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(54) **RESONATOR**

(57) An apparatus is disclosed, comprising a dielectric substrate comprising first and second surfaces and first and second electrically conductive elements respectively provided on the first and second surfaces. A post wall is provided by a plurality of electrically conductive posts, each of which is on or passes through the substrate to interconnect the first and second electrically conductive elements, the post wall defining a waveguide region in the substrate. The apparatus may also comprise a res-

onator comprising one or more first resonator elements extending from the first electrically conductive element and into the waveguide region, the one or more first resonator elements not contacting the second electrically conductive element, and one or more second resonator elements extending from the second electrically conductive element and into the waveguide region, the one or more second resonator elements not contacting the first electrically conductive element.

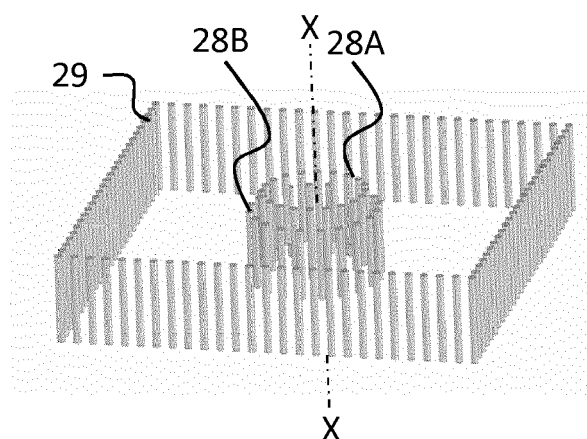


Fig. 2C

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Description

Field

[0001] This invention relates to resonators and method of manufacture thereof.

Background

[0002] Radio frequency (RF) filters may comprise one or more resonators. A resonator is a device or system that exhibits resonant behaviour.

[0003] In the field of mobile communication networks, base transceiver stations (BTS) use RF filters, for example for reducing interference by rejecting out-of-band signals that may interfere with transmission and/or reception. For example, a low-pass RF filter is commonly used in BTS filter units for removing or attenuating harmonic interference signals from the stopband. For example, a BTS duplexer may comprise a filter, able to separate transmit and receive channels. Filtering systems may employ a plurality of different resonators.

[0004] In order to achieve a desired performance, cavity filters may be employed, which typically comprise a resonator within a conducting box defining an interior cavity which acts as a waveguide. The cavity may comprise dielectric material.

Summary

[0005] The scope of protection sought for various embodiments of the invention is set out by the independent claims. The embodiments and features, if any, described in the specification that do not fall under the scope of the independent claims are to be interpreted as examples useful for understanding various embodiments of the invention.

[0006] According to a first aspect, there is provided an apparatus comprising: a dielectric substrate comprising first and second surfaces; first and second electrically conductive elements respectively provided on the first and second surfaces; a post wall provided by plurality of electrically conductive posts, each of which is on or passes through the substrate to interconnect the first and second electrically conductive elements, the post wall defining a waveguide region in the substrate; and a resonator comprising one or more first resonator elements extending from the first electrically conductive element and into the waveguide region, the one or more first resonator elements not contacting the second electrically conductive element, and one or more second resonator elements extending from the second electrically conductive element and into the waveguide region, the one or more second resonator elements not contacting the first electrically conductive element.

[0007] The first and second substrate surfaces may be substantially opposite one another.

[0008] The one or more first resonator elements and

the one or more second resonator elements may be arranged substantially parallel with one another in the waveguide region.

[0009] The one or more first resonator elements and the one or more second resonator elements may extend into the waveguide region in substantially opposite directions and may at least partially overlap when viewed from a direction which is substantially non-parallel to the extent of the one or more first and second resonator elements

[0010] The apparatus may comprise a plurality of said first resonator elements, spatially arranged so as to provide in a section of the waveguide region a substantially circular shape, or other suitable shape.

[0011] The apparatus may comprise a plurality of said second resonator elements, spatially arranged to provide in the section of the waveguide region a substantially circular shape, or other shape, which is concentric with that provided by the plurality of first resonator elements.

[0012] The one or more first and second resonator elements may comprise electrically conductive posts.

[0013] The dielectric substrate may be a ceramic material, or an organic or polymer material.

[0014] The post wall may define a plurality of adjacent waveguide regions within the dielectric substrate, and the apparatus may further comprise a signal coupling means between the adjacent waveguide regions, and wherein a said resonator may be provided in each of the waveguide regions.

[0015] The apparatus may provide a filter apparatus for a telecommunications base station.

[0016] According to another aspect, there is provided a method comprising: providing first and second electrically conductive elements respectively on first and second surfaces of a dielectric substrate; providing a post wall comprising a plurality of electrically conductive posts such that each is on or passes through the substrate to interconnect the first and second electrically conductive elements, the post wall defining a waveguide region in the substrate; and providing a resonator comprising one or more first resonator elements extending from the first electrically conductive element and into the waveguide region, the one or more first resonator elements not contacting the second electrically conductive element, and one or more second resonator elements extending from the second electrically conductive element and into the waveguide region, the one or more second resonator elements not contacting the first electrically conductive element.

[0017] The first and second substrate surfaces may be provided substantially opposite one another. The provided one or more first resonator elements and the one or more second resonator elements may be arranged substantially parallel with one another in the waveguide region. The provided one or more first blind resonator elements and the one or more second blind resonator elements may extend into the waveguide region in substantially opposite directions and at least partially overlap when viewed from a direction which is substantially non-

parallel to the extent of the one or more first and second resonator elements. The method may further comprise providing a plurality of said first resonator elements, spatially arranged so as to provide in a section of the waveguide region a substantially circular shape, although other shapes may be employed. The one or more first and second resonator elements may comprise electrically conductive posts. The dielectric substrate may be a ceramic material, or an organic or polymer material. The post wall may define a plurality of adjacent waveguide regions within the dielectric substrate, and the method may further comprise providing a signal coupling means between the adjacent waveguide regions, and wherein a said resonator may be provided in each of the waveguide regions.

