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(54) **Multi-mode resonant device**

(57) A multi-mode resonant device and a method are disclosed. The multi-mode resonant device comprises: a unitary dielectric substrate operable to produce resonant modes in response to an input signal; a plurality of mode-coupling structures operable to couple the resonant modes of the unitary dielectric substrate; and a conductive enclosure spaced away from the unitary dielectric substrate by the plurality of mode-coupling structures. By reusing the mode coupling structures, which need to be present anyway in order to provide for the mode coupling, the dielectric substrate can be suspended within the conductive enclosure using a minimal structure, thereby minimising losses and maximising the Q of the resonant device.

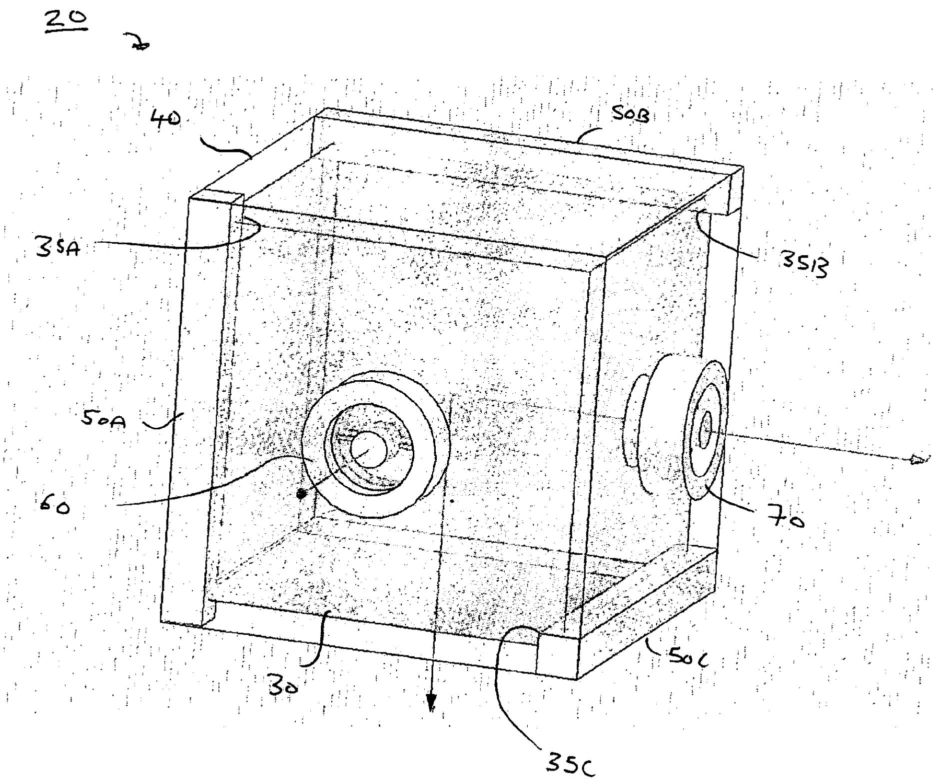

FIG 2

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a multi-mode resonant device and a method.

BACKGROUND

[0002] Resonant devices are known. In low-frequency electronics, a resonant circuit contains a capacitor and a coil. The capacitor is used to store electrical energy and the coil stores magnetic energy. At resonance, energy stored in the resonant circuit is continuously converted between two states, swapping between capacitor and coil over time. At higher frequencies, transmission lines can resonate. A half-wavelength transmission line with both ends open can be seen as a combination of a capacitor and coil, or as a travelling wave on the line, the wave being reflected at the ends of the line and bouncing back and forth to give a standing wave. Increasing the permittivity of the transmission line by using, for example, ceramic materials reduces the size of the resonator device. Ceramic resonator devices are often used in radiofrequency (RF) front ends. Such high-permittivity, low-dissipation ceramics are typically complex mixtures of various materials. Each resonator device has its own characteristics, including its own resonance frequency. The resonance frequency is dependent on the characteristics of the device and, in particular, on the characteristics of the mixtures of various materials making up the device.

[0003] It is desired to provide an improved resonant device.

SUMMARY

[0004] According to a first aspect, there is provided a multi-mode resonant device, comprising: a unitary dielectric substrate operable to produce resonant modes in response to an input signal; a plurality of mode-coupling structures operable to couple the resonant modes of the unitary dielectric substrate; and a conductive enclosure spaced away from the unitary dielectric substrate by the plurality of mode-coupling structures.

