

Microwave RF Filter with Dielectric Resonator

Field of the invention

The embodiments relate to microwave or RF filters, and more particularly to filters having at least one dielectric resonator. Preferably, the dielectric resonator has a cylindrical outer contour. Most preferably, the dielectric resonator comprises at least two cylindrical components.

Description of the related art

10 Microwave or RF filters, more specifically microwave bandpass filters are commonly used in communication systems. Mostly, such filters are based on conventional rectangular and circular waveguide resonators. There is continuous need to decrease the size and volume of these filters. This may be done by using filters based on dielectric resonators. Typically, such a dielectric resonator comprises a
15 high dielectric constant material, which preferably is in a cylindrical form. The resonator is mounted inside a metal enclosure. The electromagnetic field is concentrated mainly in the dielectric cylinder. Therefore, the Q-factor of the resonator is determined largely by the loss tangent of the dielectric material of the resonator.

20 US 5,200,721 discloses a dual-mode filter having a dielectric resonator in two separated cavities. The cylindrical resonators are designed such that at least one cavity resonates in a dual HEH_{11} mode, whereas a spurious HEE_{11} mode is shifted to a higher frequency.

A quasi-dual-mode resonator is disclosed in US 2002/0149449 A1. It comprises a
25 resonator being a half disk.

Dielectric resonator filters using a disk operating in a HEH_{11} dual-mode and an HEE_{11} dual-mode are disclosed in EP 2 151 885 B1. The resonator is mounted on a solid mounting support formed from a unitary piece of low permittivity dielectric substrate.

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Summary of the invention

The problem to be solved by the invention is to provide microwave or RF filters with a comparatively large bandwidth and low passthrough attenuation while maintaining steep slopes. The filter should be compact and robust. It should be adjustable with a high degree of flexibility.

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Solutions of the problem are described in the independent claims. The dependent claims relate to further improvements of the invention.

In a preferred embodiment, a microwave or RF bandpass filter comprises at least one dielectric resonator held in a conductive housing, forming a cavity. The at least one dielectric resonator has an outer contour of a cylindrical shape defined by a parallel pair of face surfaces, each face surface having at least two symmetry axes. Preferably, the dielectric resonator has an outer contour which is most preferably defined by a parallel pair of at least approximately face surfaces having the same size or diameter.

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In a further embodiment, the dielectric resonator has a cylindrical shape defined by a parallel pair of approximately square, octagonal, or similarly shaped face surfaces. In the case of a non-circular resonator, the diameter is defined as the mean lateral dimension. In a preferred embodiment, the face surfaces are circular and preferably have the same diameter. The cylinder may have an inner hole or bore.

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In another embodiment, there are at least two approximately cylindrical dielectric components within the outer cylindrical contour. Such a dielectric resonator may comprise two cylindrical outer sections and at least one preferably cylindrical inner section between the outer sections. The inner section may be smaller or
5 have a smaller diameter than the outer sections. There may be coupling elements preferably of a dielectric material which preferably are evenly angular spaced around the center axis. They are preferably movable in axial directions as indicated by direction indicators. The coupling elements are preferably arranged such that they intersect a common plane with the at least inner section and most
10 preferably are designed to intrude into the space between the outer sections. Furthermore, at least one spacer between the resonator sections may be provided for holding the resonator within the cavity. Using thin strips as spacer may provide enough space for the previously mentioned coupling elements. There may be any number of spacers. There may be multiple separated spacer sections. Also, the spacer sections or spacers may be combined to a single piece
15 spacer. In this embodiment, the support plates are no more required.

In a further embodiment, the dielectric resonator may also have a cuboidal shape.

It is preferred, if the dielectric resonator has a center axis defined by the centers
20 of the face surfaces. Preferably, the dielectric resonator comprises a dielectric material, most preferably having low dielectric losses and a high dielectric constant. It is preferred, if this material is a ceramic material. It is further preferred, if the resonator comprises only dielectric material and no electrically conductive material. There may also be a plastic material.

25 The housing comprises an electrically conductive material, preferably a metal. It is further preferred, if the inner surface of the housing comprises or is coated with a high conductive and preferably corrosion-resistant material, like silver,

gold, or an alloy thereof. The housing preferably forms a cylindrical cavity defined by a parallel pair of inner face surfaces having the same diameter. It is further preferred, if the housing has a center axis which may be defined by the center points of the parallel face surfaces. The housing may also have a cuboidal
5 shape. It may further have a cylindrical shape defined by a parallel pair of approximately square, octagonal, or similarly shaped surfaces. A center axis may be defined by the center of the parallel face surfaces. Preferably, the housing has a cover, which may be removable.

The dielectric resonator is held within the cavity by means of at least one support
10 plate. Preferably, there are two support plates, each at one of the face surfaces of the dielectric resonator. It is preferred, if the support plates enclose the dielectric resonator like a sandwich. The support plates preferably have a contour which interfaces with the housing. It is preferred, if at least one of the support
15 plates is rectangular, squared, circular or adapted to the inner contour of the housing. It is further preferred, if at least one the support plates interfaces with at least one groove or protrusion in the housing.

The material of the support plates preferably is a material having a low or medium dielectric constant. The relative dielectric constant is preferably in a range between 2 and 11.0 and most preferably in a range between 8.5 and 11.0. It is
20 preferred to have the support plate comprising PTFE, a plastic or a ceramic material. The thickness of the support plates is significantly less than the height of the dielectric resonator. Preferably it is less than 1/10 of the height of the dielectric resonator. Therefore and by the fact that the dielectric constant of the support
25 plates is comparatively lower than the dielectric constant of the dielectric resonator, the influence of the support plates to the dielectric resonator is comparatively low, or even negligible.

As known from prior art, ceramic resonators are held in a cavity by a solid support rod or cylinder. This support rod does not allow to access both sides of the cylinder symmetrically. Due to the support plates, coupling elements for coupling energy between different modes can be mounted at both sides of the dielectric resonator. This enables to build a quad-mode filter with one dielectric resonator as a comparatively small unit. It furthermore allows to build a largely adjustable filter, as different adjustable coupling and tuning elements can be mounted under or over the dielectric resonator.