Brief Description of the Drawings

[0018] The present disclosure will now be described, by way of non-limiting example, with reference to the drawings in which:

Figure 1 is a representational view of a cellular base transceiver station (BTS);

Figure 2A is a partially-exploded perspective view of an apparatus according to an example embodiment; Figure 2B is a plan view of part of the Figure 2A apparatus;

Figure 2C is a perspective view of the Figure 2A apparatus, showing only the post-wall and resonator elements;

Figure 2D is a sectional view of the Figure 2A apparatus;

Figure 3A shows graphical output of a computer simulation performed on the Figure 2A apparatus, representing the electric field distribution;

Figure 3B shows graphical output of a computer simulation performed on the Figure 2A apparatus, representing the magnetic field distribution;

Figure 3C shows graphical output of a computer simulation performed on the Figure 2A apparatus, representing the surface current density at the fundamental mode;

Figure 4 is a partial perspective view of an apparatus according to another example embodiment;

Figure 5 is a graph showing computer simulated test results of the Figure 4 apparatus;

Figure 6 is a flow diagram showing operations for producing an apparatus according to one or more example embodiments;

Figure 7A is a perspective view of a hybrid resonator structure, comprising the Figure 4 apparatus and a cavity resonator;

Figure 7B is a side sectional view of the Figure 7A hybrid resonator structure;

Figure 8A is a perspective view of the Figure 4 apparatus having a micro strip feed or filtering structure;

Figure 8B is a plan view of the Figure 8A apparatus;

and

Figure 9 is a plan view showing how one or more further sets of resonator elements may be incorporated into the Figure 1A - 1D structure.

Detailed Description

[0019] Embodiments described herein relate to resonators, for example as may be used in filters and also to filter systems that may comprise one or more of said resonators. The resonators described herein may however be used in any field or application.

[0020] Embodiments particularly, though not exclusively, relate to radiofrequency (RF) resonators and filters. Embodiments may also relate to methods of manufacture of such resonators and filters.

[0021] Embodiments particularly, though not exclusively, relate to RF filters for use in base transceiver stations (BTS) of mobile communications networks.

[0022] Growth in the mobile telecommunications industry has brought about advances in filter technology as new communications systems emerge, requiring more stringent filter characteristics, for example in terms of low-cost, high volume production, compactness and integration. Other desirable characteristics may include high-Q (low loss) characteristics and/or sharp cut-off.

[0023] Compactness may refer to how small the volume occupied by a resonator is, whilst providing required RF performance. Integration may refer to how one can provide one or more of such resonators on a chip or substrate, possibly with other components. Next generation communications standards, such as the 5G standard, may involve larger numbers of devices in telecommunications equipment such as the BTS. There is therefore a need for lower physical volume filters and / or high integration. Cost is also a factor.

[0024] Substrate integrated waveguides (SIW) may be used for the transmission of electromagnetic waves, generally being planar structures similar to integrated circuits (ICs). As such, they can be fabricated using standard IC or printed circuit board (PCB) processes and integrated into ICs providing one or more other resonators or other functionality. Example embodiments may employ SIW processes to provide one or more resonators, for example for 5G and/or other mm-wave systems.

[0025] Figure 1 shows a simplified cellular BTS 1 which may be part of, or associated with, an antenna tower 3 carrying one or more RF antennas 5 in signal communication with the BTS 1 using one or more conductors 7. The BTS 1 is usually housed in an enclosure located at or near the base of the antenna tower 3, but it is also known to provide the BTS or at least the radio head towards the top of the antenna tower, closely coupled to the antenna, to minimise feeder cable loss which may increase with higher frequencies, and may be a driving factor for lower size and weight of such equipment. The BTS 1 is in signal communication with a backhaul communications system 11 which provides intermediate links

to a core network. Within the BTS 1 are provided various analogue and digital signal processing modules. For example, one or more RF filter units 9 may be provided which employ one or more resonators.

[0026] A plurality of RF filter units 9 may be provided, serving different purposes. These may be low-pass, high-pass and/or band-pass filter units.

[0027] For example, a RF filter unit 9 may comprise one or more low-pass filters for removing or attenuating spurious signals from the stopband. Such spurious signals may, for example, result from harmonic interference.

[0028] For example, the RF filter unit 9 may comprise one or more band-pass filters for passing a selected range of frequencies whilst rejecting out-of-band frequencies. The RF filter unit 9 may for example comprise a duplexer for microwave telecommunication applications. Duplexers are provided at base stations, as represented in Figure 1, for enabling both transmit and receive channels to use the same filter unit.

[0029] The RF filter unit 9 may comprise an enclosure housing or providing one or more filters of one or more of the low-pass, high-pass and band-pass types.

[0030] Embodiments herein concern single and multi-mode cavity filters. Cavity filters typically comprise one or more resonators within a conducting box which defines an interior cavity within which signals propagate. The cavity provides an internal waveguide for RF signals. Cavity filters offer a high-Q (low loss) characteristic and sharp cut-off, particularly when used with one or more dielectric resonators.

[0031] Multi-mode filters typically implement two or more resonators in a single physical body, such that reductions in filter size can be obtained. Thus, a multi-mode filter may have two or more resonant peaks at different predetermined frequencies. Dielectric resonators, which may be comprised within the cavity of the cavity filter, may be used to provide the different modes at respective resonant frequencies, which may be determined by the dimensions of the dielectric resonator. A ceramic block is an example dielectric that is typically coated in a metallic layer, for example silver, to provide the cavity and prevent leakage of RF energy which will adversely affect the filter performance.

[0032] Embodiments herein describe cavity filters which comprise one or more dielectric resonators, wherein the dielectric material used may be ceramic, for example low temperature co-fired ceramic (LTCC) which may be produced in accordance with example embodiments using LTCC techniques. LTCC may provide a multi-layer glass ceramic substrate which is co-fired with low resistance conductors such as copper at a low firing temperature, usually below 1000 degrees centigrade. LTCC production is generally low cost.

[0033] In overview, example embodiments provide an apparatus comprising a dielectric substrate comprising first and second surfaces, with first and second electrically conductive elements respectively provided on the first and second surfaces. The dielectric substrate may

comprise any suitable substrate such as ceramic / LTCC. The conductive elements may comprise metal, for example metalized layers deposited on the respective first and second surfaces. Example embodiments may also comprise a post wall provided by plurality of electrically conductive posts, e.g. vias to use IC fabrication terminology, each of which is on or which passes through the substrate to interconnect the first and second electrically conductive elements. The post wall may define a waveguide region in the substrate. A resonator may be provided comprising one or more first resonator elements, connected to, and extending from, the first electrically conductive element and into the waveguide region, but not contacting the second electrically conductive element, and also one or more second resonator elements, connected to, and extending from, the second electrically conductive element and into the waveguide region but not contacting the first electrically conductive element.

