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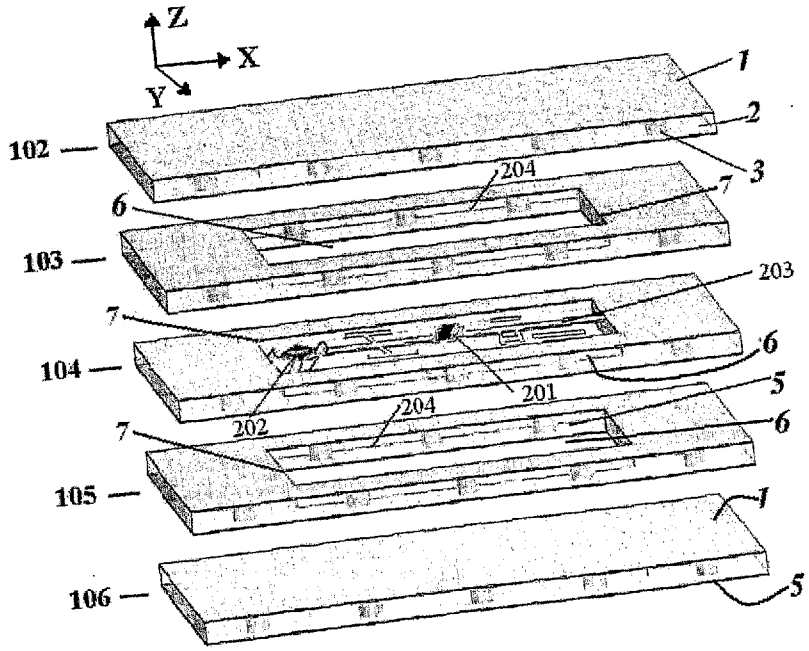
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(54) **Title:** QUASI-PLANAR CIRCUITS WITH AIR CAVITIES



(57) **Abstract:** A quasi-planar circuit comprising a plurality of boards, each of the plurality of boards comprising a substrate; at least one of the plurality of boards having at least one air cavity formed in the substrate; at least one of the plurality of boards having at least one metal layer including at least one patterned metal portion, the at least one patterned metal portion being over the at least one air cavity; wherein the at least one patterned metal portion and the at least one air cavity are for controlling at least a part of an electromagentic field distribution in the region of the at least one patterned metal portion and the air cavity.

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Quasi-planar Circuits with Air Cavities

Field of the invention

This invention relates to quasi-planar circuits with air cavities and relates particularly, though not exclusively, to circuits with air cavities for radio frequency, microwave and millimeter-wave components and systems. The circuits may be, for example, suspended microstrips, coplanar waveguides, suspended striplines, slotlines, finlines, and so forth.

Background to the Invention

Suspended striplines have proven favourable as transmission line mediums for realization of low-to-medium loss for high data-bit communication, and for waveguide components. Unfortunately, known structures lack the advantages of low cost, small volume and light weight needed for many commercial communication systems, military communication systems, and radar systems. These disadvantages are mainly due to the waveguide system not being able to be easily integrated into a single package containing other electronic components such as, for example, monolithic microwave integrated circuits ("MMICs").

Silicon-based micromachining technology is used for the manufacturing of a suspended parallel-coupled filter. However, due to its very high cost it cannot be used for commercial production and is mainly used for military products.

A suspended stripline, suspended microstrip line, slot line, fin-line or waveguide configuration has advantages in improving performance. However, known products have used a mechanical construction that is too bulky for high density integrated circuits and their packaging. Advantages in performance are at the expense of high manufacturing cost and large circuit size due to the mechanical suspending or shielding box. The box is expensive to manufacture and requires extensive tuning.

There is a need for high performance, compact size, microwave circuits that can be manufactured inexpensively, repeatedly, and in large quantities without extensive tuning.

In addition, there is a need to be able to integrate the suspended circuits into an integrated package with other electronic components.

Finally, there is a need to be able to use multilayer structures for radio frequency, microwave and millimeter circuits and systems.

Summary of the Invention

In accordance with a first preferred aspect there is provided a quasi-planar circuit comprising a plurality of boards, each of the plurality of boards comprising a substrate; at least one of the plurality of boards having at least one air cavity formed in the substrate; at least one of the plurality of boards including at least one metal layer having at least one patterned metal portion, the at least one patterned metal portion being over the at least one air cavity; wherein the at least one patterned metal portion and the at least one air cavity are for controlling at least a part of an electromagnetic field distribution in the region of the at least one patterned metal portion and the air cavity. A first end of the at least one air cavity may terminate at the patterned metal portion and a second end of the at least one air cavity terminates at one of: the substrate, another patterned metal portion, and another metal layer.

According to a second preferred aspect there is provided a quasi-planar circuit comprising a plurality of boards, each of the plurality of boards comprising a substrate; at least one of the plurality of boards having at least one air cavity formed in the substrate; there being at least one metal layer having at least one patterned metal portion over the at least one air cavity; wherein a first end of the at least one air cavity terminates at the patterned metal portion, and a second end of the at least one air cavity terminates at one of: the substrate, another patterned metal portion,

and another metal layer. The at least one patterned metal portion and the at least one air cavity may be for controlling at least a part of an electromagnetic field distribution in the region of the at least one patterned metal portion and the air cavity.

For both aspects the control of the at least a part of the electromagnetic field distribution by the at least one air cavity and the at least one patterned metal portion may also be of the electromagnetic field distribution in the substrate adjacent the at least one patterned metal portion and the at least one air cavity. The at least one air cavity may have side walls without shielding applied to the side walls. Alternatively, the side walls may have shielding applied to them. More than one board may have at least one air cavity. The air cavities in the more than one board may be substantially the same. Alternatively, some or all of the air cavities in the more than one board may be different to each other. The difference may be in at least one of: number, shape, cross-sectional area, depth, location and vertical alignment.

Extending over the air cavity may include: extending partially across the air cavity in one direction of an X-Y axis, extending completely across the air cavity in one direction but not the other, extending completely across the air cavity in both directions, having no other material between the patterned metal portion and the air cavity, and having a reduced-thickness portion of the substrate between patterned metal portion and the air cavity. The X-axis may be the longitudinal axis of the patterned metal portion, and the Y axis may be lateral to the X axis and perpendicular to the plane of the page.

The at least one air cavity in the substrate may be in at least one selected of: a top surface of the substrate, a bottom surface of the substrate, both the top surface and the bottom surface of the substrate, and completely through the substrate. The at least one air cavity in the top surface may be different to the at least one air cavity in the bottom surface, the difference being in at least one selected from the group consisting of: number, shape, area, depth and location.