The filter has four resonating modes. The first mode is a HEH_x mode having a first resonance frequency. The second mode is a HEE_x mode having a second frequency. The third mode is a HEE_y mode having a third frequency. The fourth mode is a HEH_y mode having a fourth frequency. This applies preferably to a circular cylinder dielectric resonator. There may be further modes. Reference is made to the book "*Microwave filters for Communication Systems*" by Richard J. Cameron et al., Wiley Intersciences, 2007, pages 567-583. Specifically on page 575, the electric field distribution of the HEH and the HEE modes is shown.

In the following, it is assumed that the center axis of the dielectric resonator is the same or approximately the same as the center axis of the cavity. Furthermore, there is a first orthogonal plane defined by the center axis of the dielectric resonator and the location of a first external coupling element, which will be used for connecting a signal source. There is a second orthogonal plane which is also defined by the center axis of the dielectric resonator and which is under a 90 degrees angle to the first orthogonal plane. A second external coupling element which may be connected to a load is mounted in that second orthogonal plane. To simplify the reference to the modes, an orthogonal coordinate system is introduced. It has an x-axis lying in the first orthogonal plane, pointing from the center axis of the dielectric resonator to the first external coupling element, a y-axis from the center axis of the dielectric resonator pointing towards the second

external coupling element, and a z-axis pointing along the center axis of the dielectric resonator in a direction to the bottom as used herein.

The dielectric resonator height and the dielectric resonator diameter are selected such that the degenerate HEH and HEE modes resonates at a common resonance frequency. Preferably, the ratio of dielectric resonator diameter to dielectric resonator height is in the range of 0.9 to 3.1. Preferably, the range is between 1.7 and 2.3. According to another embodiment, the range may be between 1.8 and 2.0. In specific cases a ratio of up to 7 may be used.

The filter has an input which may be connected to a signal source, and an output which may be connected to a load. It is preferred to have a first external coupling element for feeding electrical energy which may be delivered by the source into the filter, and for exiting the HEHx mode with a main electrical field component in the first orthogonal plane in x-direction.

For coupling energy from the HEHx mode to other modes, coupling elements are provided. It is preferred to have at least one second internal coupling element which preferably comprises an electrically conductive material or a dielectric material with a preferably high dielectric constant in the vicinity of the dielectric resonator, without touching the dielectric resonator, preferably under a 45 degrees angle to the first orthogonal plane and most preferably in a height between the first face surface and the second face surface of the dielectric resonator. This second internal coupling element will transfer energy from the first mode which is a HEHx mode, to the fourth mode which is a HEHy mode, orthogonally to the HEHx mode with its main electrical field component in the second orthogonal plane in y-direction. The energy from this HEHy mode may be picked up with a second external coupling element orthogonal to the first external coupling element. Although it is sufficient to have only one second internal coupling element, there may be a plurality of such coupling elements, like 2, 3, 4 or more

coupling elements, preferably oriented towards the first orthogonal plane under 45 degree angles.

Coupling from the HEHx mode and the HEHy mode to a HEE_x and a HEE_y mode is preferably done by displacement of the dielectric resonator with respect to the center of the cavity. Therefore, the center in height of the dielectric resonator is offset to the center in height of the cylindrical cavity. Such a displacement may preferably be made by displacing the location of the support plates and/or by adjusting the thickness of the support plates and/or by an offset in at least one of the two inner face surfaces of the cavity. The displacement may be adjustable by adapting the inner contour, preferably of the height of the offset in the contour of the inner face surface of the cavity. Therefore, a set of different covers forming the inner face surfaces of the cavity may be provided, from which the best fitting cover resulting in a desired coupling may be selected for each filter. By the axial displacement of the dielectric resonator with respect to the cylindrical cavity, there is an energy transfer between the HEHx mode and the HEE_x mode as well as between the HEHy mode and the HEE_y mode. This coupling may further be adjusted by third internal coupling elements which are similar components as the second internal coupling element. The third internal coupling elements preferably are arranged in plane above the second support plate and/or below the first support plate. Most preferably, the third internal coupling elements are arranged symmetrical to the center axis. There may be 4 third internal coupling elements with relative angles of 90 degrees to each other or 3 third internal coupling elements with relative angles of 120 degrees to each other. In an alternative embodiment, a resonator comprising multiple stacked dielectric cylinders with different diameters may be provided to adjust coupling from the HEHx mode and the HEHy mode to a HEE_x and a HEE_y mode. A resonator may comprise at least two different sections, each section having an outer contour defined by a parallel pair of face surfaces. Each face surface may have at least two symmetry axes, and the dielectric resonator preferably has a center axis.

For coupling the HEE_x mode to the HEE_y mode, at least one first internal coupling element is provided. It is preferred to have two such internal coupling elements, which preferably are arranged symmetrical above and below the dielectric resonator. They may be rotated against each other about the dielectric resonator center axis at an angle of 90 degrees. They may have different distances to the upper and/or lower surface of the dielectric resonator. The at least one first coupling element preferably comprises at least one bar of electrically conductive or of dielectric material, which is located approximately parallel to the upper and/or lower face surface of the dielectric resonator. Preferably, the at least one bar is arranged under a 45 degrees angle to the first orthogonal plane. Preferably, the length of the at least one first coupling element is in the range between $\frac{1}{4}$ and $\frac{7}{8}$ of the diameter of the dielectric resonator.

In order to enhance its effect, the at least one first coupling element may comprise coupling buttons at both ends of the bar pointing towards the face surface of the dielectric resonator. Furthermore, there may be at least one first internal coupling element adjustment means like a screw.