[0034] The term "blind resonator element" may be used hereinafter to refer to such resonator elements that are directly and/or electrically connected at one part to one of the electrically conductive elements but which have a free end within the waveguide region not contacting the other conductive element.

[0035] A post wall comprises a plurality of discrete, generally elongate posts which may be formed of metal. The posts may synthesise an electromagnetic waveguide by virtue of their spatial arrangement, which may need to be of a suitable density, i.e. with adjacent posts sufficiently close to suitably contain electromagnetic energy. Posts may comprise metallized "via holes" as well as solid elongate structures. The posts electrically connect the first and second conductors on the respective surfaces and hence may extend all the way through the substrate or they may be provided on the outer surface of the substrate, e.g. on or partially within a side wall. The arrangement of post walls may provide similar guided wave and mode characteristics to conventional waveguides, but are cheaper to produce and are lighter.

[0036] A blind resonator element, on the other hand, may be formed and arranged similar to a post of the post wall, being either a solid post or plated via hole, but is one that does not extend all the way between the first and second conductors; rather, one part or end is connected to, say, the first conductor and the other terminates within the substrate, stopping short of the second conductor.

[0037] The dielectric substrate may comprise a substantially cuboid block of material, having six rectangular sides, including first and second major surfaces, usually opposite one another, which carry the first and second conductors respectively. The first and second conductors may be metalized plates, which are substantially planar, and which may be deposited on the first and second major surfaces in the conventional way.

[0038] The one or more first blind resonator elements and the one or more second blind resonator elements may be arranged substantially parallel with one another

in the waveguide region. For example, the first blind resonator elements may extend generally downwards from the first conductor and the second blind resonator elements may extend generally upwards from the second conductor. They may therefore extend into the waveguide region in substantially opposite directions and may at least partially overlap, i.e. when viewed from a direction perpendicular to the major surfaces, or, put another way, when viewed from a direction which is substantially non-parallel to the extent of the one or more first and second resonator elements.

[0039] In some embodiments, the first blind resonator elements may be spatially arranged so as to provide in a section of the waveguide region a substantially circular shape, although other shapes such as rectangular oval or elliptical shapes may be provided. Similarly, the plurality of second blind resonator elements may be spatially arranged to provide in the section of the waveguide region a substantially circular, or other alternative shape, which may be concentric, i.e. sharing the same axis, within the shape provided by the plurality of first blind resonator elements when viewed from above or below. For example, referring briefly to FIG. 2C, the plurality of second blind resonator elements may share substantially the same vertical axis X-X as that of plurality of first blind resonator elements.

[0040] Figure 2A is a partially-exploded perspective view of an apparatus 20 according to an embodiment. The apparatus 20 comprises a cuboid block of a solid substrate 22, having upper and lower major surfaces 23A, 23B and four side surfaces. In some embodiments, the substrate 22 may be partially filled with another substance, such as air. The upper surface 23A has a first metal layer 24 deposited thereon and the lower surface 23B a second metal layer 26 deposited thereon. The first and second metal layers 24, 26 may be substantially planar. A first plurality of blind resonator elements 28A are each connected at one end to the first metal layer 24 and extend into substrate 22 but stop short of the second metal layer 26. The arrangement of the first blind resonator elements 28A is substantially that of a circle, when viewed from above, as shown in Figure 2B. Collectively, the first blind resonator elements 28A provide part of a resonator.

[0041] Similarly, and as shown more clearly in Figure 2C, a second plurality of blind resonator elements 28B are each connected at one end to the second metal layer 26 (not shown) and extend into the substrate 22 in the opposite direction to that of the first plurality of blind resonator elements 28A, but stop short of the first metal layer 24. The arrangement of the second blind resonator elements 28B is substantially that of a circle, when viewed from above, as shown in Figure 2D. It will be understood that the first and second blind resonator elements 28A, 28B partially overlap when viewed from one side, e.g. when viewed from a direction which is substantially non-parallel to the extent of the one or more first and second resonator elements. The circle or other shape formed by

one set may be concentric with the other set, i.e. it may have a common axis X-X.

[0042] Collectively, the first and second blind resonator elements 28A, 28B provide, in conjunction with a post wall 29 to be described below, a resonator comprising a coaxial set of overlapping blind resonator elements 28A, 28B within the post wall.

[0043] Also shown in FIGS 2C and 2D is the above-mentioned post wall 29 provided by a plurality of closely-spaced but discrete metal posts or metal-plated via holes. Each post of the post wall 29 connects the first and second metal layers 24, 26. The spatial arrangement of the posts of said post wall 29 is that of a rectangle, or other shape, when viewed from above, defining within the interior of its four "walls" a waveguide region.

[0044] The resonator provided by the first and second blind resonator elements 28A, 28B may be formed using SIW processes and fabrication technology. The result is a dense and integrated structure that is simple to produce, is low cost, is robust and has a relatively small volume. The process augments low tolerances compared with, for example, implementing a similar resonator using two machined metallic cylinders overlapping each other in an air cavity with a small gap in-between, i.e. in close proximity. This may be difficult to implement in practice, and is susceptible to mechanical tolerances, whereas embodiments described herein do not have this drawback. Minimizing the gap between two or more sets of resonator elements 28A, 28B is more straightforward to achieve using SIW and related fabrication processes. Low tolerances are a critical part of 5G and other mm-wave applications.

[0045] Figures 3A - 3C respectively show the output of computer simulations representing the electric field, magnetic field and surface current density for the Figure 2 resonator at the fundamental mode. The results shown in Figures 3A - 3C demonstrate that this resonator exhibits a typical coaxial resonator magnetic field distribution. The electric field is contained in the middle of the solid dielectric block between the overlapping set of blind resonator elements 28A, 28B. The electric field distribution demonstrates the concept of low tolerances, since once can notice that a blind resonator element's slight disposition should not have a big effect into the macroscopic performance of the resonator.

[0046] Figures 2A - 2D show an apparatus providing a single cavity resonator and similar principles can be applied to a multi-cavity resonator, as now described with reference to Figure 4. Note that a plurality of resonators may be implemented in this manner using the same or different layers as the initial structure, i.e. using physical stacking of resonators. Cross-coupling between the different resonators on different layers may be achieved using, for example, metal probes and/or openings (irises).

