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(54) Dielectric resonator construction and dielectric filter with reduced physical length

(57) In a dielectric resonator, the inner conductor comprises at least two portions, which are preferably implemented by forming two adjacent resonator holes (16, 17) in the frame block (15). The lower end of the first hole (16) is earthed and the lower end of the second hole (17) is electrically open. The upper ends of the holes are connected to one another in an electrically conductive manner. The electric length of the construction is approximately the same as the sum of the electric lengths of the portions.

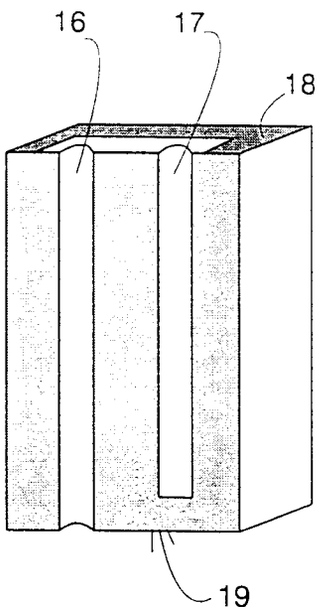

Fig. 6

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Description

The invention relates to resonator constructions, including basic constructions of dielectric resonators and filters in general, and more particularly to a way of reducing the physical length of the dielectric resonator in relation to its electric length.

Various prior art dielectric resonators are known. Figure 1 shows a known dielectric coaxial resonator, in which the body is made of ceramic material and shaped like a cylinder or rectangular block 1. A cylindrical hole 2 has been formed therein, reaching through the whole block from its upper surface 3 to its lower surface 4. The inner surface of the hole 2 and the outer surfaces of the dielectric block 1, excluding the upper surface 3, have been coated with electricity conducting material, and the coating of the hole 2 is galvanically connected to the coating of the lower surface 4 of the block. Electrically, the resonator can be described as a simple equivalent coupling according to Figure 2, in which the inner conductor 2 depicted in Figure 1 is replaced by a transmission line 5, one end of which is grounded and the other end is open.

The physical length of the resonator construction shown in Figures 1 and 2 in the direction of the main axis of the transmission line 2, 5 is in a well-known manner dependent on the relative permittivity ε_r of the material of the block 1 and the desired resonance frequency f_0 of the resonator. The dependency is of the type

$$L = \frac{c}{4f_0\sqrt{\varepsilon_r}}, \qquad (1)$$

where L denotes the physical length of the resonator, and c is the speed of light in a vacuum. It can be seen from the formula (1) that the relative permittivity ε_r of dielectric material is the only structural parameter by the choice of which the physical length L of the resonator can be affected, because the resonance frequency f_0 is determined on the basis of the operational frequency of a certain mobile phone system, and cannot be freely chosen. The construction can be shortened to some extent by applying a capacitive load on the open upper end of the resonator, but this deteriorates the quality factor of the construction disproportionately compared to the small length reduction.

The European published application EP 0 617 478 discloses another dielectric resonator construction, which consists, in accordance with Figure 3, of combined, slab-like parts 6, 7, 8 and 9 made of dielectric material. On the surface of the parts there have been formed strip conductors 10a and 11a, which have a galvanic connection to the metal coating 10b and 11b at the other end of the parts. When the construction is assembled by pressing the parts 6 - 9 against each other, the strip conductors 10a and 11a remain within the construction, thus forming the inner conductor of a dielectric resonator. The outer surfaces of the combined structure are coated with electricity conducting material, whereby the outer conductor of the resonator is formed, corresponding to the coating of the outer surface of the frame block 1 shown in Figure 1. Because the combined length of the strip conductors 10a and 11a operating as parts of the inner conductor in the construction shown in Figure 3, space reduction is attained by this construction.

However, a construction consisting of multiple parts is not easy to manufacture, because manufacturing the parts and combining them to one another reliably requires high accuracy and carefulness at many stages of the work. Electric coupling to one another of the strip conductors formed on the surfaces of separate parts is problematic, and this makes it more difficult to design the desired filter. It has been found that the quality factor of the resonator does not become as good as in coaxial resonators of the structure shown in Figure 1.

According to a first aspect of the present invention there is provided a resonator construction, which comprises a dielectric frame block, which is limited by an upper surface and a lower surface, which are substantially parallel, and by side surfaces, which are substantially perpendicular to the upper and lower surfaces, whereby at least the lower surface and one or more of the side surfaces comprise an electrically conductive coating, and a first resonator hole, which extends from the upper surface to the lower surface, the inner surface of which comprises an electrically conductive coating, thus forming a first inner conductor, which has an electrically conductive connection to the electrically conductive coating of the lower surface, characterized in that it comprises a second resonator hole, which is essentially parallel with the first resonator hole and the inner surface of which comprises an electrically conductive coating, thus forming a second inner conductor, and the electrically conductive coatings of the first and second resonator hole are connected to one another in an electrically conductive manner.