Besides the coupling elements, there is a plurality of frequency tuning elements. For tuning the frequency of the HEE_x mode, there may be at least one tuning rod in the first orthogonal plane. Generally, such tuning rods may comprise a dielectric material, preferably a ceramic material. The tuning rods are arranged above and below the dielectric resonator, preferably in close proximity to the first face surface and/or the second face surface of the dielectric resonator. There may also be at least one tuning rod at a side or between resonator sections. For the HEE_x mode, there may be a first bottom tuning rod and a third bottom tuning rod, both below the dielectric resonator in the first orthogonal plane, and a first top tuning rod and the third top tuning rod, both above the dielectric resonator in the first orthogonal plane. For adjusting the frequency of the HEE_y mode, there may be tuning rods in the second orthogonal plane, like a second bottom

tuning rod and a fourth bottom tuning rod below the dielectric resonator, and a second top tuning rod and the fourth top tuning rod above the dielectric resonator. Generally, any number of tuning rods may be used. In a very simple embodiment, 1 or 2 tuning rods may be sufficient while in a complex embodiment, 8 or more tuning rods may be used. Next to the first coupling element, these tuning rods may be used for tuning the coupling between the HEE_x mode and HEE_y mode. With increasing asymmetry between the tuning rods coupling between the modes increases. Preferably, pairs of neighbored tuning rods with respect to the center axis are set to the same position. High coupling is achieved, when a first pair of neighbored tuning rods is positioned inward and a second pair of neighbored tuning rods is positioned outward. Preferably, at least one tuning rod comprising a dielectric material is fastened to the housing and protruding into the cavity outside of the cylindrical dielectric resonator and into a direction towards the center axis above or under at least one of the face surfaces. Furthermore, it is preferred, if the projection of an end of at least one tuning rod in a direction parallel to the center axis is within one of the face surfaces.

For adjusting the frequency of the HEH_x mode, there may be a first side tuning means which is in the first orthogonal plane and preferably opposite to the first external coupling element. Furthermore, for adjusting the frequency of the HEH_y mode, there may be a second side tuning means which is arranged at the second orthogonal plane, and preferably opposite to the second external coupling element. The first and the second side tuning means preferably are arranged in a plane between the first support plate and the second support plate.

The first and second side tuning means are similar to the third internal coupling elements, and preferably provide an electrically conductive cylindrical means, which may be adjusted in its depth penetrating into the cavity.

In a preferred embodiment, the first external coupling element and/or the second external coupling element extend radially to the dielectric resonator, and therefore have an extension laterally to the dielectric resonator center axis. It is preferred, if at least one the external coupling elements is arranged in a height (z-axis) between the first face surface and the second face surface of the dielectric resonator. By such an arrangement, the external coupling elements are able to couple an electrical field extending from the dielectric resonator at its cylinder barrel. Most preferably, the external coupling elements are rod-shaped or cylinder-shaped parts which preferably protrude through the housing into the cavity in a direction orthogonal to the dielectric resonator center axis. It is further preferred, if the end of the at least one of the external coupling elements, directed towards the dielectric resonator, is enlarged to increase coupling efficiency and to improve matching. There may be a cap or a similar structure at its end.

In a further embodiment, an outer conductor is provided at at least one external coupling element. This outer conductor is attached and/or connected to the housing and may have a cylindrical shape. An outer thread may further be provided. By moving the outer conductor in or out, the reference plane may be altered and parasitic couplings between HEH_x and HEE_y , or HEH_y and HEE_x may be nullified respectively. Combining this effect with the option to tune the coupling between HEE_x and HEE_y with the help of the tuning rods or the cuboid tuning elements as mentioned above, it is possible to tune a filter without the need of a first coupling element.

Generally it is preferred, if the dielectric material of the dielectric components described herein with exception of the dielectric resonator itself has a dielectric constant which is lower than the dielectric constant of the materials of the dielectric resonator and/or may have a thickness which is significantly less than the height of the dielectric resonator.

Description of Drawings

In the following the invention will be described by way of example, without limitation of the general inventive concept, on examples of embodiment with reference to the drawings.

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Figure 1 shows a sectional view of a preferred embodiment.

Figure 2 shows an outside view of a preferred embodiment.

Figure 3 shows the bottom side of the housing of a preferred embodiment.

Figure 4 shows a top view of a housing with removed cover.

10 Figure 5 shows a sectional view from the top through a plane below the second support plate.

Figure 6 shows a further sectional view from the top, from a plane below the first support plate.

Figure 7 shows a modified embodiment.

15 Figure 8 shows a sectional view from the bottom of a preferred embodiment.

Figure 9 shows another sectional view of a preferred embodiment.

Figure 10 shows a detail of a first internal coupling element.

Figure 11 shows a detail of a further internal coupling element.

Figure 12 shows a dielectric resonator in detail.

20 Figure 13 shows a sectional top view of a dielectric resonator.

Figure 14 shows another embodiment of a dielectric resonator in detail.

Figure 15 shows a sectional top view of the above dielectric resonator.

Figure 16 shows a modified support plate.

Figure 17 shows a further modified support plate.

Figure 18 shows S parameters of a preferred embodiment.

5 Figure 19 shows a coupling scheme of coupling modes within the filter.

Figure 20 shows an extended coupling scheme.

Figure 21 shows tuning elements between two resonator sections in a side view.

Figure 22 shows tuning elements between two resonator sections in a top view.

Figure 23 shows holding of the resonator by spacers in a side view.

10 Figure 24 shows holding of the resonator by spacers in a top view.

Figure 25 shows a resonator split into multiple parts allowing access to the electrical/magnetic fields pointing from one part to another.

Figure 26 shows the above resonator in a sectional top view

15 Figure 27 shows a further resonator split into multiple parts allowing access to the electrical/magnetic fields pointing from one part to another.

Figure 28 shows the above resonator in a sectional top view

Figure 29 shows stacked dielectric cylinders with different diameter.

Figure 30 shows a combination of tuning elements.

Figure 31 shows a modified external coupling element.

In Figure 1, a sectional view of a first embodiment is shown. A microwave or RF bandpass filter based on a dielectric resonator is shown. A metal housing 702 provides a cavity 705, containing a dielectric resonator 100. Preferably, the cavity 705 has a cylindrical shape defined by a parallel pair of inner face surfaces and further defines a center axis 709. The dielectric resonator preferably comprises a dielectric material having low dielectric losses and most preferably a high dielectric constant. The material may be of ceramic. It is preferred, if the dielectric resonator is a cylindrical disk, defined by a parallel pair of face surfaces 105, 106 which most preferably have the same diameter, and define a center axis 109.