The at least one metal layer may comprise a top metal layer over at least a part of the top surface of the substrate. Additionally or alternatively, the at least one metal layer may comprise a bottom metal layer under at least a part of the bottom surface of the substrate. The substrate may be between the top metal layer and the bottom metal layer. There may be at least one opening through at least one of: the top metal layer and the bottom metal layer. The at least one opening may be through both the top metal layer and the bottom metal layer. The at least one opening through the top metal layer may be the same as the at least one opening through the bottom metal layer. Alternatively or additionally, the at least one opening through the top metal layer may be different to the at least one opening through the bottom metal layer, the difference being in at least one selected from the group consisting of: number, shape, area and location.

The at least one air cavity in the substrate may be of the same size, horizontal cross-sectional area and shape as the at least one opening through at least one of: the bottom metal layer and the top metal layer. Alternatively, the at least one air cavity in the substrate may be different to the at least one opening through the at least one of: the top metal layer and the bottom metal layer; the difference being in at least one of: number, shape, horizontal cross-sectional area, and location.

The at least one board with at least one air cavity may further comprise a plurality of via holes surrounding the at least one air cavity and through at least one of: the top metal layer, the bottom metal layer, and the substrate. The via holes may be for at least one of: interconnecting, grounding and shielding. At least one of the plurality of via holes may have a via post for at least one of: interconnecting, grounding and shielding. The plurality of via holes may have side walls that are shielded.

The quasi-planar circuit may further comprise a plurality of via slots in at least one of the top metal layer and the bottom metal layer, for at least one of: interconnecting, grounding and shielding. The plurality of via slots may have side walls that are shielded.

The patterned metal portion may be at least partially connected to one of the top metal layer and the bottom metal layer, the connection being adjacent the at least one air cavity. The patterned metal portion may be of: a stripline, a suspended micro-stripline, a conductor-backed coplanar waveguide, a slotline, and a fineline.

The quasi-planar circuit may further comprise at least one lumped electronic device selected from: diodes, transistors, inductors, capacitors, resistors, metal-insulator-metal capacitors, and integrated circuit chips.

The quasi-planar circuit may further comprise at least one in/out network for the patterned metal portion, the at least one in/out network being selected from: stripline, micro stripline, metal trace, conductor-backed coplanar waveguide, via interconnects, gap coupling, and tape line coupling.

Brief Description of the Drawings

In order that the present invention my be fully understood and readily put into practical effect, there shall be described by way of non-limitative example only preferred embodiments of the present invention, the description being with reference to the accompanying illustrative drawings.

In the drawings:

Figure 1 illustrates a first preferred embodiment, being a multilayer board-level air cavity integration circuit, after fabrication;

Figure 2 illustrates the multilayer board of Figure 1 before bonding;

Figure 3 is a series of illustrations of several possible variations in air cavities by number, size, depth, and location;

Figure 4 is an illustration of some possible variations in air cavities by shape;

Figure 5 is an illustration of some possible variations in air cavities in the substrate as against the openings in the metal layers;

Figure 6 is a vertical cross-sectional view (not to scale) of a second embodiment;

Figure 7 is a vertical cross-sectional view (not to scale) of a third embodiment;

Figure 8 is a vertical cross-sectional view (not to scale) of a fourth embodiment;

Figure 9 is a vertical cross-sectional view (not to scale) of a fifth embodiment;

Figure 10 is a vertical cross-sectional view (not to scale) of a sixth embodiment;

Figure 11 is a vertical cross-sectional view (not to scale) of a seventh embodiment;

Figure 12 is a vertical cross-sectional view (not to scale) of an eighth embodiment;

Figure 13 is a vertical cross-sectional view (not to scale) of a ninth embodiment;

Figure 14 is a vertical cross-sectional view (not to scale) of a tenth embodiment;

Figure 15 is an illustration of an eleventh embodiment in the form an antenna with air cavity;

Figure 16 is an illustration of a twelfth embodiment in the form an antenna with board air cavity;

Figure 17 is an illustration of a thirteenth embodiment in the form of a configuration on three boards;

Figure 18 is an illustration of a fourteen embodiment in the form of a further configuration on three boards;

Figure 19 is a vertical cross-sectional view (not to scale) of a fifteenth embodiment;

Figure 20 is a vertical cross-sectional view (not to scale) of a sixteenth embodiment;

Figure 21 is an illustration of a patterned metal portion in the form of a suspended low pass filter;

Figure 22 is an illustration of a patterned metal portion in the form of a quasi-lumped suspended resonator;

Figure 23 is an illustration of a patterned metal in the form of a mixer;

Figure 24 is an illustration of board-level integration of digital, analogy and radio frequency circuits for SIP applications;

Figure 25 is a graph of the results of an exemplification using a 18.6GHz band pass filter; and

Figure 26 is a graph of the results of an exemplification using a 16.7GHz band pass filter.

Detailed Description of Preferred Embodiments

As shown in Figures 1, 2 and 3, the preferred embodiment 101 has multiple boards. There may be any suitable, required or desired number of boards. As shown, there are five – 102, 103, 104, 105 and 106. The five boards 102, 103, 104, 105 and 106 may be different to each other, or may all be the same, and they may be in any required sequence. Two or more of them may be the same as each other, but different to the remaining boards. As shown, boards 102 and 106 are the same, but are different to the boards 103, 104 and 105. Boards 103 and 105 are the same as each other, but are different to boards 102, 104 and 106. Board 104 is different to the other four boards.

Each board 102, 103, 104, 105 and 106 has a substrate 2. The substrates 2 may be of one or more layers, and may be of any suitable or required material such as, for example, rigid flex, polyimide, liquid crystal polymer boards, benzocyobutene ("BCB") layer, low temperature co-fired ceramics ("LTCC"), or other microwave boards, substrates or laminates. Substrates 2 may have metal layers 1, 5 on all or a part of the top 107 and bottom 108 surfaces respectively of each substrate 2. The layers 1, 5 preferably completely cover the top 107 and bottom 108 surfaces respectively of the substrates 2. Via holes 3 may be formed through the layers 1, 5 as well as the substrates 2 of each board 102, 103, 104, 105 and 106. As can be seen from Figure 1 the via holes 3 may be axially aligned through two or more of the boards 102, 103, 104, 106 and 106. Some of the via holes 3 may be used to enable the boards 102, 103, 104, 105 and 106 to be secured together without the need for a suspending or shield box.