Embodiments in accordance with the invention may provide a dielectric resonator construction, which has a small physical length compared to its electrical length and may provide a shortened resonator construction of this kind, which has a high quality factor. Embodiments in accordance with the invention may also provide a resonator construction which is easy to manufacture, and in addition, may provide a radio frequency filter based on the above resonator construction.

Embodiments in accordance with the invention may be realised by forming at least two resonator holes in a dielectric frame block, which holes are concatenated by combining them electrically in a manner described in more detail hereinafter.

According to a second aspect of the present invention there is provided a dielectric filter, which comprises a dielectric frame block, which is limited by an upper surface and a lower surface, which are substantially parallel, and by side surfaces, which are substantially per-

pendicular against the upper and lower surfaces, whereby at least the lower surface and one or more of the side surfaces comprise an electricity conducting coating, and a first resonator and a second resonator, of which the first resonator comprises a first hole, which extends from the upper surface to the lower surface, the inner surface of which comprises an electrically conductive coating, thus forming a first inner conductor, which has an electrically conductive connection to the electrically conductive coating of the lower surface, and the second resonator comprises a second hole, which extends from the upper surface to the lower surface, and the inner surface of which comprises an electrically conductive coating, thus forming a second inner conductor, which has an electrically conductive connection with the electrically conductive coating of the lower surface, characterized in that said first resonator comprises a third hole, which is substantially parallel with said first hole, and the inner surface of which comprises an electrically conductive coating, thus forming a third inner conductor, and the electrically conductive coatings of said first and third hole are connected to one another in an electrically conductive manner.

A dielectric filter in accordance with the invention, the first resonator of which comprises a first hole and the second resonator of which comprises a second hole may be characterized in that said first resonator comprises a third hole, which is essentially parallel with said first hole, and the inner surface of which comprises an electrically conductive coating, thus forming a third inner conductor, and the electrically conductive coatings of said first and third resonator holes are connected to one another in an electrically conductive manner.

Embodiments in accordance with the invention may be based on the idea that the inner conductor of the resonator can be "folded" within the dielectric block. Thus the inner conductor need not be formed of one straight conductor, but several conducting portions can be combined electrically, whereby the circuit formed by them has the same resonator properties as one resonator, which has essentially the same electric length as the sum of the electric lengths of the portions.

The invention may be applied to a known ceramic resonator construction, for example by forming two adjacent resonator holes in the frame block, the first of which holes has its lower end earthed and the second of which has an electrically open lower end, and the upper ends of which have a galvanic connection to one another. In this context, the terms "lower end" and "upper end" refer to names used in a known manner for certain surfaces of the frame block, and they do not place restrictions to the positioning of the resonator construction in relation to the local upward and downward direction. If both the resonator holes reach through the whole frame block, their combined electric length is essentially twice the electric length of one similar resonator hole, whereby a considerable 50 per cent reduction of the physical length is achieved.

The second resonator hole may also extend only partly through the ceramic block, whereby its electrically open lower end remains within the block. By an arrangement like this, the electromagnetic stray radiation to the environment can be substantially reduced. The shape of the ceramic frame block can be different from the simple rectangular prism, whereby it can have a higher portion and a lower portion in the direction of the axes of the resonator holes, and by concatenating the resonator holes of varying length formed therein, a resonator construction of the desired electrical length can be attained.

A radio frequency filter in accordance with the invention preferably has at least two pairs or groups of holes, each of which forms one resonator, whereby the resonators are connected to one another by means of the electromagnetic field of the dielectric frame material. Switching patterns can be formed on the surface of the ceramic frame block, which switching patterns influence the coupling between the resonators, and by which it is possible to influence the electromagnetic field so as to attenuate the undesired harmonic frequencies, for example. Separate components, such as switching diodes, can also be attached to the solder spots formed on the surface of the block. The filter can also comprise a circuit board, to the surface of which the ceramic resonator block is attached, whereby both the circuit board and the surface of the ceramic block which is against the circuit board can comprise switching patterns in a previously known manner.