The cylinder is held within the cavity 705 by means of at least one support plate. Preferably, the dielectric resonator center axis 109 is parallel to the cavity center axis 709, and most preferably the axes are the same. Preferably, there is a first support plate 110 at the first face surface 105 and a second support plate 120 at the second face surface 106. Preferably, the support plates comprise a material having a low dielectric constant. The material may be one of a plastic material, for example PTFE, or a ceramic material. As the support plates are comparatively thin, there is only a negligible influence on the resonating characteristics of the dielectric resonator 100. It is preferred to use a material with a low or medium dielectric constant which further reduces the influence on the dielectric resonator. The dielectric resonator height 101 and the dielectric resonator diameter 102 are selected such that the degenerate HEH and HEE modes resonate at a common resonance frequency. Preferably, the ratio of dielectric resonator diameter to dielectric resonator height is in the range of 0.9 to 3.1. Preferably, the range is between 1.7 and 2.3.

The support plates may be held within the housing 702 by means of grooves 760, 770, 780, 790 within the inner wall of the cavity 705, which preferably extend parallel to the cavity center axis 709.

Within the cavity 705 is a plurality of coupling elements and tuning elements.

There is a first external coupling element 210 of which only a part is shown in this figure. It is connected to a first external connector 212, which may act as a source feed for the dielectric resonator. It is furthermore preferred to have first
5 internal coupling elements with a bottom first internal coupling element 230 and a top first coupling element 240. Generally, the spatial relations of top or bottom relate to the cavity as shown in Figure 1, to simplify explanation. It is obvious that these relationships can be exchanged, for example by simply rotating the device.

10 It is preferred, if at least one of the external coupling elements 210, 220 extends radially to the dielectric resonator or orthogonally to the dielectric resonator center axis 109. It is preferred, if the at least one external coupling element 210, 220 is arranged in a height (z-direction) between the first face surface 105 and the second face surface 106 of the dielectric resonator 100.

15 Preferably, the structure of the bottom first internal coupling element 230 is symmetrical to the structure of the top first internal coupling element 240. These internal coupling elements provide coupling at least of HEx and HEy modes within the dielectric resonator. Preferably, they are movable parallel to the cavity center axis 709, most preferably by means of a thread or a screw. Therefore,
20 coupling may be adjusted by moving the first internal coupling elements closer to the dielectric resonator or moving them away therefrom. By the symmetry of these first internal coupling elements, a better coupling and a better mode uniformity within the dielectric resonator can be achieved. Such a symmetrical arrangement is only possible by holding the dielectric resonator between a first
25 support 110 and a second support 120, forming thin plates. If the dielectric resonator would be held by rod-like support as known from prior art, it would not be possible to have the lower first internal coupling element 230, as the space required for this coupling element is required by the dielectric resonator support.

The first internal coupling elements comprise a bar 232, 242 having coupling buttons 245, 246 at its ends and being mounted to an adjustment screw 231, 241.

The position and the movement of the bar 232 is held by support rods 243, 244.

The bar preferably is arranged orthogonally to the dielectric resonator center

5 axis 109. It is under an angle 238 of 45 degrees to an axis defined between the first external coupling element 210 and the dielectric resonator center axis 109, which also passes through a first orthogonal plane 107, as shown in the following Figures.

Furthermore, it is preferred to have at least one second internal coupling ele-

10 ment 250 and a plurality of third internal coupling elements 260, 270, 280, and 290. All these second and third internal coupling elements preferably are short conducting studs or cylinders preferably having a circular cross-section, which protrude into the cavity 705 under predetermined angles at predetermined positions. Preferably, the length of the second and third internal coupling elements and therefore the depth of protrusion into the cavity 705 may be adjusted. Ad-
15 justment preferably is done by a screw or by means of a thread. Preferably, the center of the second internal coupling element 250 is arranged on a plane having a height between the first face surface 105 and the second face surface 106 of the dielectric resonator 100. Most preferably, it is in the center plane of the die-
20 lectric resonator, which is at the center between the first face surface 105 and the second face surface 106. It is furthermore preferred to have the second internal coupling element 250 under an angle of 45 degrees with respect to the first orthogonal plane 107. Further possible positions of the second internal coupling element 250 may be displaced about 90, 180 and 270 degrees around the
25 center axis. Preferably, the second internal coupling element 250 is for coupling the HEH_x mode to the HEH_y mode. The third internal coupling elements 260, 270, 280, and 290 preferably are arranged within the same plane orthogonally to the dielectric resonator center axis 109, which is further above the second face surface 106 of the dielectric resonator. Alternatively, they may be arranged be-

low the first face surface 105. Preferably, the third internal coupling elements are spaced relatively to each other at angles of 90 degrees, whereas the angle of each third internal coupling element with respect to the first orthogonal plane 107 is 45 degrees.

- 5 These third internal coupling elements are for fine-tuning of the coupling the HEHx mode to the HEE_x mode and for coupling the HEH_y mode to the HEE_y mode. Basically, coupling between these modes is achieved by displacement of the dielectric resonator 100 along the dielectric resonator center axis 109 within the cavity 705, to obtain an offset from the center of the height of the cavity 705.
- 10 As the height cannot be adjusted, the third internal coupling elements are provided for fine-tuning.

There may be a plurality of side tuning means like the first side tuning means 630, which may be used for tuning a first frequency of the HEH_x mode.

- For frequency tuning of the filter, it is further preferred to provide a plurality of
- 15 tuning rods. Preferably, there is a first set of tuning rods 410, 420, 430, 440 at the bottom arranged below the first support plate 110, and/or a second set of tuning rods 510, 520, 530, 540 at the top arranged above the second support plate 120. It is preferred to arrange the tuning rods within the first orthogonal plane 107 or within a second orthogonal plane 108, being orthogonal to the first
- 20 orthogonal plane 107. The tuning rods preferably are made of a material having a high dielectric constant and low dielectric losses. It is preferred to use a ceramic material. The tuning rods protrude into the cavity and preferably are adjustable in their length protruding into the cavity.

Herein, angles of 45 and 90 degrees are mentioned. These are preferred values.

- 25 It is obvious to a person skilled in the art that there may be minor deviations of these angles, as the embodiments would also operate with ranges of the angles between 40 and 50 degrees or 80 and 100 degrees. In the figure a Cartesian co-

ordinate system is defined, wherein a z-axis is defined by the dielectric resonator center axis in a direction downward in the figure. An x-axis is defined in the dielectric resonator center plane and in a direction towards the first external coupling element 210. A y-axis is defined in the dielectric resonator center plane and
5 in a direction towards the second external coupling element 220 which is shown in another figure. In the following figures the same coordinate system is shown for spatial reference.