For all boards 102, 103, 104, 105 and 106 one or more of the metal layers 1, 5 may be patterned. At least one metal layer 1, 5 will be patterned. However, some of the metal layers 1, 5 may not be patterned. The patterning of the metal layers 1, 5 may be different for each board 102, 103, 104, 105 and 106.

Boards 103, 104, and 105 have an air cavity 6 for assisting in the controlling of field distributions around a patterned metal portion 203 and the air cavity 6. The nature and location of the air cavities 6 may be as required or desired in respect to their: number, size, shape, depth and location, provided the air cavities 6 perform the required function of assisting the controlling of the field distribution around the patterned metal portion 203 and the air cavity 6. Air cavities 6 on different boards 103, 104 and 105 may be the same or different, and may be vertically aligned, or may be mis-aligned. They may be laterally offset.

As shown in Figure 3, in the air cavity 6 may be in:

(a) the top surface 107 of the substrate 2;

(b) the bottom surface 108 of the substrate 2;

(c), (d), (e) and (g) it may be in both the top surface 107 and the bottom surface 108; and/or

(f) completely through the substrate 2.

If in both the top surface 107 and the bottom surface 108, the air cavities may be of the same number, size, shape, depth and location. However, one or more of each of: the number, size, shape, depth and location may be changed, as can be seen from (c), (d), (e) and (g).

Figure 4 shows that any of the air cavities 6 may have a horizontal cross-sectional area that may be of any shape such as, for example:

(a) rectangular (including regular and irregular rectangles);

(b) elliptical (including regular and irregular ellipses; and

(c) circular.

Many other suitable horizontal shapes may be used such as, for example: irregular, octagonal, hexagonal, and triangular. If there is more than one air cavity 6 on the one board, the air cavities 6 may be of different shapes and and/or depths and/or locations.

As shown in Figure 5, those of the boards 102, 103, 104, 105 and 106 having a top metal layer 1 and/or bottom metal layer 5 may have all or some of their material of the layers 1, 5 removed to form openings 7. The openings 7 may be aligned with the air cavities 6. The openings 7 may be:

(a) of the same number, size, shape and location as the air cavities 6;

(b) of the same number, shape and location as the air cavities 6 but of a larger size;

(c) through top and bottom layers 1, 5 and be of the same number, size, shape and location as the air cavities 6;

(d) of the same number, shape and location as the air cavities 6 but of a smaller size; and

(e) of a different size and/or shape as the air cavities 6; and

(f) any other possible variant in one or more of: number, size, shape and location as the air cavities 6 including of different shape and/or number and/or location and/or size.

As shown in Figure 2, the boards 103, 105 have air cavities 6 of the same nature as those of Figure 3(f) and openings 7 the same as Figure 5(c). Board 104 has an air cavity 6 of Figure 3(b), with substrate 2 of reduced thickness above the air cavity 6. Board 104 also has openings 7 in top metal layer 1 and bottom metal layer 5 that are the same horizontal cross-sectional area, size, shape and location as air cavity 6. Board 104 has a patterned metal portion 203 supported by substrate 2 of reduced thickness and extending over the air cavity 6 and across top opening 7. "Over" the air cavity 6 includes, but is not limited to at least one of:

(a) extending partially across the air cavity 6 in a first direction within the X-Y plane and completely across the air cavity in a second direction within the X-Y plane,

(b) extending completely across the air cavity 6 in the first direction but not completely across the air cavity 6 in the second direction, and

(c) extending completely across the air cavity 6 in both the first and second directions;

and:

(d) having no other material between the patterned metal portion and the air cavity 6, or

(e) having a reduced-thickness portion of the substrate 2 between the patterned metal portion 203 and the air cavity 6.

The second direction is different to the first direction, and is preferable perpendicular to the first direction. The first direction may be the direction of the X axis. The X-axis is the longitudinal axis of the surface of the patterned metal portion adjacent the substrate 2. The Y axis is lateral to the X axis and perpendicular to the plane of the page.

The patterned metal portion 203 may be formed from the material of the metal layer 1 or 5 of which it is a portion. It may be formed by and during the creation of the opening 7. However, the patterned metal portion 203 may be separately formed and may subsequently be placed over the opening, if required or desired.

The patterned metal portion 203 and the air cavity 6 control at least a part of a field distribution in the region of the patterned metal portion 203 and the air cavity 6, and may also do so in the substrate 2.

There may be lumped electronic devices forming part of board 104. As shown there is a capacitor 201 and an integrated circuit chip 202. The lumped electronic devices may include, but are not limited to, one or more of diodes, transistors, inductors, capacitors, resistors, metal-insulator-metal capacitors, and integrated circuit chips (hereinafter termed "lumped electronic devices").

Any possible combination of the various possibilities, including boards without air cavities 6 and/or boards with no metal layers 1, 5, may be used to meet the functional requirement of controlling the distributions produced by the circuits of each board.

The electromagnetic field produced by the patterned metal portion 203 will therefore be at least in part controlled by the air cavity 6 in board 104 as well as the air gap 6 in board 103. The two air gaps 6, in this case, are aligned and of the same shape, size, horizontal cross-sectional area and location. But they are dissimilar in depth. Openings 7 are also all of the same size, area and location.

The air cavity 6 in board 104 has at its top end the patterned metal portion 203 supported by the reduced-thickness portion of the substrate 2; and at its bottom end the air cavity 6 has the top metal layer 1 of board 106. Every air cavity 6 will have a patterned metal portion 203 at one end, and either substrate, a metal layer 1 or 5, or another patterned metal portion at the other end. The patterned metal portion 203 may be supported by a reduced-thickness portion of the substrate 2.

The structure illustrated in Figures 1 and 2 will form part of the circuits on a multilayer, printed circuit board. Each board 102, 103, 104, 105 and 106 may have an in/out ("I/O") feed network (not shown) that may be any suitable, known I/O feed network and ports. There may be different stacking sequences of the boards 102, 103, 104, 105 and 106, and also different metal layers 1, 5. The thickness and materials of the boards 102, 103, 104, 105 and 106 are preferably the same as that of the corresponding multilayer printed circuit board.