[0047] Referring to Figure 4, an apparatus according to another example embodiment comprises a cuboid block of a solid substrate 41, having upper and lower

major surfaces 42A, 42B and four side surfaces. The upper surface 42A has a first metal layer (not shown) deposited thereon and the lower surface 42B a second metal layer (not shown) deposited thereon. The first and second metal layers may be substantially planar. A first plurality of blind resonator elements 44 are each connected at one end to the first metal layer and extend into substrate 41 but stop short of the second metal layer. The same is true of a second and third plurality of blind resonator elements 45, 46. The arrangement of the first, second and third plurality of blind resonator elements 44, 45, 46 is substantially that of a circle, or other shape, such as an oval or elliptical or similar, when viewed from above. Collectively, each set of blind resonator elements provide one part of a resonator. Although not shown, there are also provided fourth to sixth pluralities of blind resonator elements, respectively concentric with, e.g. sharing a common vertical axis, the first to third pluralities of resonator elements 44, 45, 46, which extend in the opposite direction from the second metal layer on the lower surface 42B. These 'pairs' of resonator elements provide three co-axial type structures. Note that the physical properties of the different pluralities of blind resonator elements can differ between individual elements. They can differ in terms of, for example, the number of resonator elements, the diameter of the circle or other shape, and also in terms of their length and the diameter of the elements. The protrusion length or depth can also differ.

[0048] Also not shown are the metal posts of a post wall arranged around, or just within, the substrate 41, e.g. similar to the post wall 29 in Figures 2C and 2D.

[0049] Each of the three resonators indicated partially in Figure 4 is located within a respective waveguide portion 43A - 43C. Adjacent waveguide portions 43A - 43B and 43B - 43C are divided by means of opposed pairs of stub-like walls 47 that are inward extensions of the perimeter post wall and are similarly formed of metal posts or metalized via holes that connect to both the first and second metal layers. These define one or more irises 48 that act coupling structures between said adjacent waveguide portions 43A - 43B and 43B - 43C for electromagnetic coupling. The shape of the irises 48 can control aspects of the coupling that may be provided at the design stage. The first and third waveguide portions 43A, 43C also comprise input and output excitation ports 49A, 49B for input and output of RF signals. The ports 49A, 49B may be provided by blind or fully interconnecting posts. Excitation may be provided by other means, such as by micro strip excitation or coplanar waveguide excitation (CPW). The apparatus 40 shown in Figure 4 therefore provides a three-pole resonator filter having the same or similar advantages as that shown in Figures 2A - 2D.

[0050] It should be appreciated that any number of waveguide portions may be provided to provide a different filter response. It should also be appreciated that greater than two rows / circles of blind posts may be provided in a given resonator.

[0051] In any of the above embodiments, tuning means may be provided using conventional means, such as by providing one or more protruding devices such as screws, or by modifying external surfaces.

[0052] In any of the above embodiments, the ceramic block 22, 41 may be replaced with any suitable dielectric material, for example a printed circuit board (PCB) or other media, such as LTCC media. Organic or polymer materials may also be used instead of ceramic. As mentioned, the ceramic (or other material) block 22, 41 may be solid or may comprise one or more air pockets.

[0053] The relative permittivity of the ceramic block may be in the order of 2 - 12, but can be outside of these numbers.

[0054] Figure 5 is a graph showing computer simulated test results of the Figure 4 three-pole resonator apparatus 40. The graph shows the s-parameter frequency response, particularly for S_{11} and S_{21} parameters, and indicates a bandwidth of approximately 458 MHz, a fractional bandwidth of approximately 10.06 % and an insertion loss (IL) of approximately 0.4 dB.

[0055] Figure 6 is a flow diagram illustrating processing operations in manufacturing or fabricating a resonator apparatus according to example embodiments. The order of the operations is not necessarily indicative of a required order of processing and further operations may be involved.

[0056] The operations may comprise a first operation of providing (61) first and second electrically conductive elements respectively on first and second surfaces of a dielectric substrate.

[0057] A further operation may comprise providing (62) a post wall comprising a plurality of electrically conductive posts such that each is on or passes through the substrate to interconnect the first and second electrically conductive elements, the post wall defining a waveguide region in the substrate.

[0058] A further operation may comprise providing (63) a resonator comprising one or more first blind resonator elements extending from the first electrically conductive element and into the waveguide region and one or more second blind resonator elements extending from the second electrically conductive element and into the waveguide region.

[0059] Embodiments therefore provide a cavity filter apparatus which comprises one or more dielectric resonators constructed and arranged to support one or more predetermined resonant modes. The structure and production methods which may be used may produce a filter apparatus that is particularly suited to future telecommunications requirements, including those of low cost and higher density.

[0060] Dielectric resonators as described herein may also be provided in combination with other resonator technologies to provide hybrid technologies such as hybrid filters.

[0061] For example, Figures 7A and 7B show a hybrid apparatus 70 which may comprise the Figure 4 dielectric

resonator apparatus 40 according to an example embodiment mounted as a 'lid' for a more conventional cavity resonator 72. For example, the hybrid apparatus 70 may provide a Frequency Division Duplexing (FDD) filter to separate transmitted (higher power / performance) signals to the conventional cavity resonator 72 and lower power received signals to the dielectric resonator apparatus 40. Another option may be to utilise the dielectric resonator apparatus 40 as a low-pass filter or as a notch filter to assist the conventional cavity resonator 72 in particular use cases. Suitable coupling means may couple signals between the dielectric resonator apparatus 40 and the conventional cavity resonator 72, e.g. coupling irises. Cavity walls are not shown in Figures 7A and 7B.

[0062] Figures 8A and 8B show how the Figure 4 dielectric resonator apparatus 40 may comprise a section or structure 80 that utilises a micro strip or coplanar waveguide excitation (CPW) feed and/or provides an additional micro strip or CPW filter, e.g. for additional low-pass or notch filtering.

[0063] The Figure 7 and 8 examples are not limited to the Figure 4 embodiments, and indeed any resonator apparatus according to example embodiments may employ such hybrid and/or micro strip / CPW feed or filtering structures.