In Figure 2, an outside view of a preferred embodiment is shown. In this Figure, the housing 702 is closed with the attached cover 701. The cover preferably is
10 locked to the housing 702 by a plurality of cover screws 703. Preferably, the housing has an approximately cylindrical shape defined by two parallel inner face surfaces. In this Figure, the cavity center axis 709 is shown which is defined by the center of the cavity shown in the previous figure. Preferably, this axis is the same as the center axis of the housing, although this is not necessarily the case.
15 The housing preferably has a first external connector 212 which may be used to feed electrical power into the filter, and a second external connector 222, which may be used to receive electrical power from the filter. A load may be connected thereto.

A plurality of adjustment means are accessible from the outside of the housing
20 for adjusting and tuning the filter. In this view, a third bottom tuning rod 430 and a third top tuning rod 530, as well as a fourth bottom tuning rod 440 and a fourth top tuning rod 540 can be seen. The tuning rods may be secured by means of a third bottom tuning rod locking nut 432 and a third top tuning rod locking nut 532 as shown. It is obvious that the other tuning rods also may have such
25 locking nuts, although no specific reference numbers have been assigned to these locking nuts.

Furthermore, there may be third internal coupling elements 270, 280, 290 as previously described. These third internal coupling elements may also have locking nuts similar to the previously mentioned tuning rod locking nuts.

Furthermore, a second internal coupling element 250 is shown. This may also be
5 locked by a second internal coupling element locking nut 252. Adjustment may be made by a second internal coupling element adjustment screw 251, which may have a hexagon socket.

At the top of the cover 701, parts of the top first internal coupling element 240 are shown. It may be adjusted by the top first internal coupling element adjust-
10 ment screw 241, which may preferably have a hexagon socket.

In Figure 3, the bottom side of the housing of a preferred embodiment is shown. Close to the first and second external connectors 212, 222, there are first and second bottom tuning rods 410 and 420. At the center of the bottom of the housing, a bottom first internal coupling element 230 is shown, which may be
15 adjusted by a bottom first internal coupling element adjustment screw 231.

In Figure 4, a top view of the housing 702 with removed cover 701 (not shown) is shown. The housing 702 forms a cavity 705, in which the dielectric resonator 100 is located with its dielectric resonator center axis 109, a first orthogonal plane 107 and a second orthogonal plane 108 with their intersection at the center axis.
20 In this Figure a plurality of screw holes 704 for holding the cover screws 703 (shown in a previous Figure) are shown. Furthermore, the third internal coupling elements 260, 270, 280, and 290 are shown, which are in a plane above the second support plate 120, which furthermore is above the dielectric resonator 100, which is only indicated but cannot be seen, as it is covered by the second support
25 plate 120. Furthermore, a first 510, second 520, third 530, and fourth 540 top tuning rods are shown. Preferably, there are four grooves 760, 770, 780, 790 for holding the first support plate 110 and the second support plate 120, which

preferably fit with their corners into the grooves and may slide along parallel to the cavity center axis 709.

In Figure 5, a sectional view from the top in a plane below the second support plate 120 is shown. Here, the first external coupling element 210 and the second external coupling element 220 are shown in more detail. It is preferred to have the first external coupling element 210 closer to the dielectric resonator 100 than the second external coupling element 220. Preferably, at least one of the coupling elements has an extended head oriented towards the dielectric resonator. Furthermore, the second internal coupling element 250 is shown, which is in approximately the same plane as the first external coupling element and the second external coupling element, the plane being orthogonal to the dielectric resonator center axis 109. It preferably has the shape of a conductive cylinder, which is adjustable in its length and which is protruding into the cavity. Furthermore the first side tuning means 630 the second side tuning means 640 for adjusting the HEH frequency are shown.

In Figure 6, a further sectional view from the top, from a plane below the first support plate 110 is shown. Here, the first 410, second 420, third 430, and fourth 440 bottom tuning rods are shown. Furthermore, the bottom first internal coupling element 230 is shown.

Figure 7 shows a modified embodiment, where the center axis of the tuning rods are slightly offset, preferably for half the diameter of a tuning rod. By this, the tuning rods may be moved with their ends together without forming a gap.

In Figure 8, a view from the bottom to the first support plate 110 covering the dielectric resonator 100. As it is preferred to have the grooves 760, 770, 780, 790 as shown in one of the previous Figures, ending at a position corresponding to the position of the first support plate 110, these grooves are not shown in this Figure. In this view, the first 410, second 420, third 430, and fourth 440 bottom

tuning rods are shown. Preferably, each is held by a nut in the housing 702.

There may further be a means like a collet to firmly hold the tuning rods in a position. For tuning the filter, the length of the tuning rods protruding into the cavity can be adjusted and preferably later be fixed, so that the tuning rods would
5 not move over time. In this Figure, furthermore a bottom first internal coupling element 230 is shown. It preferably has a bar 232, whereas the bar preferably has an axis 237, which is under an angle 238 of about 45 degrees to the first orthogonal plane 107.

In Figure 9, a sectional view of a preferred embodiment is shown. Here again,
10 some of the previously mentioned components can be seen. This Figure shows some more details, for example a sectional view of the second side tuning means 640, which is exemplarily for the other stud-type tuning means disclosed herein. It may have an outer thread 643 to be held in the housing 702, and a locking nut 642 for securing within the housing. Furthermore, there may be a screw or slider
15 645 which may be actuated along its center axis 649, preferably by means of a screw internal to the second side tuning means. This second side tuning means may be provided for tuning a fourth frequency of the HEHy mode. In this Figure, furthermore a preferred connection of external connectors is shown. Here, the second external connector 222 has a second external inner conductor 221 which
20 is connected to the second external coupling element 220. There may be means for adjusting the length or the depth of protrusion into the cavity of the second external coupling element 220. This Figure further shows some essential dimensions of the embodiment. The dielectric resonator 100 has a dielectric resonator diameter 102 and a dielectric resonator height 101. The cavity 705 has a diameter 713 with a center axis 709. It furthermore has a height 712. The dielectric
25 resonator 100 is mounted in a height 711 above the bottom of the cavity 705. Preferably, the center of the dielectric resonator 100 is slightly offset to the center of the height 712 of the cavity.