The air cavities 6 and openings 7 of the boards 102, 103, 104, 105 and 106 may be aligned in a plane perpendicular to the top metal layers 1. Alternatively, they may not be aligned. Therefore, any air cavity 6 may have above and/or below it: an opening 7, another air cavity 6, metal layer 1, metal layer 5, patterned metal portion 203, or a substrate 2, depending on whether the air cavity 6 is in the top surface 107, bottom surface 108, or completely through the substrate 2; and also depending in which board the air cavity 6 is located. The air cavities 6 should not be in the sides or ends of the boards 102, 103, 104, 105 and 106. Openings 7 should not be in the sides or ends of the metal layers 1, 5 of the boards 102, 103, 104, 105 and 106.

The air cavities 6 have their side walls 204 formed by the substrate 2. Preferably, the air cavities 6 do not have shielding on the side walls 204, particularly for non-resonant circuits such as, for example, power dividers, baluns, and couplers.

The air cavities 6 may be adjacently surrounded by one or more of: the via holes 3, via slots 11, metal 1 and/or 5, and via posts, particularly for resonant circuits such as, for example, filters and oscillators. The metal 1 and vias 3 around the air cavities 6, 7 may be connected. For grounding, the vias 3, via slots 11, or via posts, may be used. If required, the via holes 3 and via slots 11 may be metalized by being, for example, electroplated with a conductive metal on their side walls to provide shielding around the air cavities 6.

Vias 3, via posts and metal layers 1, 5 may be aligned on each board to form overall vias 3. One or more of the vias 3, may have via posts. Blind via holes or slots may be in positions that are misaligned or aligned for the different boards.

To now refer to Figures 6 to 14, there are shown several embodiments of varying structures.

In Figure 6 there are six boards 601, 602, 603, 604 and 605 each having a substrate 2. Each substrate 2 may have multiple layers, if required or desired. Top board 601 has a top metal layer 1 and a bottom metal layer 5. Board 602 may also have a top metal layer 1 and/or bottom metal layer 5, or may have no top metal layer 1 or bottom metal layer 5. Board 602 has an air cavity 6(a) for the full height of its substrate 2. If board 602 has a bottom metal layer 5, the bottom metal layer 5 will have an opening 7 of a shape the same as air cavity 6(a) and a horizontal cross-sectional area at least as large as that of the air cavity 6(a). The air cavity 6(a) is terminated at its top end by top metal layer 1 of board 602 or bottom metal layer 5 of board 601, and at its bottom end by a patterned metal portion 606 extending across an opening 7 of the top metal layer 1 of board 603. The bottom metal layer 5 of board 603 also has an opening 7 across which extends a patterned metal portion 607 that may be different to the patterned metal portion 606. Board 604, like board 602, may have a top metal layer 1 with an opening 7 of a shape the

same as air cavity 6(b) and a horizontal cross-sectional area at least as large as that of air cavity 6(b), or may have no top metal layer 1. Board 604 may or may not have a bottom metal layer 5, but does have the air cavity 6(b) that extends completely through substrate 2. Air cavity 6(b) terminates at its top end with the patterned metal portion 607 and at its bottom end by bottom metal layer 5 of board 604 or top metal layer 1 of board 605. Board 605 also has a bottom metal layer 5. The side walls 608 of air cavities 6(a) and 6(b) are not shielded, shielding being by metalized vias 3. One or more of the vias 3 may contain via posts.

The structure illustrated in Figure 7 is similar to that of Figure 6 except that top metal layer 1 and bottom metal layer 5 of board 705 have openings 7. This is suitable if the patterned metal portion 707 is, for example, an antenna. The absence of metal layers 1, 5 at openings 7 allows the transmission through substrate 2 of board 705 of the relevant electromagnetic field. In this case, air cavity 6(b) terminates at its top end at patterned metal portion 707, and at its bottom end at substrate 2 of board 705.

In Figure 8, the structure is similar to that of Figure 6 except that the board 801 has an opening 7 in its bottom metal layer 5 and the air cavity 6(a) extends into substrate 2 of board 801, there being an opening in bottom metal layer 5 of board 801. Therefore air cavity 6(a) terminates at its top end with substrate 2 of board 801 and its bottom end with patterned metal portion 806. Air cavity 6(b) extends into the substrate of board 805, there being an opening 7 in the top metal layer 1 of board 805. Therefore, air cavity 6(b) terminates at its upper end with patterned metal layer 807 and at its bottom end with substrate 2 of board 805.

The embodiment of Figure 9 is similar to that of Figure 6 except that board 903 has an opening 7 in its bottom metal layer 5, and air cavity 6(b) extends through the substrate 2 of board 903. Therefore, air cavity 6(b) terminates at its top end with patterned metal portion 906 and at its bottom end with top metal layer 1 of board 905.

In Figure 10, the structure is again similar to that of Figure 6 except that the vias 3 are removed. If desired, shielding may be provided by metalizing (coating with a metal) the side walls 1008 of

air cavities 6(a) and 6(b). A patterned metal portion 1006 extends across and separates both air cavities 6(a) and 6(b). Air cavity 6(a) terminates at its top end with bottom metal layer 5 of board 1001 and its bottom end with patterned metal portion 1006. Air cavity 6(b) terminates at its top end with patterned metal portion 1006 and at its bottom end with top metal layer 1 of board 1005.

Figure 11 is essentially the same as Figure 6 except that the patterned metal portion 1106 has lumped electronic devices, generally shown as 1110, connected to the patterned metal portion 1106 by connections 1109. The connections may be via binding connections.

Figure 12 is again similar to the embodiment of Figure 6 except that board 1201 has openings 7 in its top metal layer 1 and bottom metal layer 5. The opening 7 in top metal layer 1 is larger in horizontal cross-sectional area than the air cavity 6(a) whereas opening 7 in bottom metal layer 5 is the same horizontal cross-sectional area as air cavity 6(a). Board 1205 also has openings 7 in its top metal layer 1 and bottom metal layer 5, with both openings 7 being of the same horizontal cross-sectional area as air cavity 6(b). Air cavity 6(a) terminates at its top end with substrate 2 of board 1201, and at its bottom end with patterned metal portion 1206. Air cavity 6(b) terminates at its top end with patterned metal portion 1207 and at its bottom end with substrate 2 of board 1205. This structure is of advantage where patterned metal portions 1206, 1207 are, for example, antennas as the openings 7 allow transmission of electromagnetic fields through substrate 2 of boards 1201, 1205. Substrates 2 of boards 1201, 1205 enclose the air cavities 6(a) and 6(b) and thus provide protection for the patterned metal portions 1206, 1207 and therefore perform a packaging function.