[0064] In some example embodiments, further sets of resonator elements, for example additional to the first and second pluralities of resonator elements 28A, 28B described above with respect to Figures 2A - 2D may be provided. For example, at least a third "ring" or other shape of resonator elements (not shown) by pass within or through the waveguide region in the dielectric substrate. Referring to Figure 9, for example, which is a modified version of the Figure 2A - 2D structure, there is shown how a third ring of resonator elements 28C is provided within the first and second sets of resonator elements 28A, 28B. There is no requirement for this additional set of resonator elements to overlap with the others, nor on which metallic layer the resonator elements make contact with, as they can extend inwards from either side of the cavity. Providing additional resonator elements in this way can reduce tolerances by increasing the compactness of the resonator.

[0065] It will be appreciated that the above described embodiments are purely illustrative and are not limiting on the scope of the invention. Other variations and modifications will be apparent to persons skilled in the art upon reading the present application.

[0066] Moreover, the disclosure of the present application should be understood to include any novel features or any novel combination of features either explicitly or implicitly disclosed herein or any generalization thereof and during the prosecution of the present application or of any application derived therefrom, new claims may be formulated to cover any such features and/or combination of such features.

Claims

1. Apparatus comprising:

a dielectric substrate comprising first and second surfaces;
first and second electrically conductive elements respectively provided on the first and second surfaces;
a post wall provided by plurality of electrically conductive posts, each of which is on or passes through the substrate to interconnect the first and second electrically conductive elements, the post wall defining a waveguide region in the substrate; and
a resonator comprising one or more first resonator elements extending from the first electrically conductive element and into the waveguide region, the one or more first resonator elements not contacting the second electrically conductive element, and one or more second resonator elements extending from the second electrically conductive element and into the waveguide region, the one or more second resonator elements not contacting the first electrically conductive element.

2. The apparatus of claim 1, wherein the first and second substrate surfaces are substantially opposite one another.

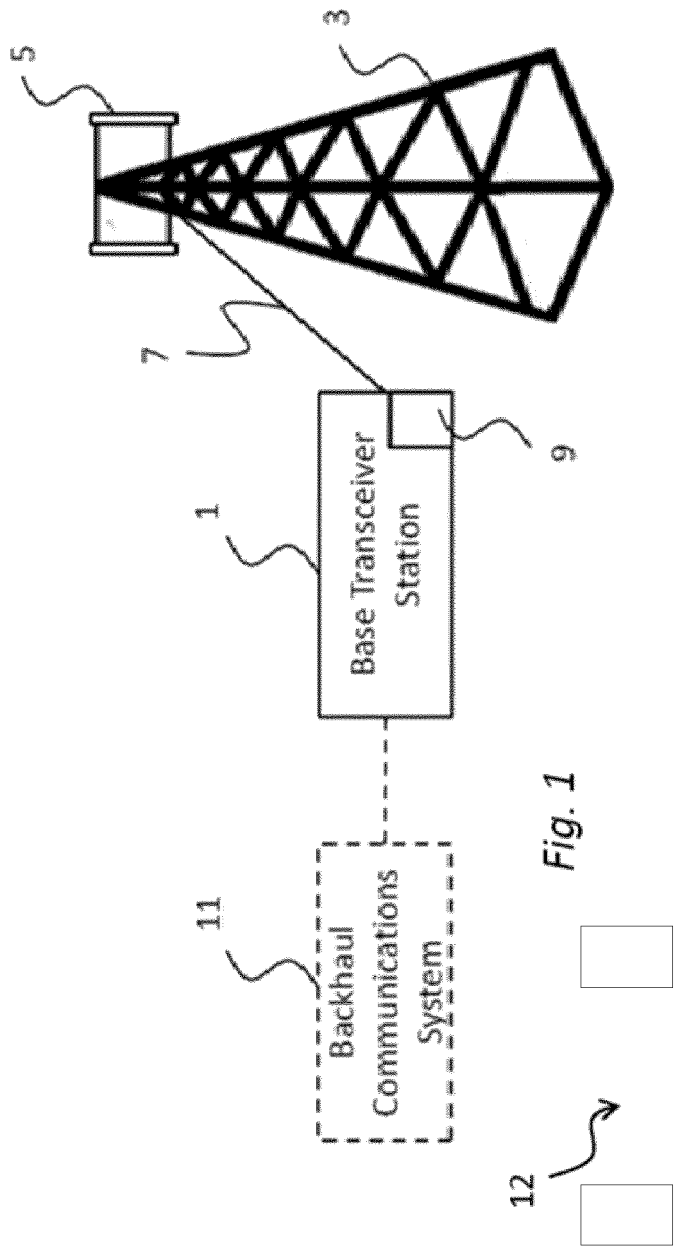
3. The apparatus of claim 1 or claim 2, wherein the one or more first resonator elements and the one or more second resonator elements are arranged substantially parallel with one another in the waveguide region.