[0005] The first aspect recognises that a problem with multi-mode resonant devices is being able to provide a device with a sufficiently high quality factor (Q). In particular, the first aspect recognises that losses occur due to contact between the dielectric substrate and any surrounding conductive enclosure. This is a particular problem where the surrounding conductive enclosure is deposited directly on the surface of the dielectric substrate. Whilst spacing the conductive enclosure away form the dielectric substrate helps to reduce these losses and improve the Q of the device, the presence of any spacing material between the conductive enclosure and the dielectric substrate can unnecessarily contribute to these losses and degrade the Q of the device.

[0006] Accordingly, a unitary or single element dielectric substrate may be provided which produces resonant modes in response to an input signal. Mode coupling structures may be provided which facilitate the coupling of the resonant modes within the dielectric substrate. A conductive enclosure may be provided which is spaced away from the dielectric substrate by the mode coupling structures to create a gap between the dielectric substrate and the conductive enclosure.

[0007] The first aspect recognises that mode-coupling structures are required to enable the modes to be propagated within the dielectric structure. The first aspect also recognises that it is possible to reuse these mode-coupling structures to provide the necessary spacing or gap between the conductive enclosure and the dielectric substrate without needing any other structures to achieve this spacing. By reusing the mode coupling structures, which need to be present anyway in order to provide for the mode coupling, the dielectric substrate can be suspended within the conductive enclosure using a minimal structure, thereby minimising losses and maximising the Q of the resonant device. Accordingly, it can be seen that such an approach provides for a device having a high Q.

[0008] In one embodiment, the unitary dielectric substrate comprises a monolithic body. Accordingly, the dielectric substrate may be a monolithic or solid body (i.e. a single, non-composite structure having no holes or voids through the substrate). In one embodiment, the dielectric substrate may be jointless.

[0009] In one embodiment, the unitary dielectric substrate comprises a ceramic body. Ceramics typically provide a high permittivity.

[0010] In one embodiment, the unitary dielectric substrate is a solid prismatoid. Such a prismatoid may be shaped to provide a resonant device having the desired resonant modes.

[0011] In one embodiment, the unitary dielectric substrate is a solid cuboid. Such a cuboid may be shaped to provide a resonant device having the desired resonant modes at similar or matching frequencies. It will be appreciated that the cuboid may not be a completely regular cuboid but may have dimensions which differ in each of the axes. In one embodiment, each of the plurality of mode-coupling structures is disposed between the unitary dielectric substrate and the conductive enclosure. Accordingly, the spacing or gap between the dielectric substrate and the conductive enclosure may be achieved by placing the mode coupling structures between the dielectric substrate and the conductive enclosure, thereby using the mode coupling structures for both mechanical and electrical purposes.

[0012] In one embodiment, each of the plurality of mode-coupling structures is disposed against the unitary dielectric substrate. Accordingly, the mode coupling structures may be placed directly in contact with the dielectric substrate in order to facilitate the coupling of the resonant modes.

[0013] In one embodiment, the plurality of mode-coupling structures and the unitary dielectric substrate are provided with complimentarily-shaped surfaces to facilitate contact therebetween. Accordingly, the mode coupling structures and the dielectric substrate may be shaped to enhance the contact between them. For example, either the mode-coupling structures or the dielectric substrate may present a generally-convex surface and the other may provide a complimentary generally-concave surface. Likewise, both may be provided with complimentary chamfered or bevelled surfaces. The shaping of the surfaces may be in order to both enhance the mode coupling within the dielectric substrate and to enhance the mechanical retention of the dielectric substrate within the conductive enclosure.

[0014] In one embodiment, one of the unitary dielectric substrate and the plurality of mode-coupling structures is provided with recesses shaped to receive the other.

[0015] In one embodiment, each of the plurality of mode-coupling structures is elongate and are arranged to extend along a corresponding unitary dielectric substrate edge. Accordingly, the mode-coupling structures may be provided along edges of the dielectric substrate. Providing the mode-coupling structures at the edges enhances the mode coupling within the dielectric substrate, minimises the surface contact of the mode coupling structures with the dielectric substrate (and therefore reduces losses), as well as facilitates the spacing of the dielectric substrate from the conductive enclosure.