In Figure 10, a detail of a first internal coupling element is shown. Here, the bottom first internal coupling element 230 comprises a bar 232 which is rotatably coupled to an adjustment screw 231. Preferably, the screw has a hexagon socket or similar means for rotating the screw at the end distant from the bar. By rotating the adjustment screw 231, the height of the bar with respect to the housing and therefore with respect to the dielectric resonator can be adjusted. As the bar preferably is under an angle of 45 degrees to the first orthogonal plane 107, it must not rotate, when the adjustment screw 231 is rotated. To prevent rotation, preferably at least one support rod 233, 234 is provided. Coupling buttons 235, 236 are provided at the bar and being directed towards the dielectric resonator 100. They allow to place the bar more distant from the resonator, preferably to keep the bar distant of the upper and/or lower tuning rods. The coupling buttons 235, 236 are electrically connected by means of the bar 232. Preferably, the top first internal coupling element 240 is identical with a bar 242, support rods 243, 244 and coupling buttons 245, 246.

In Figure 11, a detail of a further internal coupling element is shown. Here, the bottom first internal coupling element 230 comprises a bar 232 which is rotatably coupled to an adjustment screw 231. The bar may comprise a dielectric material or a conductive material. It may have a circular or a rectangular cross section.

In Figure 12, a dielectric resonator is shown in detail. The dielectric resonator 100 is preferably defined by two parallel face surfaces 105, 106 forming a cylinder having a height 101 which is defined by the distance of the parallel face surfaces 105, 106 and a diameter 102. Preferably, the dielectric resonator 100 is held by a first support plate 110 and a second support plate 120. The first support plate 110 preferably is at the first face surface 105, whereas the second support plate 120 preferably is at the second face surface 106. It is obvious, that minor devia-

tions from the general shape like an elliptical shape, chamfers others do not affect the general operation principle of the invention.

In Figure 13, a sectional top view of a dielectric resonator 100 is shown. At the center, there is a dielectric resonator center axis 109.

5 In Figure 14, another dielectric resonator is shown in detail. The dielectric resonator 100 comprises a pair of outer sections 103 and an inner section 104 between the outer sections. In this embodiment, all sections are of a cylindrical shape having circular top and bottom surfaces. Preferably, all sections comprise dielectric material. Preferably, the overall contour of the resonator 100 as de-
10 fined by the larger outer sections is a cylindrical contour, which corresponds to the outer contour of the dielectric resonator shown above. Therefore, this resonator may be used in all embodiments described herein. It is further preferred, if the outer sections 103 and the inner section 104 are centered about a common center axis 109. In another preferred embodiment, the inner section comprises a
15 material different from the outer sections. Preferably, the material of the inner section is selected such that its thermal changes in its electrical and/or mechanical properties compensate changes in the electrical and/or mechanical properties of the outer sections. Thus, a thermal compensation can be achieved, resulting in a broader temperature range with constant operating characteristics.

20 In Figure 15, a sectional top view of a dielectric resonator 100 is shown. At the center, there is a dielectric resonator center axis 109.

In Figure 16, a modified support plate 110 is shown. Either one of the support plates or both may be modified accordingly. There may be at least one compensation plate 111, 112, 113, 114 attached to the surface of a support plate. Preferably, the at least one compensation plate is arranged close to the corners of
25 the support plate. The at least one compensation plate may be at the side of the support plate opposite to the dielectric resonator 100. Although it is also possi-

ble to arrange the at least one compensation plate at the same side. The at least one compensation plate preferably comprises a dielectric material, most preferably the same or a similar material as the support plate. The dielectric material of the at least one compensation plate as well as the dielectric material of the support plate are penetrated by the fields of the HEH modes and therefore may influence the HEH mode, but not the HEE modes. Therefore the compensation plates may be used for selective temperature compensation of the HEH modes, if the temperature coefficient of the compensation plates is selected accordingly. At least one of the compensation plates may have a chamfered outer edge to minimize the influence to the HEE modes. This is shown exemplarily by compensation plate 114. It may be sufficient to provide at least one pair of opposing compensation plates (111, 113) or (112, 114). The compensation plates shown herein may have a thickness in a range between 0.5mm and 5mm. In a further embodiment, at least one additional compensation plate (111, 112, 113, 114) is modified by at least one cut edge. Furthermore, at least one additional compensation plate may comprise a dielectric material having a dielectric constant which is lower than the dielectric constant of the materials of the dielectric resonator and/or may have a thickness which is significantly less than the height of the dielectric resonator.

In Figure 17, a further modified support plate 110 is shown. Here, the compensation plates 111, 112, 113, 114 are arranged along the edges of the support plate.

In Figure 18, electrical characteristics defined by their S-parameters of a preferred embodiment are shown. This diagram has a horizontal axis showing a frequency starting with 1700 MHz at the left side and ending with 1950 MHz at the right side. At the vertical axis, it shows attenuation in dB (decibels) starting from 0 dB at the top and ending with -100 dB at the bottom. A first curve 951 shows S11 which is the signal reflected at the first external connector 212 with relation to a signal fed into this connector. The second curve 952 shows S21 which is the

attenuation of a signal at the second external connector 222 related to an input signal at the first external connector 212. These curves result from a filter as described herein, where the cavity has a diameter of 60mm and a height of 60mm. The outer dimensions of the resonator are 34mm diameter and 18mm height.

5 The resonator has relative dielectric constant of 36.

In Figure 19, a coupling scheme of coupling modes within the filter is shown.

There are four modes. A HEHx mode has a first frequency, a HEEEx mode has a second frequency, a HEEy mode has a third frequency and HEHy mode has a fourth frequency. A signal is input at a source 901 and coupled via coupling path 10 921 with the HEHx mode 911 of the filter. Energy is coupled from this mode via coupling path 922 with the HEHy mode 914, via coupling path 923 with the HEEy mode 913 and via coupling path 924 with the HEEEx mode 912. From the HEEEx mode, energy may be coupled via coupling path 925 with the HEEy mode 913 or with said HEHy mode 914 via coupling path 926. The HEEy mode 913 may couple 15 energy with the HEHy mode 914 via coupling path 927. Energy may be coupled from the HEHy mode 914 via coupling path 928 to the load 902. All these couplings are reciprocal and therefore bidirectional.