In the following, preferred embodiments of the invention will be described, by way of example, with reference to the accompanying drawings, in which

Figure 1 shows one known dielectric resonator construction,

Figure 2 shows a simple equivalent circuit of a known construction according to Figure 1,

Figure 3 shows another known dielectric resonator construction,

Figure 4 shows a simple equivalent circuit of a resonator construction in accordance with the invention,

Figure 5 shows a schematic diagram of one preferred embodiment in accordance with the invention,

Figure 6 shows a section of the embodiment shown in Figure 5,

Figure 7 shows a section of a modification of the embodiment shown in Figures 5 and 6,

Figure 8 shows a section of another preferred

embodiment in accordance with the invention,

Figure 9a shows a detail of the embodiment shown in Figure 8,

Figure 9b shows another alternative for the detail shown by Figure 9a,

Figure 10 shows a section of a third preferred embodiment in accordance with the invention,

Figure 11 shows a section of a fourth preferred embodiment in accordance with the invention,

Figure 12 shows a schematic diagram of a preferred embodiment of a radio frequency filter in accordance with the invention, and

Figure 13 shows a schematic diagram of another preferred embodiment of a radio frequency filter in accordance with the invention.

Above, in connection with a description of the prior art, reference has been made to Figures 1 to 3, and thus in the following description of the preferred embodiments, reference is mostly made to Figures 4 to 13. The same reference numbers are used for corresponding parts in the figures.

Figure 4 shows an equivalent coupling, which represents the electric construction of one preferred embodiment in accordance with the invention. It has two transmission lines 12 and 13, the upper ends of which are combined electrically by means of a third transmission line 14. The lower end of the first transmission line 12 is grounded, and the lower end of the second transmission line 13 is open. A construction like this is a quarter-wave resonator, the electric length of which is equal to the combined electric length of the transmission lines 12, 13 and 14. The construction can also be formed into a half-wave resonator by grounding the lower end of the second transmission line 13. If it is assumed that the transmission lines 12 and 13 are electrically much longer than the transfer line 14 connecting their upper ends, the electric length of the latter can be ignored, whereby the electric length of the construction is approximately the combined electric length of the transmission lines 12 and 13.

Figure 5 shows one way of implementing the construction of Figure 4 in practice. Two resonator holes 16 and 17 have been drilled in the ceramic block 15. According to the customary practice, the surface 18 of the block 15, which faces upwards in the picture, is called the upper surface, and the surface 19 opposite to it is called the lower surface. All the surfaces of the block, with the exception of the upper surface 18, are coated with electrically conductive material, which is shown white in the figure. The inner surfaces of the resonator holes 16 and 17 are also made electrically conductive. The upper ends of the holes are connected by an electrically conductive area 20 formed on the upper surface 18 of the block, which area has a galvanic connection to the coating of the inner surface of each hole, thus also forming the input/output port of the construction. Figure 6 shows a section of the construction, from which it can be seen that only hole 16 extends through the whole block 15. Its coating has a galvanic connection to the coating of the lower surface 19 of the block. The lower end of hole 17 does not have a galvanic connection to anywhere, in which case it is said to be electrically open. The fact that the hole 17 is physically closed at its lower end, can cause confusion of the terms "open" and "closed".

An electric connection between the upper ends of resonator holes 16 and 17 can also be implemented by other means than the strip conductor shown in Figures 5 and 6. The planar strip conductor 20 shown in Figures 5 and 6 can be replaced by a groove-like construction, for example, in which the upper ends of resonator holes 16 and 17 are connected by a groove which is coated with electrically conductive material. In another embodiment, the upper ends of the resonator holes can be connected by means of a coated hole formed in the frame block. Figure 7 shows a section of a modification of the embodiment shown in Figures 5 and 6, in which modification the upper ends of the resonator holes 16 and 17 are connected by a separate, electrically-conductive "bridge" 21. It can be a bent piece of a conductor, for example, which is inserted into the resonator holes and soldered or by other means fastened on place. Instead of a mere conductor or in addition to it, the "bridge" 21 can comprise inductive and/or capacitive separate components. By making a connection thereto, an input/output port of the construction can be formed by any means known to a person skilled in the art.

Figure 8 shows a section of one preferred embodiment in accordance with the invention, where both the resonator holes 22 and 23 extend through the dielectric block 15 from its upper surface 18 to its lower surface 19. So as to make the lower end of the second resonator 23 electrically open in accordance with the invention, it must be isolated from the electrically conductive coating of the lower surface 19 of the block. This can be implemented in many ways, two of which are shown in Figures 9a and 9b, in which block 15 is shown as seen from the direction of the lower surface 19. In the alternative shown in Figure 9a, a ring-shaped zone encircling the lower end of the resonator hole 23 has been left uncoated on the lower surface. In Figure 9b, the half of the lower surface which is on the side of the resonator hole 23 has been left uncoated. The uncoated portion can be placed, instead of the lower surface of the block or in

addition to it, on the inner surface of the resonator hole 23. By varying the size of the uncoated area and the distance of the edge of the coating from the resonator hole 23, the capacitive earth potential coupling at the open end of the resonator 23 can be influenced and thus the electric properties of the whole resonator arrangement can be changed. The lower end of the resonator 23 can also be isolated from the coating on the lower surface of the block mechanically by machine-tooling, whereby the lower surface and the inner surfaces of the resonator holes are at first entirely covered with a metal, and thereafter for example a small conical expansion is made on the lower end of one resonator hole by drilling.