[0016] In one embodiment, each of the plurality of mode-coupling structures are arranged to extend along at least an entire length of the corresponding unitary dielectric substrate edge. Providing mode coupling structures which extend along the length of the edges both enables uniform mode coupling and enables good mechanical support of the dielectric substrate when suspended within the conductive enclosure.

[0017] In one embodiment, each of the plurality of mode-coupling structures are arranged to extend beyond the length of the corresponding unitary dielectric substrate edge. Accordingly, the mode coupling structures may be longer than the edges or may extend beyond those edges in order to provide for spacing in other axes.

[0018] In one embodiment, at least one of the plurality of mode-coupling structures is provided along diametrically-opposing unitary dielectric substrate edges extending in at least two orthogonal axes.

[0019] In one embodiment, at least one of the plurality of mode-coupling structures is provided along at least one unitary dielectric substrate edge extending in each of three orthogonal axes. Providing a mode coupling structure extending along each orthogonal axis helps to enable coupling of each mode and enables spacing and support of the dielectric substrate within the conductive enclosure in each axis.

[0020] According to a second aspect, there is provided a method of constructing a multi-mode resonant device, comprising the steps of: providing a unitary dielectric substrate operable to produce resonant modes in response to an input signal; providing a plurality of mode-coupling structures operable to couple the resonant modes of the unitary dielectric substrate; and spacing a conductive enclosure away from the unitary dielectric substrate using the plurality of mode-coupling structures.

[0021] In one embodiment, the unitary dielectric substrate comprises a monolithic body.

[0022] In one embodiment, the unitary dielectric substrate comprises a ceramic body.

[0023] In one embodiment, the unitary dielectric substrate is a solid prismatoid.

[0024] In one embodiment, the unitary dielectric substrate is a solid cuboid.

[0025] In one embodiment, the step of spacing comprises disposing each of the plurality of mode-coupling structures between the unitary dielectric substrate and the conductive enclosure.

[0026] In one embodiment, the step of spacing comprises disposing each of the plurality of mode-coupling structures against the unitary dielectric substrate.

[0027] In one embodiment, the plurality of mode-coupling structures and the unitary dielectric substrate are provided with complimentarily-shaped surfaces to facilitate contact therebetween.

[0028] In one embodiment, one of the unitary dielectric substrate and the plurality of mode-coupling structures is provided with recesses shaped to receive the other.

[0029] In one embodiment, each of the plurality of mode-coupling structures are elongate and the step of spacing comprises arranging each of the plurality of mode-coupling structures to extend along a corresponding unitary dielectric substrate edge.

[0030] In one embodiment, the step of spacing comprises arranging each of the plurality of mode-coupling structures to extend along at least an entire length of the corresponding unitary dielectric substrate edge.

[0031] In one embodiment, the step of spacing comprises arranging each of the plurality of mode-coupling structures to extend beyond the length of the corresponding unitary dielectric substrate edge.

[0032] In one embodiment, the step of spacing comprises providing at least one of the plurality of mode-coupling structures along diametrically-opposing unitary dielectric substrate edges extending in at least two orthogonal axes.

[0033] In one embodiment, the step of spacing comprises providing at least one of the plurality of mode-coupling structures along at least one unitary dielectric substrate edge extending in each of three orthogonal axes.

[0034] Further particular and preferred aspects of the present invention are set out in the accompanying independent and dependent claims. Features of the dependent claims may be combined with features of the independent claims as appropriate, and in combinations other than those explicitly set out in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] Embodiments of the present invention will now be described further, with reference to the accompanying drawings, in which:

Figure 1 illustrates an example resonator device; and
Figure 2 illustrates a resonator device according to one embodiment.

DESCRIPTION OF THE EMBODIMENTS

[0036] Figure 1 illustrates the principle construction and operation of a resonant device, generally 10, which exhibits several resonant modes. To help improve clarity, only the dielectric material 10 is shown around which a metallic structure is formed. An electromagnetic field is applied to the structure and the dielectric material resonates at specific frequencies. Such resonance is known as a mode. Such a resonant device may often be used in a radio frequency (RF) filter. The physical size of the resonant device can be reduced (for a given resonance frequency) by increasing the permativity of the dielectric material filing the resonator. This can be done completely or partially. For a homogeneously-filled resonator device, the resonance frequency decreases as a square route of the relative permativity of the device. A typical resonant device exhibits several resonance modes with a similar or closely nearby resonant frequency. Such a device is useful because multi-resonator structures such as filters can use the same physical resonator device more than once, thereby providing a volume-saving solution. In the example shown, a perfect cube exhibits three orthogonal (in other words independent) resonant modes at the same frequency. By slightly deviating from the cubic shape, resonant modes at different frequencies can be achieved. As will be explained in more detail below, if coupling discontinuities are added to couple between the modes, a multi-resonant filter with the form factor of a single resonant device is provided.