Figure 20 shows the same coupling scheme of figure 14, but with added reference sign of the relevant elements. For example coupling between the HEEEx 20 mode 912 and the HEEy mode 913 via coupling path 925 is done by means of the bottom first internal coupling element 230 and the top first internal coupling element 240.

Figure 21 shows coupling elements intersecting the space between two cylindrical dielectric resonator sections in a side view. These coupling elements may be 25 cuboid. .

Figure 22 shows corresponding to figure 21 a sectional top view cut in half transversally to the z-axis at the center of the z-axis. There are preferably four cou-

pling elements 810, 820, 830, 840 preferably of a dielectric material which preferably are evenly angular spaced around the center axis 109. They are preferably movable in axial directions as indicated by direction indicators 811, 821, 831, 841. The coupling elements may be moved into the space between the outer
5 sections 103. With these coupling elements, it is possible to interact directly with the field lines of the HEE_x and HEE_y mode. Without the separation into an upper and a lower dielectric resonator section, only the field lines leaking out of the resonator are available for tuning. With this setup, a direct access to the field lines is opened up. Thus, by shifting the coupling elements in and out symmetri-
10 cally over all entities, it is possible to shift HEE frequencies. By shifting the coupling elements unevenly, coupling between the HEE modes appear. By using these coupling elements, the bottom and top tuning rods are no more required.

A further embodiment is shown in figure 23 in a side view. At least one spacer 860, 870, 880, 890 between the two cylindrical resonator sections may be used
15 for holding the resonator within the cavity. Here, the resonator sections preferably are glued together with the at least one spacer.

Figure 24 shows a sectional top view corresponding to figure 23. The at least one spacer 860, 870, 880, 890 is extended outwards so far that it may touch the walls of the cavity. Using thin strips, as shown in this figure provide enough space for
20 the coupling elements shown in figure 22. There may be any number of spacers. There may be multiple separated spacer sections. Also, the spacer sections or spacers may be combined to a single piece spacer. In this embodiment, the support plates are no more required.

Figure 25 shows a resonator 170 split into multiple sections 171, 172, 173, 174
25 allowing access to the electrical/magnetic fields pointing from one part to another. Preferably, each section is a cylinder section, most preferably having a sectional angle of about 90 degrees. It is preferred to have spaces between the

sections for inserting coupling elements 174, 175, 176, 177. In extension of the multiple dielectric resonators shown above, it is possible to use resonators which are split into more pieces (see above). This gives access to even more slits where tuning and coupling elements may be positioned. This embodiment allows to
5 hold a first coupling element 230, 250 in its position. In normal operation, by moving the first coupling element along the z-axis, the electrical field between the nearest resonator's face surface and the first coupling element are tuned. This tuning may also be done by pushing a dielectric rod or slab between the first coupling element and the dielectric resonator.

10 Figure 26 shows the above resonator in a sectional top view.

Figure 27 shows a resonator 180 split into first multiple sections 181, 182, 183, 184 and second multiple sections 185, 186, 187, 188 allowing extended access to the electrical/magnetic fields pointing from one part to another. The sections 181 and 183 are hidden behind the sections 184 and 183. Preferably, each of the
15 first and second sections is a cylinder section, most preferably having a sectional angle of about 90 degrees. It is preferred to have spaces between the sections for inserting coupling elements like the coupling elements 174, 175, 176, 177 shown in the previous figures. This embodiment allows to hold a first coupling element 230, 250 in its position. In normal operation, by moving the first coupling
20 element along the z-axis, the electrical field between the nearest resonator's face surface and the first coupling element are tuned. This tuning may also be done by pushing a dielectric rod or slab between the first coupling element and the dielectric resonator.

Figure 28 shows the above resonator in a sectional top view. Here, the second
25 resonator sections 185, 186, 187, 188 can be seen from the top. Sections 181, 182, 183, 184 which are not shown herein have basically the same shape and are positioned above the sections 185, 186, 187, 188.

Figure 29 shows a further embodiment having a resonator 150 comprising multiple stacked dielectric cylinders 151, 152 with different diameters. This embodiment shows a first resonator cylinder 151 having a larger diameter and a second resonator cylinder 152 having a smaller diameter. For the sake of pretuning, the coupling between the HEHx mode and the HEEEx mode as well as between the HEHy mode and the HEEy mode, different diameters and heights may be used for the cylindrical dielectric resonator sections. Thus, this may be used as an alternative for the displacement of the resonator along the z-axis.

Figures 30 shows a combination of tuning elements. A bar 232 is combined with coupling elements 801, 803 which may be moved radially into directions 802, 804. These directions preferably lie in line with the orientation of the bar. The coupling elements 801, 803 may have a cylindrical shape with circular or rectangular cross section.

Figure 31 shows an adjustable outer conductor 211 of the external coupling element 210. This outer conductor 211 is attached and/or connected to the housing 702 and preferably is cylindrically shaped. An outer thread may further be provided. By moving this outer conductor in or out, the reference plane may be altered and parasitic couplings between HEHx and HEEy, or HEHy and HEEEx may be nullified respectively. Combining this effect with the option to tune the coupling between HEEEx and HEEy with the help of the tuning rods or the cuboid tuning elements as mentioned above, it is possible to tune a filter without the need of a first coupling element 230, 250. This embodiment may also be applied to any other external coupling element.

List of reference numerals

100	dielectric resonator
101	dielectric resonator height
102	dielectric resonator diameter
103	outer section
104	inner section
105	first face surface
106	second face surface
107	first orthogonal plane
108	second orthogonal plane
109	dielectric resonator center axis
110	first support plate
111, 112, 113, 114	compensation plates
120	second support plate
150	stacked dielectric resonator
151	first resonator cylinder
152	second resonator cylinder
170	split dielectric resonator
171, 172, 173, 174	split resonator sections
175, 176, 177, 178	tuning elements
180	split dielectric resonator
181, 182, 183, 184	first split resonator sections
185, 186, 187, 188	second split resonator sections
210	first external coupling element
212	first external connector
220	second external coupling element
221	second external inner conductor
222	second external connector
230	bottom first internal coupling element
231	bottom first internal coupling element adjustment screw