Again, Figure 13 is similar to the embodiment of Figure 6 except that board 1305 has patterned metal portion 1306 in its top metal layer 1, and a patterned metal portion 1307 in its bottom metal layer 5. As such, air cavity 6(a) terminates at its top end with bottom metal layer 5 of board 1301 and at its bottom end with patterned metal portion 1306 of board 1303; and air cavity 6(b) terminates at its top end with patterned metal portion 1307 of board 1303, and at its bottom end with patterned metal portion 1306 of board 1305. Patterned metal portions 1306 may be the

same or different, and patterned metal portions 1307 may be the same of different. Patterned metal portions 1306 will normally be different to patterned metal portions 1307 although this is not essential – they may be the same.

The embodiment of Figure 14 is similar to that of Figure 6 except that board 1403 has an opening 7 in its bottom metal layer 5, and air cavity 6(b) extends into but not completely through substrate 2 of board 1403. In this way the air cavity 6(b) is terminated at its top end by the reduced-thickness portion 1408 of substrate 2 of board 1403, and at its bottom end by top metal layer 1 of board 1405. The reduced – thickness portion supports the patterned metal portion 1406. Therefore, patterned metal portion 1406 is over air cavity 6(b) but with the reduced-thickness portion 1408 between them.

In this way the suspended substrate integration of passive components with a three-dimensional air cavity 6 can be directly based on multilayer printed circuit boards. The suspended stripline and air cavity circuits may also have multi-layer board integration for passive components including those with backed three-dimensional air cavities in multilayer boards. It can also be used to enhance single component packages that require improved circuit performance and reduced board size as it allows multiple advanced packaging technologies, such as multi-chip modules and single in-line packages, to be combined to create solutions customized for the required application.

The patterned metal portions may be any required or desired pattern or microwave planar structure. In the embodiments suspended line configurations are mainly used. However, circuits using slot lines, conductor backed coplanar waveguides, and fin-line structures may be formed. Though embodiments described below are high frequency components, high frequency system integration and packaging may also benefit. A single shielded cavity structure in Figure 1, or several shielded structures, may be formed. For multiple shielded structures, the necessary interconnects from one component or structure to the others will be necessary. Interconnects among the components may be via connects, bonding wires, or planar transmission lines such

as, for example, suspended striplines, micro striplines, and conductor-backed coplanar waveguides, slotlines and finelines.

For high power applications, wider metal trace and low input loss for the same characteristic impedance may result, thereby reducing heat generation. Any transmission lines with an air cavity may demonstrate lower insertion loss, sometimes wide metal trace.

For low noise applications, a passive circuit with three-dimensional air cavity backing may reduce the matching loss and thus reduce noise.

An example of an antenna configuration with air cavity is illustrated in Figure 15. This is before bonding in the same manner as for Figure 2. The antenna is a patch antenna and is feed by a tap on the same board as the patch. The top directive patch may be multilayered to further increase the directivity of the antenna. As such, the antenna has high directivity, and low side lobes, when compared to known such antennas. As described above, antenna may be used to form radiation circuits. One board 1501 with metal 5 patterned with an optional directive patch 27 is used as the top of the structure, with there being an intermediate board 1502 of the same category, two boards 1503 and 1504 of a second category similar to that of Figure 3(f), and a board 1505 with no air cavities. The intermediate board 1502 is preferably in the middle, between two boards 1503 and 1504 of a different category, each of which has a central through air cavity 6. The main patch 28 on the intermediate board 1502 is fed by an I/O feed network that may be stripline, conductor-backed coplanar waveguide, or by via inter connects. The height of the air cavity 6 can be determined by the requirements of the product specification, the board thickness, and the number of layers of boards. The top board 1501 may be replaced by multiple boards of the same category stacked together to achieve certain performance requirements such as, for example, directivity, beam width, and so forth.

Figure 16 shows an example of an antenna configuration with board air cavity backing. This is before bonding in the same manner as for Figure 2. It is a patch antenna with cross slot and broad side gap coupling being used to form a dual polarized antenna. The antenna may use the multilayer stacked configuration of Figure 16 to increase the gain of the antenna. One board 1601 with a top-only air cavity 6 similar to that of Figure 3(a) is used on the bottom of the structure for the radiation aperture. The main cross slot patch 29 on the bottom 5 of the intermediate or middle board 1602 is fed on its top by a feed network as described above. A board 1603 with no air cavities is used as the top, with boards 1604, 1605 each having a through air cavity 6. Board 1604 and 1605 are on either side of the middle board 1602.

In Figure 17 is shown an example of a configuration on three different boards. This is before bonding in the same manner as for Figure 2. The top metal layer 1 and the substrate 2 of the bottom board 1701 are partially removed to form opening 7 and air cavity 33. The bottom metal layer 5 and the substrate 2 of the top board 1702 are partially removed to form the mirror-image and identical air cavity 31. The portion of the bottom metal layer 5 below the air cavity 6, the portion of the top metal layer 1 above the air cavity 6, and the substrate 2 of the third board 1703 directly above and below the air cavities 33, 31 are completely removed to form the through-cavity 6. The support of the patterned metal portion is partially by the lateral metal portion 1710 connected to a gap 1711 in the metal layer 1701 on the same board and partially on the metal layer 1701. Patterns without substrates have an extremely high Q-factor. The quarter-wavelength step impedance resonator 30 is suspended on the board 1703 by the portions 30a, 30b that connected it to the substrate 2 and top metal 1. The I/O feed networks 9 and 10 are a gap coupling and a tape line coupling respectively. The substrate 2 adjacent air cavity 6 of the board 1703 supports the patterned metal portion. The configuration can also be used as tunable resonator by adding a varactor.

Figure 18 illustrates another example of a configuration on three boards. A single board 1801 between two boards 1802 and 1803 is used to form the air cavity 6. The metal layers 1, 5 on the

boards 1802 and 1803 are manly used for shielding of the air cavity 6 and the I/O port coupling for air cavity 6. The air cavity 6 may be of any shape or size. The air cavity 6 may also be in series, parallel or stacked to form multiple air cavities. The air cavity 6 of the multilayer structure forms a board-level waveguide. Patterns without substrates have an extremely high Q-factor. In this configuration, one side of each board 1802 and 1803 is completely shielded by metal except where the coupling slot 29 on each board is needed. The I/O feed networks 9 and 10 may be of any suitable form including, but not limited to, coplanar waveguide, micro strip line, strip line, slot, and so forth, with appropriate configurations. As illustrated they are gap coupling 9 below a metal trace 10. This configuration can also be used to form the air cavity waveguide on multilayer boards. Internal vias 26 are formed for grounding as is required by the gap coupling for the air cavity 6.