Figure 10 shows a section of one more preferred embodiment in accordance with the invention, in which the ceramic frame block 24 is not a simple rectangular prism, but consists of two portions, a and b, of different heights. Thus the block has an upper surface 25 and two lower surfaces 26 and 27 parallel to it, both of which have an area of approximately half of the upper surface area, and form a stepped structure at the lower end of the block. The resonator hole 28 extending from the upper surface 25 to the first lower surface 26 is shorter than the resonator hole 29 extending to the second lower surface 27. The upper ends of the resonator holes 28 and 29 opening to the upper surface are galvanically connected to one another in any of the manners described above, and the lower end of one of them is connected to the coating of the lower end to which the lower end of the resonator hole opens. The lower end of the second resonator is isolated from the coating of the block in a manner shown in Figure 9a or 9b, for example.

Figure 11 shows an embodiment in which the resonator consists of three portions. Three holes 31, 32 and 33 have been formed on the frame block 30, reaching from the upper surface of the block to the lower surface. The lower end of the first hole 31 is galvanically connected to the coating of the lower surface of the block, and its upper end is connected by a strip conductor 34 to the upper end of the second hole 32. Similarly, the lower end of the second hole is connected by a strip conductor (not separately shown in the figure) to the lower end of the third hole 33, and the upper end of the third hole is open. The electric length of the construction is approximately the same as the sum of the electric lengths of the resonator portions 31, 32 and 33.

The resonator construction in accordance with the invention can be applied for implementing a ceramic filter. In that case, each resonator can be formed in its own ceramic block, whereby the blocks are set side by side, attached to each other (multi-block construction), or several resonators can be formed in one frame block (mono-block construction). Figure 12 shows a ceramic resonator implemented in the latter manner, comprising a first resonator 35 and a second resonator 36, both of which consist of two resonator holes, coated with electrically conductive material and attached to one another by strip conductors 37 and 38. The electric coupling between the resonators takes place by means of an electromagnetic field through the frame block. The first strip conductor 37 operates as the input port of the filter, i.e., the electric signal is brought to the filter through it. Similarly, the second strip conductor 38 operates as the output port, i.e., the filtered signal is directed through it out of the filter. Figure 11 shows a band-pass filter, in which the connections to the input and output ports of the filter are made via the capacitive elements 39 and 40.

Figure 13 shows a resonator construction in accordance with the invention as applied to a general, well-known filter construction, in which the frame block 41 is attached at one side surface to a substrate plate 42. Two resonators, 43 and 44, have been formed in the frame block, each of which comprise two resonator holes. Coupling to the resonators takes places via the strip conductors connecting the upper ends of each pair of holes, which strip conductors are extended as connecting strips 45 and 46 to the side of the frame block which comes against the substrate plate 42. In accordance with the known filter construction, in which the side surface is attached to the substrate plate, this surface is otherwise uncoated.

It has been found by measurements that a resonator construction in accordance with the invention can attain a relatively high quality factor, and it is thus suited to be used in mobile stations of cellular networks, for example. It is to be noted that the alternatives presented above, relating to the number, shape and location of the resonator holes, the dimensions and shape of the frame block and different methods for coupling to the resonators and for arranging an electric connection between the resonator holes, are presented by way of example. A person skilled in the art can, in the light of this specification and in view of the prior art, easily present various modifications and combinations of different alternatives, which are nevertheless covered by the scope of the invention as defined by the following claims.

Claims

1. A resonator construction, which comprises

   - a dielectric frame block (15; 24; 30; 41), which is limited by an upper surface (18) and a lower surface (19), which are substantially parallel, and by side surfaces, which are substantially perpendicular to the upper and lower surfaces, whereby at least the lower surface (19) and one or more of the side surfaces comprise an electrically conductive coating, and
   - a first resonator hole (16; 28; 31), which extends from the upper surface to the lower surface, the inner surface of which comprises an electrically conductive coating, thus forming a first inner conductor, which has an electrically conductive connection to the electrically con-

ductive coating of the lower surface,

- characterized in that it comprises a second resonator hole (17; 29; 32), which is essentially parallel with the first resonator hole and the inner surface of which comprises an electrically conductive coating, thus forming a second inner conductor, and the electrically conductive coatings of the first and second resonator hole are connected to one another in an electrically conductive manner.