232	bar
233, 234	support rods
235, 236	coupling button
237	axis of bar
238	angle between axis of bar and first orthogonal plane
240	top first internal coupling element
241	top first internal coupling element adjustment screw
242	bar
243, 244	support rods
245, 246	coupling buttons
250	second internal coupling element
251	second internal coupling element adjustment screw
252	second internal coupling element locking nut
260, 270, 280, 290	third internal coupling elements
410	first bottom tuning rod
420	second bottom tuning rod
430	third bottom tuning rod
432	third bottom tuning rod locking nut
440	fourth bottom tuning rod
510	first top tuning rod
520	second top tuning rod
530	third top tuning rod
532	third top tuning rod locking nut
540	fourth top tuning rod
630	first side tuning means
640	second side tuning means
642	second side tuning means locking nut
643	second side tuning means outer thread
645	second side tuning means locking nut
649	second side tuning means center axis

701	cover
702	housing
703	cover screws
704	screw holes
705	cavity
709	cavity center axis
711	dielectric resonator base height
712	inner height
713	inner diameter
760, 770, 780, 790	grooves
801, 803	coupling elements
802, 804	direction indicators
810, 820, 830, 840	coupling elements
811, 821, 831, 841	direction indicators
860, 870, 880, 890	spacers
901	source
902	load
911	HEHx mode
912	HEEx mode
913	HEEy mode
914	HEHy mode
921	coupling source – HEHx
922	coupling HEHx – HEHy
923	coupling HEHx – HEEy
924	coupling HEHx – HEEx
925	coupling HEEx – HEEy
926	coupling HEEx – HEHy
927	coupling HEEy – HEHy
928	coupling HEHy - load

Claims

1. A microwave or RF bandpass filter comprising:
 - a housing (702) of a conductive material defining a cylindrical cavity (705);
 - at least one cylindrical dielectric resonator (100) having an outer contour defined by a parallel pair of face surfaces (105, 106), each face surface having at least two symmetry axes, the dielectric resonator having a center axis (109),
 - wherein the dielectric resonator is held by holding means within the cavity, characterized in that
 - at least two tuning rods (410, 420, 430, 440, 510, 520, 530, 540) comprising a dielectric material are fastened to the housing (702) and protruding into the cavity (705) outside of the cylindrical dielectric resonator (100) and into a direction towards the center axis (109) above or under at least one of the face surfaces (105, 106) and whereby the projection of an end of at least one tuning rod in a direction parallel to the center axis is within one of the face surfaces (105, 106), and
 - at least one first internal coupling element (230, 240) comprising a conductive bar (232, 242) is provided in a plane orthogonal to the cylinder axis (109), and wherein
 - the at least one first internal coupling element (230, 240) is moveable parallel to the dielectric resonator center axis or
 - at least one of the tuning rods comprising a dielectric material is fastened to the housing and protruding into the cavity between the ends of the first internal coupling element and the dielectric resonator.
2. The microwave or RF bandpass filter according to claim 1, characterized in that

at least one tuning rod (410, 420, 430, 440, 510, 520, 530, 540) of the at least two tuning rods has a circular cross section.

3. The microwave or RF bandpass filter according to any one of the preceding claims,
characterized in that
if more than two tuning rods (410, 420, 430, 440, 510, 520, 530, 540) are provided, the at least two of the tuning rods (410, 420, 430, 440, 510, 520, 530, 540) are evenly arranged in a plane orthogonal to the center axis (109).
4. The microwave or RF bandpass filter according to any one of the preceding claims,
characterized in that
one, two or four of the tuning rods (410, 420, 430, 440) are arranged in a first plane above and parallel to a first face surface (105) of the pair of face surfaces and further, one, two or four of the tuning rods (510, 520, 530, 540) are arranged in a second plane above and parallel to a second face surface (106) of the pair of face surfaces.
5. The microwave or RF bandpass filter according to any one of the preceding claims,
characterized in that
the at least one conductive bar (232, 242) comprises a coupling button (235, 245, 236, 246) at each end.
6. The microwave or RF bandpass filter according to any one of the preceding claims,
characterized in that
the at least one dielectric resonator (150) comprising at least two different

sections (151, 152), each section having an outer contour defined by a parallel pair of face surfaces, each face surface having at least two symmetry axes, and the dielectric resonator having a center axis (109).

7. The microwave or RF bandpass filter according to any one of the preceding claims,
characterized in that
the at least one cylindrical dielectric resonator (100) having an outer contour defined by a parallel pair of circular face surfaces (105, 106) and/or the dielectric resonator comprises two cylindrical outer sections (103) distant from each other and may have at least one cylindrical inner section (104) between the outer sections.
8. The microwave or RF bandpass filter according to any one of the preceding claims,
characterized in that
the holding means comprise at least one support plate of a dielectric material, arranged parallel to at least one of the face surfaces (105, 106), which is further held by the housing.
9. The microwave or RF bandpass filter according to any one of the preceding claims,
characterized in that
the dielectric resonator comprises a ceramic material and/or
the ratio of dielectric resonator diameter (102) to dielectric resonator height (101) is in the range of 0.9 to 3.1 or in the range between 1.7 and 2.3.
10. The microwave or RF bandpass filter according to any one of the preceding claims,

characterized in that

the bandpass filter further comprises at least one external coupling element (210, 220) which extends from the housing orthogonally to the dielectric resonator center axis (109) and/or

the at least one first internal coupling element (230, 240) is provided above and/or below the cylindrical dielectric resonator (100).

11. The microwave or RF bandpass filter according to any one of the preceding claims,
characterized in that
the bandpass filter further comprises at least one of a plurality of conductive third internal coupling elements (260, 270, 280, 290) which is protruding into the cavity (705) and being arranged within a plane orthogonally to the dielectric resonator center axis (109) above or under the dielectric resonator.
12. The microwave or RF bandpass filter according to any one of the preceding claims,
characterized in that
the dielectric resonator is displaced axially with respect to the center of the cavity for coupling from the HEH_x mode and the HEH_y mode to a HEE_x and a HEE_y mode.
13. The microwave or RF bandpass filter according to any one of the preceding claims,
characterized in that
the dielectric material of the dielectric components with exception of the dielectric resonator itself has a dielectric constant which is lower than the dielectric constant of the material of the dielectric resonator and/or has a

thickness which is significantly less than the height of the dielectric resonator.