[0037] Before discussing the embodiments in any more detail, in overview, an approach is provided in which air is used to fill the critical gap between the ceramic and the outer metal enclosure. This is because air is an effective (lossless) dielectric for filling the gap (although, of course, other gases or a vacuum could be used). By utilising existing chamfered or cut edges used for electrical mode couplings to mechanically support the ceramic cube in air, any need to fill the gap with a more lossy dielectric (which leads to a lower Q for the device) is obviated. In this way, an easily manufacturable device is provided which achieves a high Q.

[0038] Figure 2 illustrates a triple-mode resonator device, generally 20, according to one embodiment. The triple-mode resonator device 20 comprises a dielectric 30 suspended within a metallic outer metal enclosure 40 using metallic coupling strips 50A-50C. Coupled with the outer metal enclosure 40 is an input port 60 for receiving an input signal to be filtered and an output port 70 for outputting the filtered signal.

[0039] The ceramic cube 30 is made from a suitable dielectric material and is dimensioned to cause resonance to occur at the desired frequencies. The ceramic cube 30 is a single, continuous, monolithic ceramic. In this example, the ceramic cube 30 is provided with three recesses 35A-35C which extend along the lengths of three edges of the ceramic cube 30. In this example, a rebate is cut along the edges which are shaped to receive the coupling strips 50A-50C. Although in this example a square-shaped rebate is cut along the edges, it will be appreciated that a different shaped rebate may be used which matches the outer profile of the coupling strips 50A-50C. For example, a curved profile may instead be cut to fit a similarly curved profile on the coupling strips 50A-50C. Alternatively, the edges may be chamfered. Also, rather than the rebate being cut into the ceramic cube 30, it will be appreciated that instead a rebate may be cut into the coupling strips 50A-50C.

[0040] The interaction between the ceramic cube 30 and the coupling strips 50A-50C provides two functions. The first is to provide for mode coupling within the ceramic cube 30. The second is to cause the ceramic cube 30 to become located away from the metallic enclosure 40. Locating the ceramic cube 30 away from the metallic enclosure 40 provides for an air gap between the ceramic cube 30 and the metal enclosure 40, which helps to reduce losses and improve the Q of the device. By suspending the cube using the coupling strips 50A-50C within the metal enclosure, the amount of support material occupying the gap between the metal enclosure 40 and the ceramic cube 30 is reduced which also helps to minimise any losses and improves the Q of the device. Although in this arrangement the coupling strips 50A-50C extend along the entire length of the edges, it will be appreciated that this need not be the case and instead the coupling strips 50A-50C may only be provided at positions along the edges (although this may impact on the mode coupling and other characteristics of the device). Also, whilst the coupling strips 50A-50C are configured to protrude beyond the edge of the ceramic cube 30, which assists in locating the coupling strips within the metal enclosure 40 and helps with the spacing of the ceramic cube 30 within the metal enclosure 40, the coupling strips 50A-50C need not extend beyond the length of the edges of the ceramic cube 30. Furthermore, although a coupling strip is located on one edge of each of the three orthogonal axes of the ceramic cube 30 (which provides for a minimal support structure), it will be appreciated that the coupling strips may be provided on more edges, if required.

[0041] Hence, it can be seen that a multi-mode filter design with a ceramic cube that is partially suspended in air by three mechanical support structures is provided. These support structures also provide the critical electrical mode couplings within the filter.

[0042] Accordingly, instead of depositing the conductor directly onto the ceramic, having a small air gap between the ceramic and the conductor improves the Q of the filter. Having the air gap contributes to the increase in Q; an ideal filter design is one with the ceramic cube suspended in air since any support material occupying the air gap will inadvertently degrade the Q.