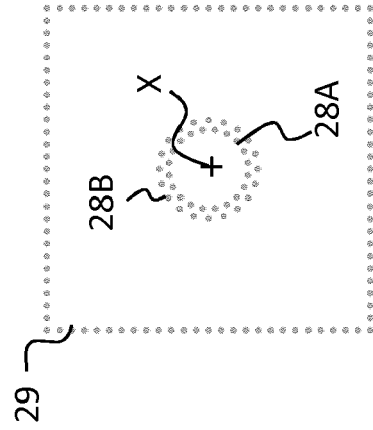
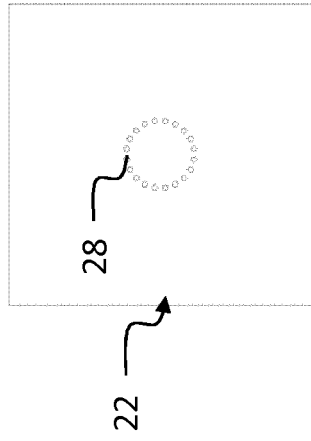
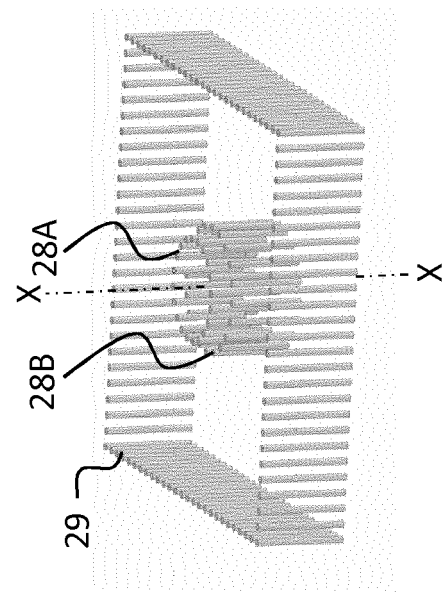
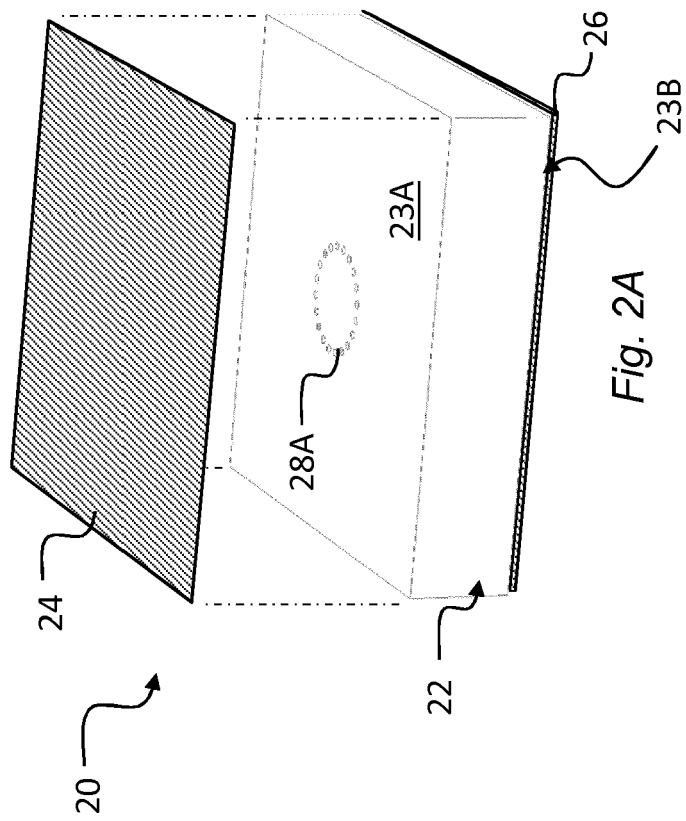
4. The apparatus of any preceding claim, wherein the one or more first resonator elements and the one or more second resonator elements extend into the waveguide region in substantially opposite directions and at least partially overlap when viewed from a direction which is substantially non-parallel to the extent of the one or more first and second resonator elements.

5. The apparatus of any preceding claim, comprising a plurality of said first resonator elements, spatially arranged so as to provide in a section of the waveguide region a substantially circular shape.

6. The apparatus of claim 5, comprising a plurality of said second resonator elements, spatially arranged to provide in the section of the waveguide region a substantially circular shape which is concentric with that provided by the plurality of first resonator elements.

7. The apparatus of any preceding claim, wherein the one or more first and second resonator elements comprise electrically conductive posts.
8. The apparatus of any preceding claim, wherein the dielectric substrate is a ceramic material.
9. The apparatus of any preceding claim, wherein the post wall defines a plurality of adjacent waveguide regions within the dielectric substrate, the apparatus further comprising a signal coupling means between the adjacent waveguide regions, and wherein a said resonator is provided in each of the waveguide regions.
10. The apparatus of any preceding claim, providing a filter apparatus for a telecommunications base station.
11. A method comprising:
- providing first and second electrically conductive elements respectively on first and second surfaces of a dielectric substrate;
- providing a post wall comprising a plurality of electrically conductive posts such that each is on or passes through the substrate to interconnect the first and second electrically conductive elements, the post wall defining a waveguide region in the substrate; and
- providing a resonator comprising one or more first resonator elements extending from the first electrically conductive element and into the waveguide region, the one or more first resonator elements not contacting the second electrically conductive element, and one or more second resonator elements extending from the second electrically conductive element and into the waveguide region, the one or more second resonator elements not contacting the first electrically conductive element.
12. The method of claim 11, wherein the first and second substrate surfaces are provided substantially opposite one another.
13. The method of claim 11 or claim 12, wherein the provided one or more first resonator elements and the one or more second resonator elements are arranged substantially parallel with one another in the waveguide region.
14. The method of any of claims 11 to 13, wherein the provided one or more first blind resonator elements and the one or more second blind resonator elements extend into the waveguide region in substantially opposite directions and at least partially overlap when viewed from a direction which is substantially non-parallel to the extent of the one or more first and second resonator elements.
15. The method of any of claims 11 to 14, further comprising providing a plurality of said first resonator elements, spatially arranged so as to provide in a section of the waveguide region a substantially circular shape.