2. A resonator construction according to Claim 1, wherein said second resonator hole comprises an upper end and a lower end, of which the upper end is connected to the electrically conductive coating of said first resonator hole in an electrically conductive manner, and the lower end is electrically open.

3. A resonator construction according to Claim 1 or 2, wherein it comprises a strip conductor (20; 34) for connecting said first and second inner conductors to one another in an electrically conductive manner.

4. A resonator construction according to Claim 3, wherein said strip conductor is formed on the surface of the dielectric frame block and is electrically isolated from the electrically conductive coating of the surfaces.

5. A resonator construction according to Claim 1 or 2, wherein it comprises a groove coated with electrically conductive material in the frame block for connecting said first and second inner conductors to one another in an electrically conductive manner.

6. A resonator construction according to Claim 1 or 2, wherein it comprises a hole coated with electrically conductive material in the frame block for connecting said first and second inner conductors to one another in an electrically conductive manner.

7. A resonator construction according to Claim 1 or 2, wherein it comprises a separate connection means (21) for connecting said first and second inner conductors to one another in an electrically conductive manner.

8. A resonator construction according to any one of the preceding claims, wherein the electric length of said second inner conductor is different from that of said first inner conductor.

9. A resonator construction according to any one of the Claims 2 to 8, wherein the lower end of said second resonator hole (17) is physically closed.

10. A resonator construction according to any one of the Claims 2 to 8, wherein the lower end of said second resonator hole (23) is physically open and opens to the lower surface (19) of said frame block, whereby said lower surface comprises an electrically non-conducting area around the lower end of said second resonator hole.

11. A resonator construction according to any one of the preceding claims, wherein said lower surface comprises a first surface portion (26) and a second surface portion (27), which are substantially parallel, whereby the distance (a) from the first surface portion to the upper surface (25) is different to the distance (b) from said second surface portion to said upper surface (25), and said first resonator hole (28) intersects said first surface portion, and said second resonator hole (29) or its imaginary extension intersects said second surface portion.

12. A dielectric filter, which comprises

- a dielectric frame block (41), which is limited by an upper surface and a lower surface, which are substantially parallel, and by side surfaces, which are substantially perpendicular against the upper and lower surfaces, whereby at least the lower surface and one or more of the side surfaces comprise an electricity conducting coating, and
- a first resonator (35; 43) and a second resonator (36; 44), of which the first resonator comprises a first hole, which extends from the upper surface to the lower surface, the inner surface of which comprises an electrically conductive coating, thus forming a first inner conductor, which has an electrically conductive connection to the electrically conductive coating of the lower surface, and the second resonator comprises a second hole, which extends from the upper surface to the lower surface, and the inner surface of which comprises an electrically conductive coating, thus forming a second inner conductor, which has an electrically conductive connection with the electrically conductive coating of the lower surface,
- characterized in that said first resonator comprises a third hole, which is substantially parallel with said first hole, and the inner surface of which comprises an electrically conductive coating, thus forming a third inner conductor, and the electrically conductive coatings of said first and third hole are connected to one another in an electrically conductive manner.

13. A dielectric filter according to Claim 12, wherein said second resonator comprises a fourth hole, which is substantially parallel with said second hole, and the inner surface of which comprises an electrically conductive coating, thus forming a fourth in-

ner conductor, and the electrically conductive coatings of said second and fourth hole are connected to one another in an electrically conductive manner.

