR]) 13 November 1996 (1996-11-13) * columns 10-15-19; figure 18 * -----	1	H01P
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The present search report has been drawn up for all claims

3

Place of search	Date of completion of the search	Examiner
The Hague	24 May 2007	Den Otter, Adrianus

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