[0043] Hence, rather than using a dedicated spacer to hold the ceramic cube in place (which compromises the Q of the filter because all spacer materials have finite losses; causes difficulty in finding extremely low-loss spacer materials; and requires extra assembly steps for the spacer materials during manufacturing), instead, the coupling strips are reused to provide for such suspension of the ceramic cube within the conductive enclosure. Since the ceramic cube used in a multi-mode filter has to be chamfered or cut at all three edges to allow couplings of the three modes to form a filter, metal conductors can be placed at those chamfered edges to partially suspend and also to secure the ceramic in air. Those conductors serve dual purposes: as a means for electrical mode coupling and also as mechanical supports for the ceramic cube. In this way, the critical air gap structure necessary to provide high Q can be achieved without additional dielectric materials, less material is required, less assembly steps are required, and therefore a superior device can be made which is cheaper and easier to manufacture.

[0044] The description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass equivalents thereof.

Claims

1. A multi-mode resonant device, comprising:

a unitary dielectric substrate operable to produce resonant modes in response to an input signal;
a plurality of mode-coupling structures operable to couple said resonant modes of said unitary dielectric substrate; and
a conductive enclosure spaced away from said unitary dielectric substrate by said plurality of mode-coupling structures.

2. The multi-mode resonant device as claimed in claim 1, wherein said unitary dielectric substrate comprises a monolithic body.

3. The multi-mode resonant device as claimed any preceding claim, wherein said unitary dielectric substrate comprises a ceramic body.

4. The multi-mode resonant device as claimed in any preceding claim, wherein said unitary dielectric substrate is a solid prismatoid.

5. The multi-mode resonant device as claimed in any preceding claim, wherein said unitary dielectric substrate is a solid cuboid.

6. The multi-mode resonant device as claimed in any preceding claim, wherein each of said plurality of mode-coupling structures are disposed between said unitary dielectric substrate and said conductive enclosure.

7. The multi-mode resonant device as claimed in any preceding claim, wherein each of said plurality of mode-coupling structures is disposed against said unitary dielectric substrate.

8. The multi-mode resonant device as claimed in any preceding claim, wherein said plurality of mode-coupling structures and said unitary dielectric substrate are provided with complimentarily-shaped surfaces to facilitate contact therebetween.

9. The multi-mode resonant device as claimed in any preceding claim, wherein one of said unitary dielectric substrate and said plurality of mode-coupling structures is provided with recesses shaped to receive the other.

10. The multi-mode resonant device as claimed in any preceding claim, wherein each of said plurality of mode-coupling structures are elongate and are arranged to extend along a corresponding unitary dielectric substrate edge.

11. The multi-mode resonant device as claimed in any preceding claim, wherein each of said plurality of mode-coupling structures are arranged to extend along at least an entire length of said corresponding unitary dielectric substrate edge.

12. The multi-mode resonant device as claimed in any preceding claim, wherein each of said plurality of mode-coupling structures are arranged to extend beyond said length of said corresponding unitary dielectric substrate edge.

13. The multi-mode resonant device as claimed in any preceding claim, wherein at least one of said plurality of mode-coupling structures is provided along diametrically-opposing unitary dielectric substrate edges extending in at least two orthogonal axes.

14. The multi-mode resonant device as claimed in any preceding claim, wherein at least one of said plurality of mode-coupling structures is provided along at least one unitary dielectric substrate edge extending in each of three orthogonal axes.

15. A method of constructing a multi-mode resonant device, comprising the steps of:

providing a unitary dielectric substrate operable to produce resonant modes in response to an input signal;
providing a plurality of mode-coupling structures operable to couple said resonant modes of said unitary dielectric substrate; and
spacing a conductive enclosure away from said unitary dielectric substrate using said plurality of mode-coupling structures.