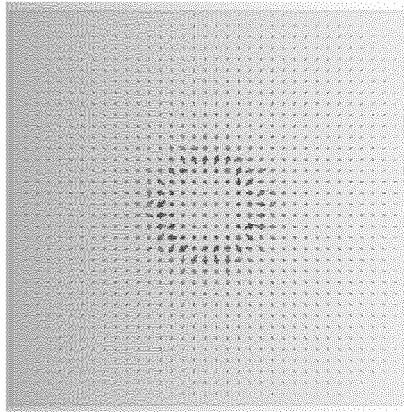


Fig. 3A

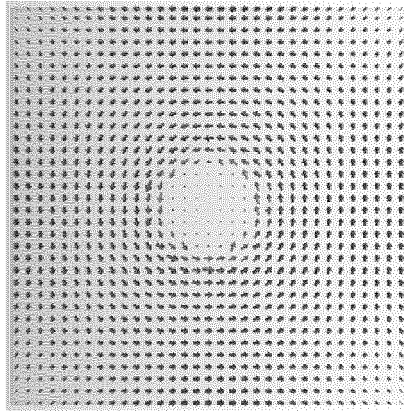


Fig. 3B

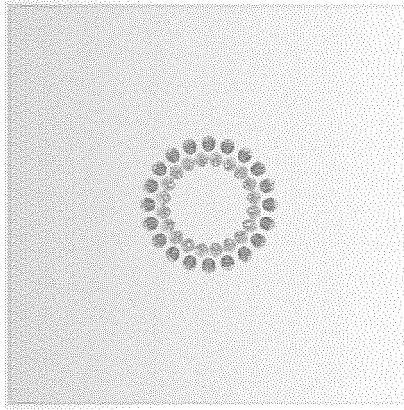


Fig. 3C

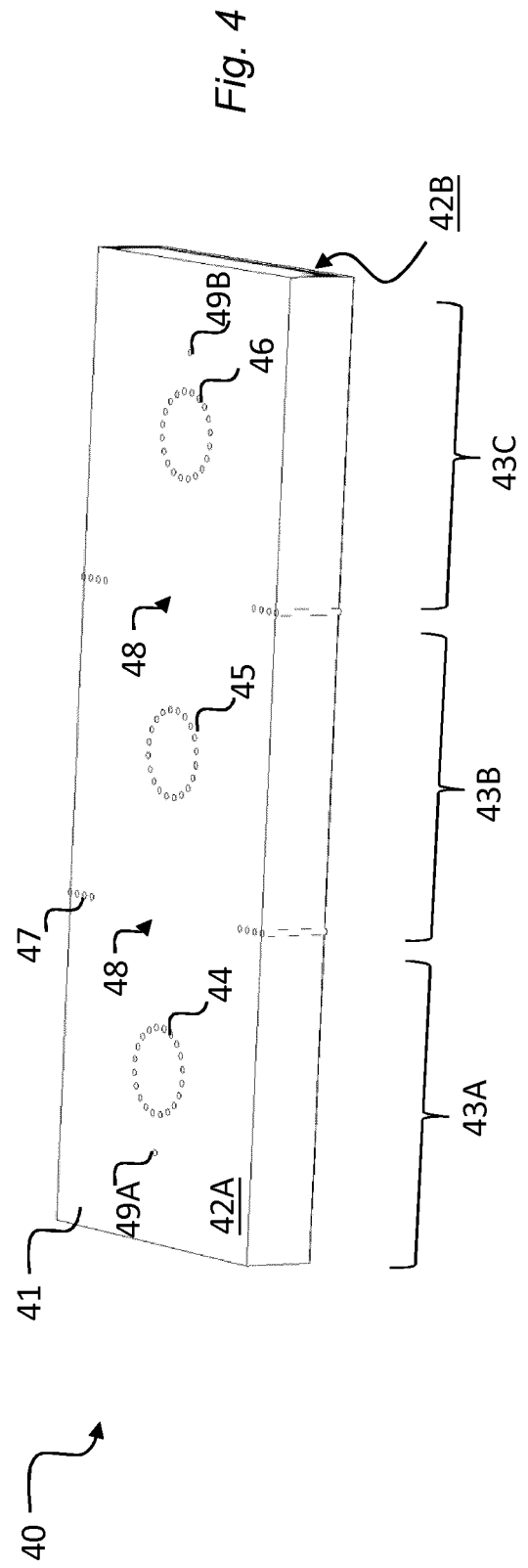


Fig. 4

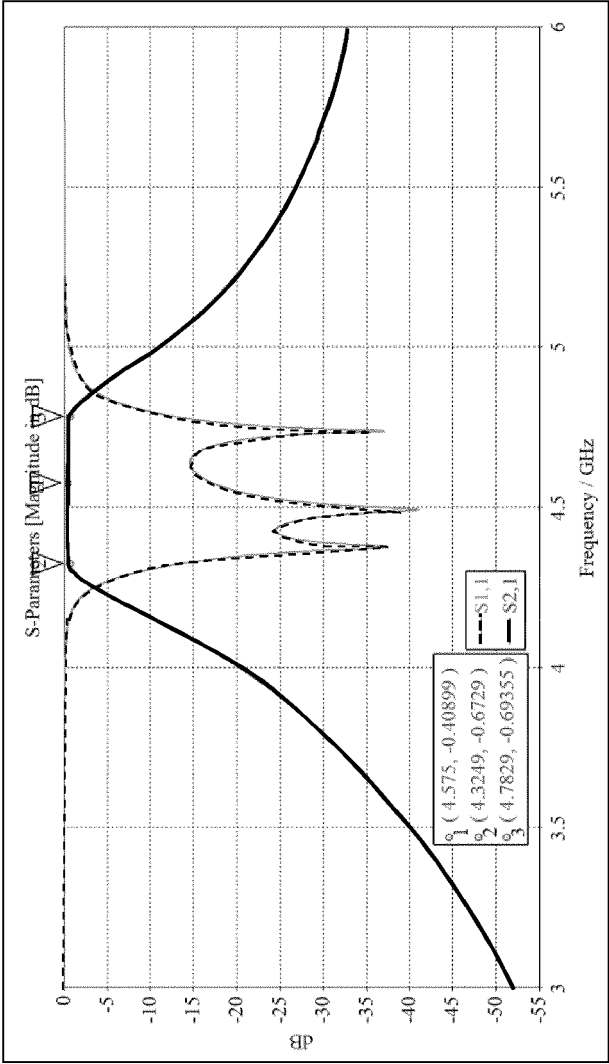


Fig. 5

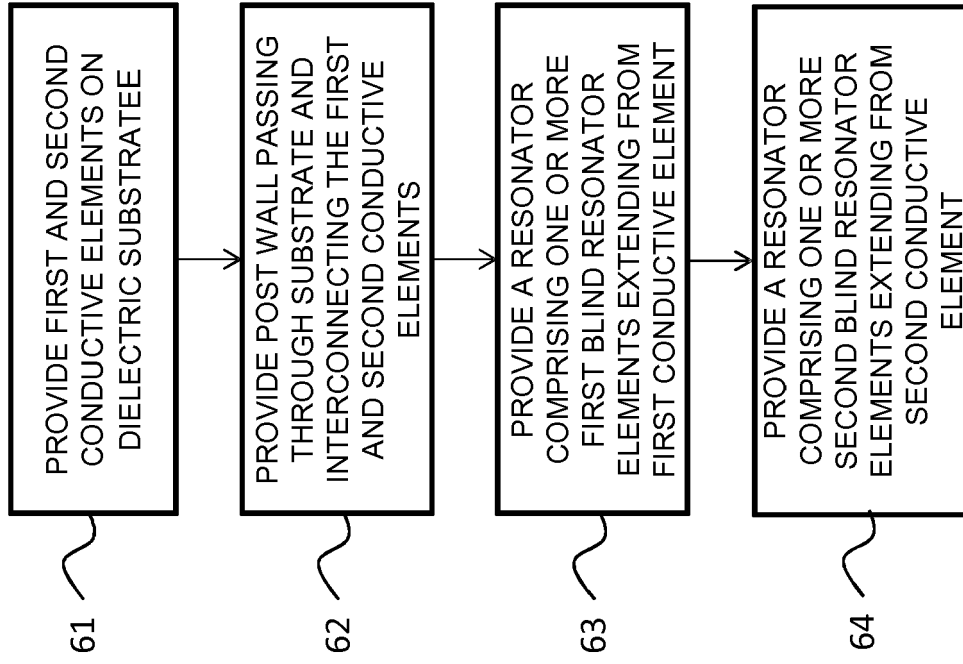


Fig. 6

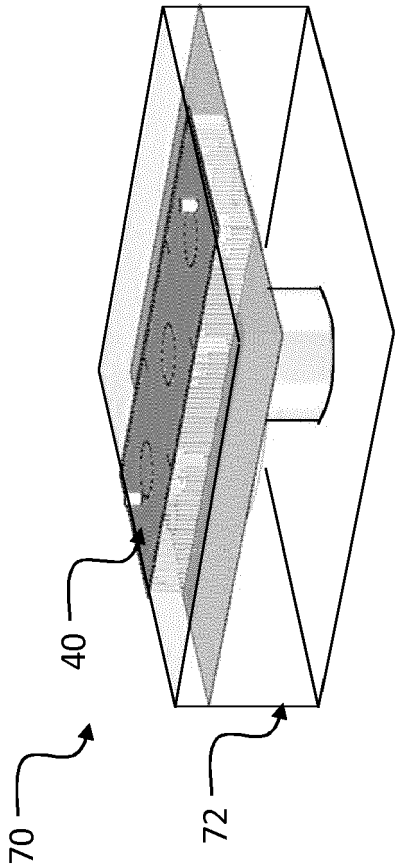


Fig. 7A

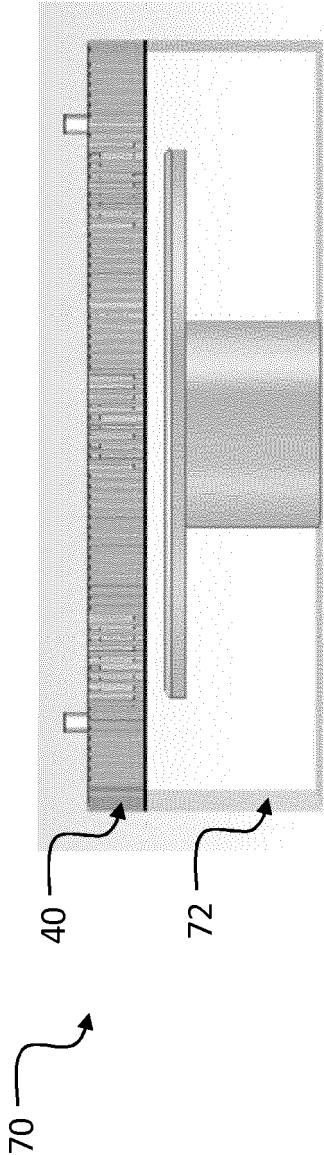


Fig. 7B

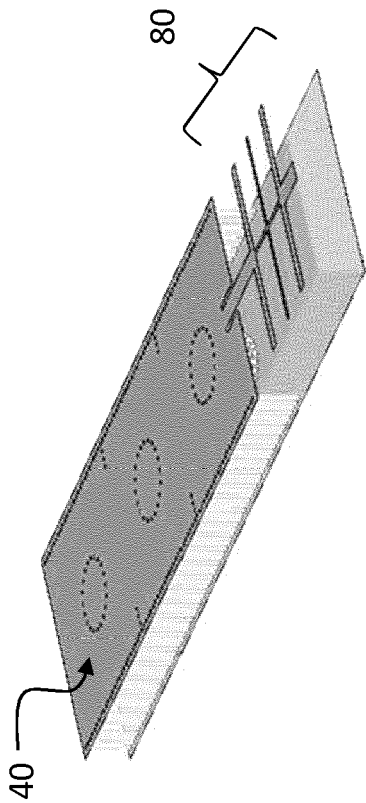


Fig. 8A

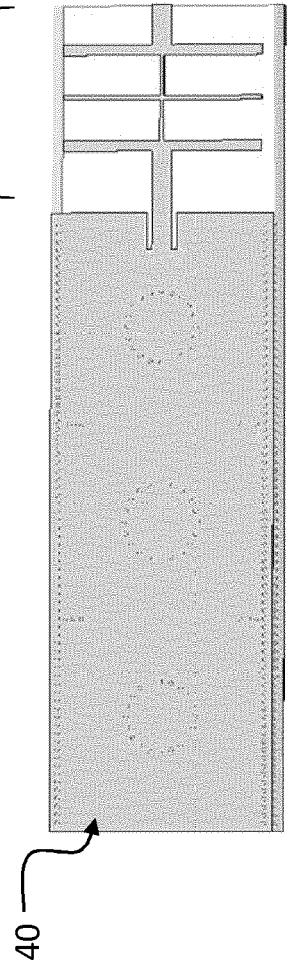


Fig. 8B

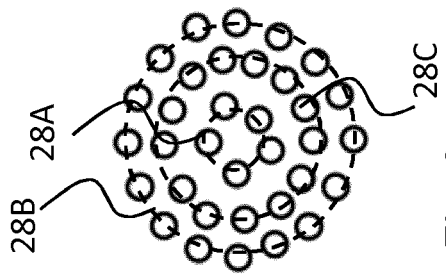


Fig. 9



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A	* page 1, column 1 - page 2, column 4; figures 1-7 *	4,14	
X	----- HUANG LIWEN ET AL: "Ultra-Wideband Ridged Half-Mode Folded Substrate-Integrated Waveguide Filters", IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, IEEE SERVICE CENTER, NEW YORK, NY, US, vol. 28, no. 7, 1 July 2018 (2018-07-01), pages 579-581, XP011686579, ISSN: 1531-1309, DOI: 10.1109/LMWC.2018.2835666 [retrieved on 2018-07-03]	1-3,7, 10-13	
A	* page 1, column 2 - page 3, column 5; figures 1-4 *	4,14	
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 6 February 2020	Examiner E1-Shaarawy, Heba
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	

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