Figure 19 shows a three board structure having boards 1901, 1902 and 1903. All boards 1901, 1902 and 1903 have a substrate 2 that may be multiple layers, or a single layer. A cavity 6(a) is formed in substrate 2 of board 1901 and having at its upper end a substrate 2 portion 1908 of a reduced thickness, and at its bottom end a patterned metal portion 1906 formed over an opening 7 in the top metal layer 1 of board 1902. Board 1901 may have a bottom metal layer 5, but that metal layer 5 will have an opening 7 with a shape the same as, and a horizontal cross-sectional area at least as great as, those of the air cavity 6(a). Board 1902 also has a bottom metal layer 5 with an opening 7 and a patterned metal portion 1907. Board 1903 may have a top metal layer 1 but it will have an opening 7 with a shape the same as, and a horizontal cross-sectional area at least as great as, those of the air cavity 6(b) formed in substrate 2 of board 1903. Air cavity 6(b) terminates at its top end with patterned metal portion 1907 and at its bottom end with a portion of reduced thickness of substrate 2 of board 1903. Board 1903 has a bottom metal layer 5.

Figure 20 shows a further five board structure having boards 2001, 2002, 2003, 2004 and 2005. All boards 2001, 2002, 2003, 2004 and 2005 have a substrate 2. Each substrate may be a single layer or may have multiple layers. An air cavity 6(a) is formed completely through the substrate 2

of board 2002; and an air cavity 6(b) is formed completely through substrate 2 of board 2004. Air cavity 6(a) terminates at its bottom end with patterned metal portion 2006 of top metal layer 1 of board 2003; and at its top end with bottom metal layer 5 of board 2001 if board 2002 does not have a top metal layer 1 or, if board 2002 does have a top metal layer 1, with top metal layer 1 of board 2002. Air cavity 6(b) terminates at its top end with patterned metal port in 2007 of bottom metal layer 5 of board 2003; and at its bottom end with top metal layer of board 2005 if board 2004 does not have a bottom metal layer 5 or, if board 2004 does have a bottom metal layer 5, with bottom metal layer 5 of board 2004.

The side walls of air cavities 6(a) and 6(b) are formed by the substrates 2 in which the air cavities 6(a) and 6(b) are formed. Those side walls have a metallic coating or plating 2009 for shielding. Blind vias 2010 may be provided through board 2003 to connect the metal plating 2009 of cavities 6(a) and 6(b).

With this structure there are a plurality of vias 3 through each of the boards 2001, 2002, 2003, 2004 and 2005. None of the vias 3 pass through all the boards. The boards 2001, 2002, 2003, 2004 and 2005 may be secured to each other by, for example, adhesive between top metal layers 1 and bottom metal layer 5.

In Figure 21 a low pass filter is illustrated. Both sides of the metal layers 1, 5 are partially etched to form the pattern. The top metal layer 1 has traces 31 that include wide metal traces 31a and narrow metal traces 31b connected at intervals. The top wide trace 31a also has wide bottom trace 13a to form an equivalent metal-insulator-metal ("MIM") capacitor, while the top narrow traces 31b and the bottom narrow traces 13b are offset to reduce parasitic capacitance. Such an air cavity backed configuration of a low pass filter has a wide stop band and a low input loss. The pattern of the top metal layer 1 is similar to that of a micro strip step impedance low pass filter while the bottom metal 5 is a similar to a defected ground pattern. Thus the structure will have the photo band gap effects and the filter will demonstrate distinctive pass band and stop band

performance. The surrounding grounding metal via slot 11 is used to suppress possible leakage into neighbouring circuits. Such a structure may also be applicable to other photo band gap structures.

The illustrated circuit forms only a part of the board. The I/O feeds networks 9, 10 may be of any suitable form including, but not limited to, stripline, conductor-backed coplanar waveguide, or by via interconnects.

Figure 22 is an example of a quasi-lump resonator on a board. The resonator has high Q-factor and can be used for high-performance, voltage-controlled oscillators. This also illustrates how to build up a quasi-lump element circuit on a board by using metal patterns. Lump elements such as, for example, inductors and MIM capacitors, may also be used to form other passive components such as, for example, filters, baluns, and broad bandwidth, high-frequency circuits such as a bias Tee. The bottom metal 5 of the board is at least partially removed in the region of the air cavity 6 to form an opening 7. The resonator has a suspended spiral inductor 24 and an MIM capacitor 25. An inner via connect 26 is used to connect the top metal 1with the bottom metal 5 trace 13. The MIM capacitor 25 is a sandwich structure formed by the top metal 1, substrate 2 and bottom metal 5. The MIM capacitor 25 can also be replaced by the lump varactor with bias circuit. Thus the resonator becomes tunable. As such, the tunable resonator can be used for a voltage controlled oscillator, and a tunable filter, with a more compact construction. Again, the illustrated circuit forms only part of the board.

An example of a mixer is shown in Figure 23. Both active and passive circuits may be designed for the air cavity backed print circuit board. Furthermore, lumped electronic devices such as, for example, diodes, transistors, inductors, capacitors and resistors may be mounted with passive components or traces, as may be a broad-band, double-balance star mixer. The circuit shown in Figure 23 is for active utilization. The metal pattern may be an active radio frequency circuit or a radio frequency system. The bottom metal 5 is removed in the region of the air cavity 6 to form an

opening 7. The radio frequency signal is input by metal trace 17. The signal of a local oscillator 16 is fed through a suspended-line, parallel-line, coupled filter 14. The local oscillator and radio frequency signals are applied to the diodes 18 through a suspended strip line branch line coupler 20. The intermediate frequency signal is output at 15 and DC leakage is blocked by a lump capacitor 19.

By using air cavity backed circuits, the system noise characteristic, conversion loss, and out of pass band characteristics may be improved with a cost, size and weight better than that of a waveguide system.

Figure 24 illustrates an example of board level integration of digital, analog and radio frequency circuits for system-in-packaging ("SIP") applications. The air cavity is embedded in the radio frequency parts of the communication system. It is of some convenience to integrate the communication system including digital and analog components 37, and radio frequency components 38, on the same multilayer board. Leakages in the radio frequency components 38 may be reduced by using the via holes 3 or via post shielding. High performance radio frequency components may be implemented with low frequency components using the same multilayer boards and fabrication technologies. The system has the advantage of high performance, low cost, light weight and compact size.