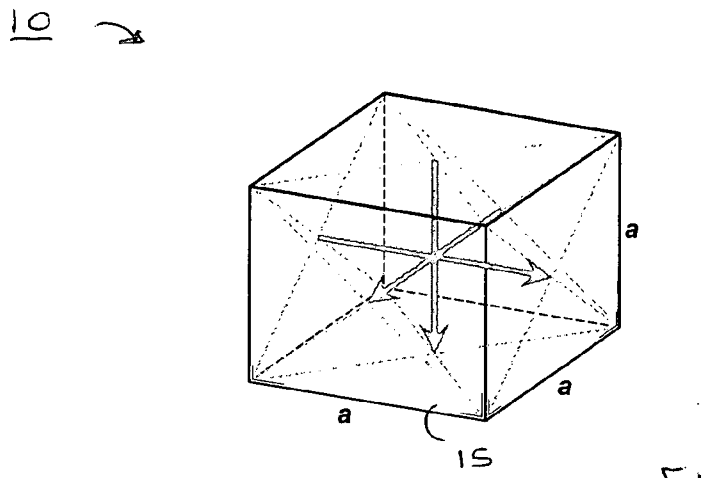

FIG 1

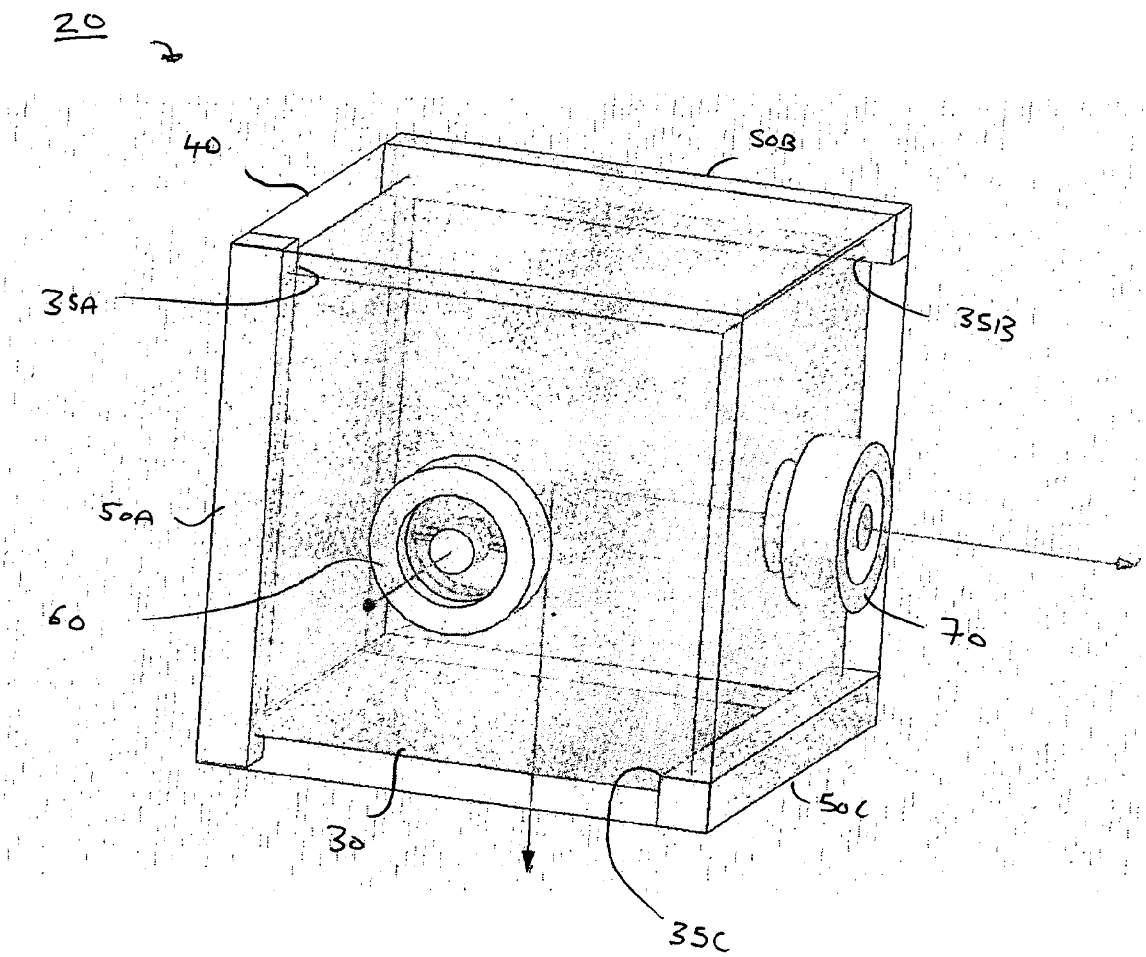

FIG 2

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EUROPEAN SEARCH REPORT

Application Number
EP 09 36 0050

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	1 February 2011	Pastor Jiménez, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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