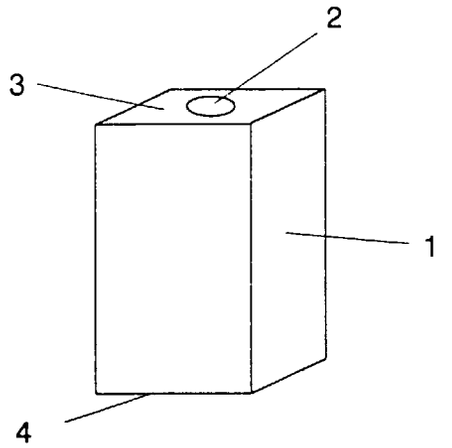

Fig. 1
PRIOR ART

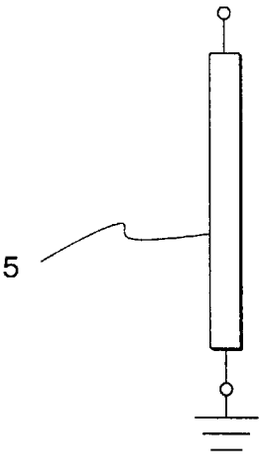

Fig. 2
PRIOR ART

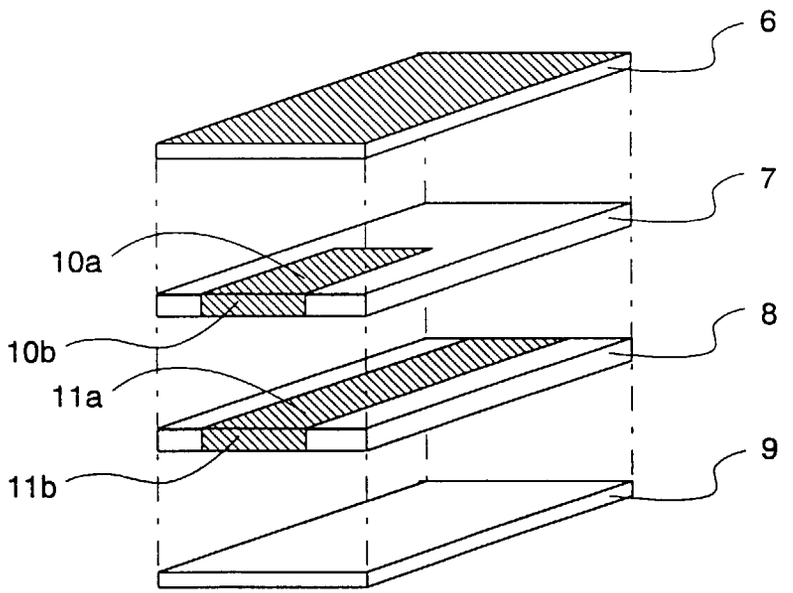

Fig. 3
PRIOR ART

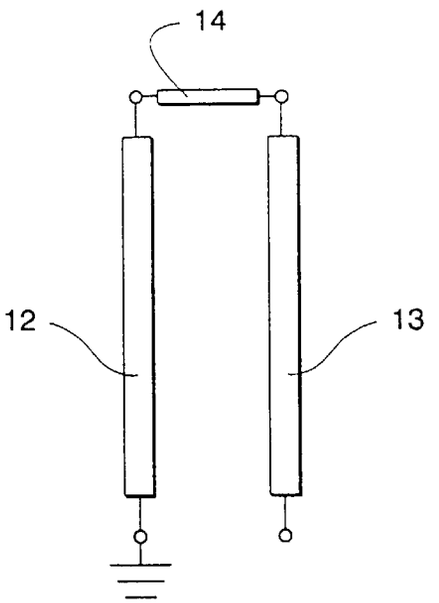

Fig. 4

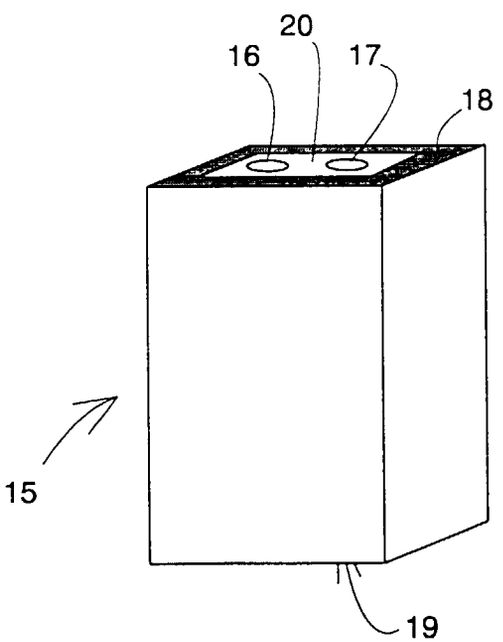

Fig. 5

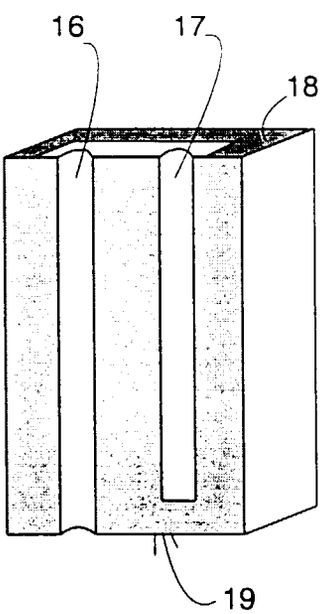

Fig. 6

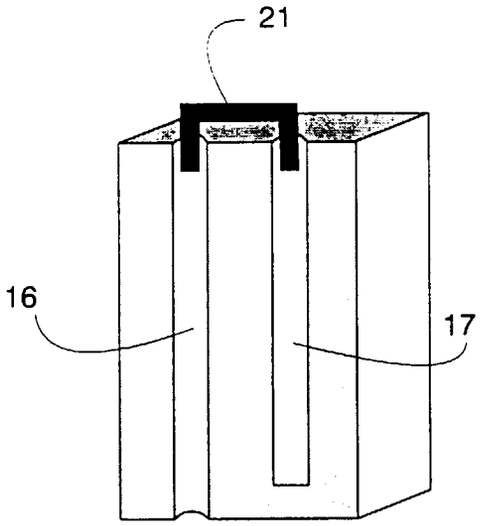

Fig. 7

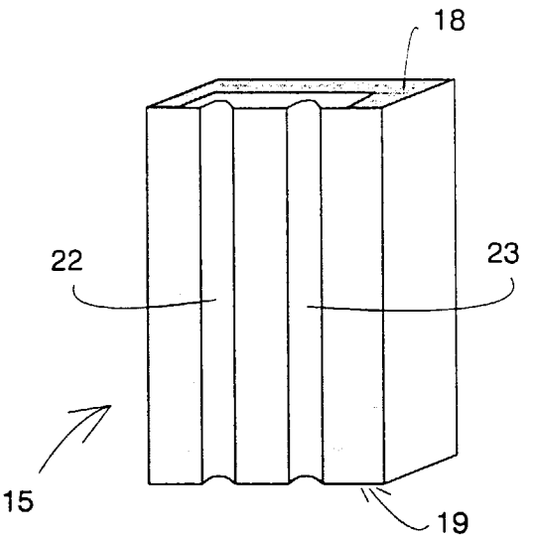

Fig. 8

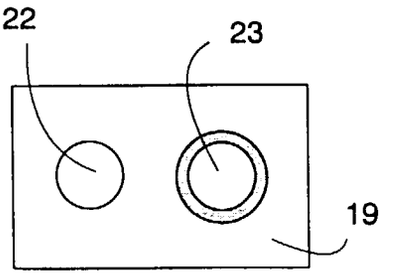

Fig. 9a

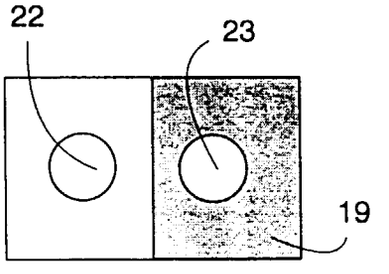

Fig. 9b

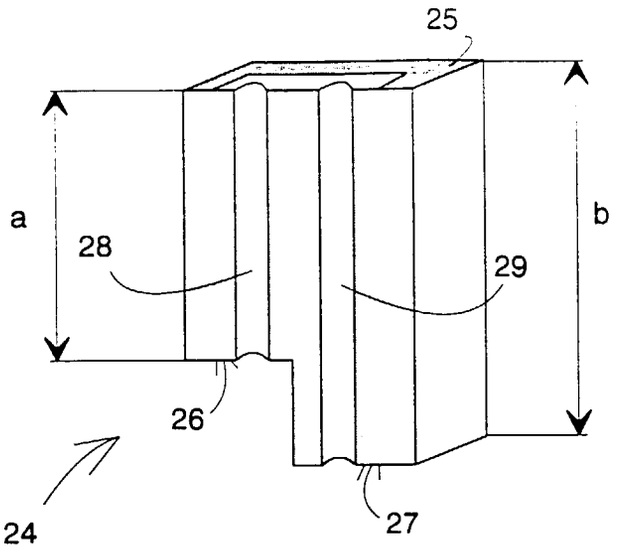