Figure 25 shows the full-wave electromagnetic results of an exemplification using an 18.6GHz band pass filter. The calculated fractional bandwidth is 3.5%. The insertion loss of the traditional planar filter with the same fractional bandwidth is larger than 2.5 dB. The band pass filter is a self-packaged surface-mounted-device and there is no need for any additional packaging circuit.

Figure 26 shows the full-wave electromagnetic simulated results of another band pass filter. The calculated fractional bandwidth is 1.5%. The insertion loss of the traditional planar filter with the

same fractional bandwidth is larger than 3 dB. The band pass filter is a self-packaged surface-mounted-device and there is no need for any additional packaging circuit.

Whilst there has been described in the foregoing description preferred embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations or modifications in details of design, construction or operation may be made without departing from the present invention.

The Claims:

1. A quasi-planar circuit comprising a plurality of boards, each of the plurality of boards comprising a substrate; at least one of the plurality of boards having at least one air cavity formed in the substrate; at least one of the plurality of boards having at least one metal layer including at least one patterned metal portion, the at least one patterned metal portion being over the at least one air cavity; wherein the at least one patterned metal portion and the at least one air cavity are for controlling at least a part of at least one portion of an electromagnetic field distribution in the region of the at least one patterned metal portion and the air cavity.

2. A quasi-planar circuit as claimed in claim 1, wherein a first end of the at least one air cavity terminates at the patterned metal portion and a second end of the at least one air cavity terminates at one of: the substrate, another patterned metal portion, and another metal layer.

3. A quasi-planar circuit comprising a plurality of boards, each of the plurality of boards comprising a substrate; at least one of the plurality of boards having at least one air cavity formed in the substrate; there being at least one metal layer having at least one patterned metal portion over the at least one air cavity; wherein a first end of the at least one air cavity terminates at the patterned metal portion, and a second end of the at least one air cavity terminates at one of: the substrate, another patterned metal portion, and another metal layer.

4. A quasi-planar circuit as claimed in claim 3, wherein the at least one patterned metal portion and the at least one air cavity are for controlling at least a part of at least one portion of an electromagnetic field distribution in the region of the at least one patterned metal portion and the air cavity.

5. A quasi-planar circuit as claimed in any one claims 1, 2 and 4, wherein the control of the at least a part of at least one portion of the electromagnetic field distribution by the at least one air cavity and the at least one patterned metal portion is also of the electromagnetic field distribution in the substrate adjacent the at least one patterned metal portion and the at least one air cavity.

6. A quasi-planar circuit as claimed in any one of claims 1 to 5, wherein the at least one air cavity has side walls without shielding applied to the side walls.

7. A quasi-planar circuit as claimed in any one of claims 1 to 6, wherein the at least one air cavity has side walls with shielding applied to them.

8. A quasi-planar as claimed in any one of claims 1 to 7, wherein more than one board has at least one air cavity.

9. A quasi-planar circuit as claimed in claim 8, wherein the air cavities in the more than one board are substantially the same.

10. A quasi-planar circuit as claimed in 8, wherein some of the air cavities in the more than one board are different to each other, the difference being in at least one selected from the group consisting of: number, shape, cross-sectional area, depth, location and vertical alignment.

11. A quasi-planar circuit as claimed in any one of claims 1 to 10, wherein over the air cavity includes at least one of: extending partially across the air cavity in a first direction within an X-Y plane and completely across the air cavity in a second direction within the X-Y plane, extending completely across the air cavity in the first direction but not extending completely across the air cavity in the second direction, extending completely across the air

cavity in both the first and second directions; and one of: having no other material between the patterned metal portion and the air cavity, and having a reduced-thickness portion of the substrate between the patterned metal portion and the air cavity.

12. A quasi-planar circuit as claimed in claim 11, wherein the first and second directions are different; the X-axis being the longitudinal axis of a surface of the patterned metal portion adjacent the substrate, and the Y axis being lateral to the X axis and perpendicular to the plane of the page.

13. A quasi-planar circuit as claimed in any one of claims 1 to 12, wherein the at least one air cavity in the substrate is in at least one selected from the group consisting of: a top surface of the substrate, a bottom surface of the substrate, both the top surface and the bottom surface of the substrate, and completely through the substrate.

14. A quasi-planar circuit as claimed in claim 13, wherein the at least one air cavity in the top surface is different to the at least one air cavity in the bottom surface, the difference being in at least one selected from the group consisting of: number, shape, area, depth and location.

15. A quasi-planar circuit as claimed in claims 13 or claim 14, wherein the at least one metal layer comprises a top metal layer over at least a part of the top surface of the substrate.

16. A quasi-planar circuit as claimed in any one of claims 13 to 15, wherein the at least one metal layer comprises a bottom metal layer under at least a part of the bottom surface of the substrate.

17. A quasi-planar circuit as claimed in claim 16 when appended to claim 15, wherein the substrate is between the top metal layer and the bottom metal layer.

18. A quasi-planar circuit as claimed in claim 17, wherein there is at least one opening through at least one of: the top metal layer and the bottom metal layer.

19. A quasi-planar circuit as claimed in claim 18, wherein the at least one opening is through both the top metal layer and the bottom metal layer.

20. A quasi-planar circuit as claimed in claim 18 or claim 19, wherein the at least one opening through the top metal layer is the same as the at least one opening through the bottom metal layer.

21. A quasi-planar circuit as claimed in claim 18 or claim 19, wherein the at least one opening through the top metal layer is different to the at least one opening through the bottom metal layer, the difference being in at least one selected from the group consisting of: number, shape, area and location.

22. A quasi-planar circuit as claimed in claim 18 or claim 19, wherein the at least one air cavity in the substrate is of the same size, area and shape as the at least one opening through at least one of: the bottom metal layer and the top metal layer.

23. A quasi-planar circuit as claimed in any one of claims 18 to 21, wherein the at least one air cavity in the substrate is different to the at least one opening through the at least one of: the top metal layer and the bottom metal layer; the difference being in at least one selected from the group consisting of: number, shape, area, depth and location.

24. A quasi-planar circuit as claimed in ant one of claims 18 to 23, wherein the at least one patterned metal portion extends across the at least one opening.

25. A quasi-planar circuit as claimed in any one of claims 16 to 24, wherein the patterned metal portion is at least partially connected to one of the top metal layer and the bottom metal layer, the connection being adjacent the at least one air cavity.

26. A quasi-planar circuit as claimed in any one of claims 16 to 25, wherein the patterned metal portion is at least one selected from the group consisting of: stripline, suspended micro stripline, conductor-backed coplanar waveguides, slotlines, and finelines.