Fig. 10

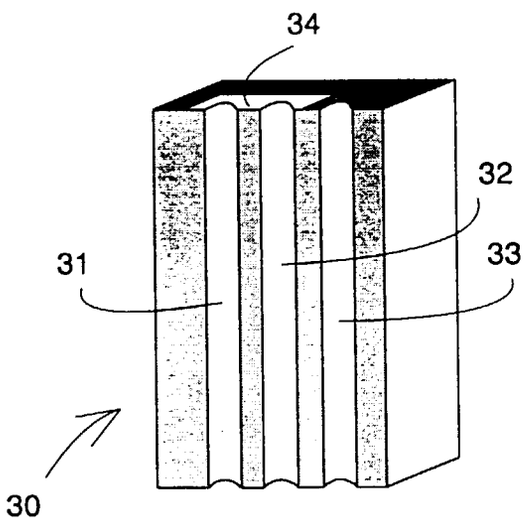

Fig. 11

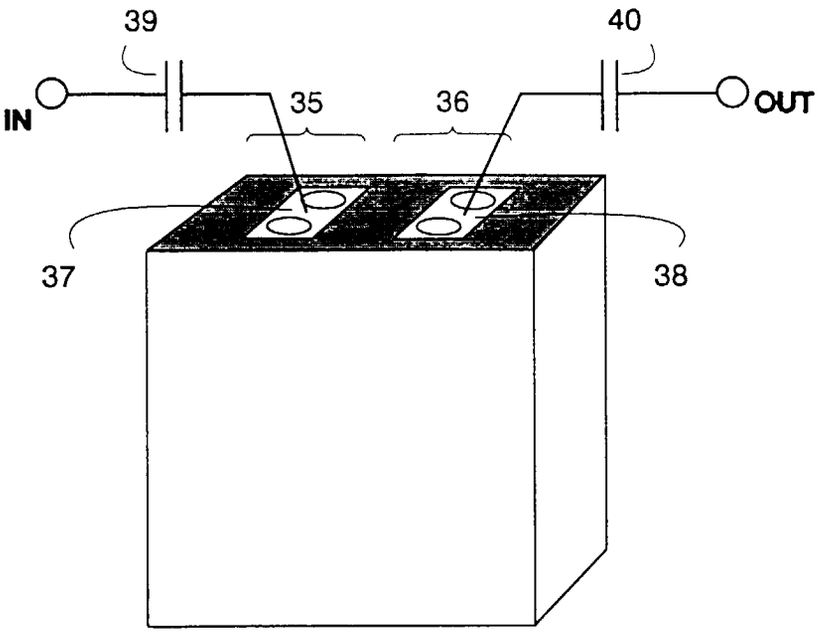

Fig. 12

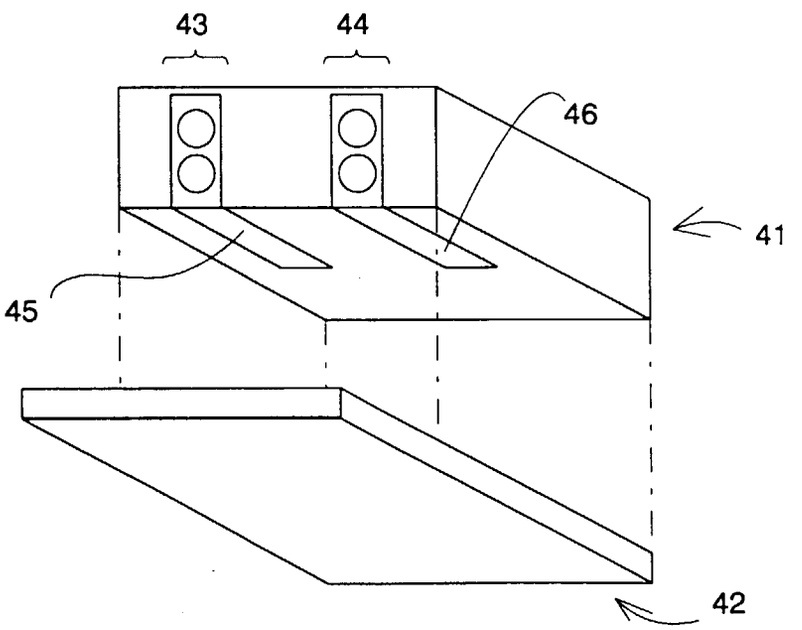

Fig. 13

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 30 0228

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 8, no. 66 (E-234) [1503] , 28 March 1984 & JP 58 215102 A (FUJITSU K.K.), 14 December 1983, * abstract *	1-4,12, 13	H01P1/205 H01P7/04
Y	---	6-8,11	
Y	WO 85 00929 A (AMERICAN TELEPHONE AND TELEGRAPH COMP.) * page 2, line 11 - page 3, line 11; figure 1 *	6	

Y	US 5 173 672 A (HEINE) * column 2, line 19 - column 3, line 39; figure 1 *	7	

Y	US 5 327 108 A (HOANG ET AL.) * column 5, line 17 - column 6, line 40; figure 3 *	8,11	
	---		TECHNICAL FIELDS SEARCHED (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 12, no. 49 (E-582), 13 February 1988 & JP 62 198201 A (TDK CORP), 1 September 1987, * abstract *	1	H01P

A	US 3 706 948 A (CHOI ET AL.) * column 2, line 42 - line 44; figure 2 *	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29 April 1997	Den Otter, A

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