27. A quasi-planar circuit as claimed in any one of claims 16 to 26, wherein the at least one board with at least one air cavity further comprises a plurality of via holes surrounding the at least one air cavity and through at least one selected from the group consisting of: the top metal layer, the bottom metal layer, and the substrate.

28. A quasi-planar circuit as claimed in claim 27, wherein the via holes are for at least one selected from the group consisting of: interconnecting, grounding and shielding.

29. A quasi-planar circuit as claimed in claim 27 or claim 28, wherein at least one of the plurality of via holes has a via post for at least one of: interconnecting, grounding and shielding.

30. A quasi-planar circuit as claimed in any one of claims 27 to 29, wherein the plurality of via holes have side walls that are shielded.

31. A quasi-planar circuit as claimed in any one of claims 16 to 30 further comprising a plurality of via slots in at least one of the top metal layer and the bottom metal layer for at least one of: interconnecting, grounding and shielding.

32. A quasi-planar circuit as claimed in claim 31, wherein the plurality of via slots have side walls that are shielded.

32. A quasi-planar circuit as claimed in any one of claims 1 to 32 further comprising at least one lumped electronic device selected from the group consisting of: diodes, transistors, inductors, capacitors, resistors, metal-insulator-metal capacitors, and integrated circuit chips.

34. A quasi-planar circuit as claimed in any one of claims 1 to 33 further comprising at least one in/out network for the patterned metal portion, the at least one in/out network being selected from the group consisting of: stripline, microstrip line, metal trace, conductor-backed coplanar waveguide, via interconnects, gap coupling, and tape line coupling.

35. A quasi-planar circuit as claimed in any one of claims 1 to 34, wherein the substrate is a multi-layer substrate.

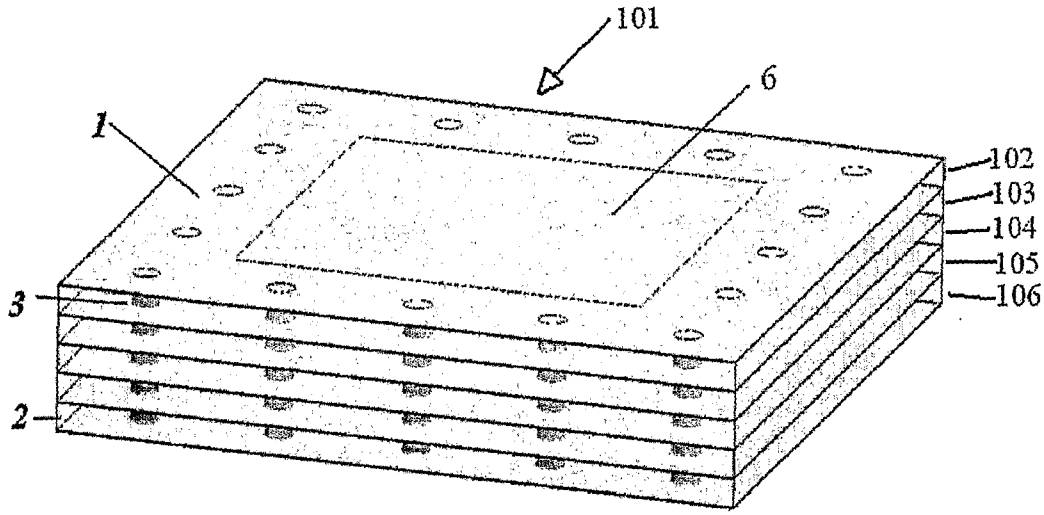


Figure 1

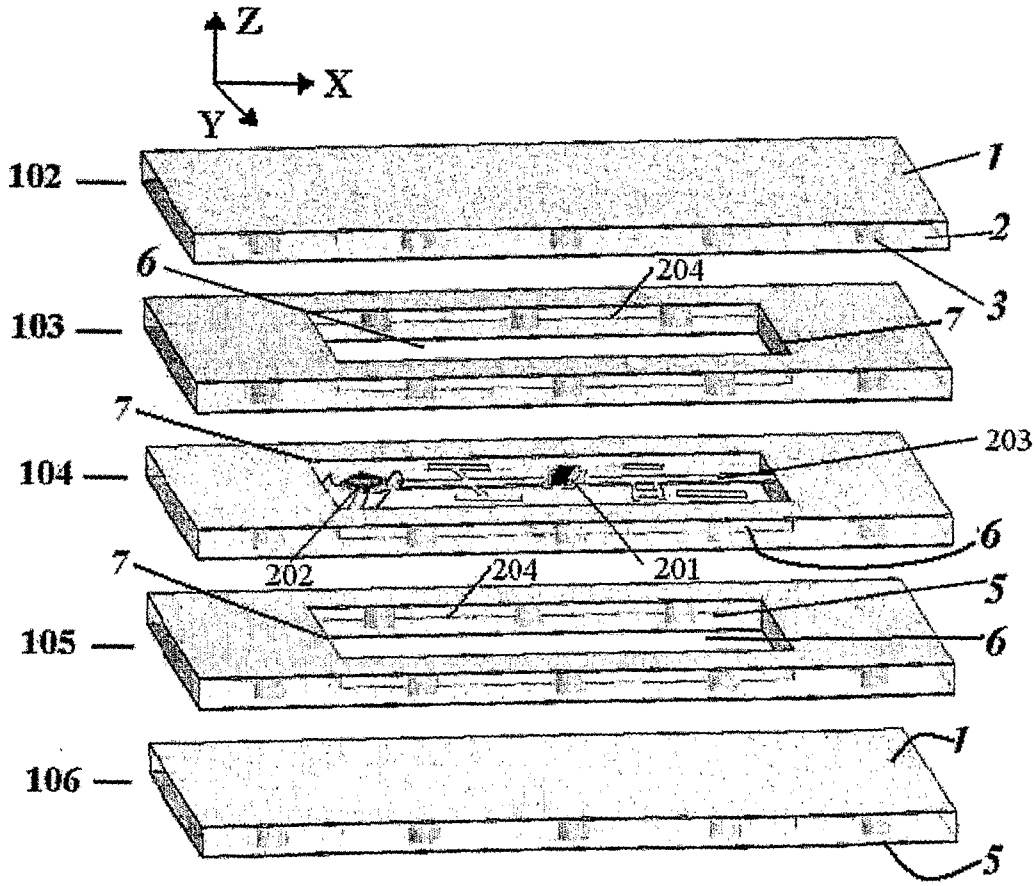


Figure 2

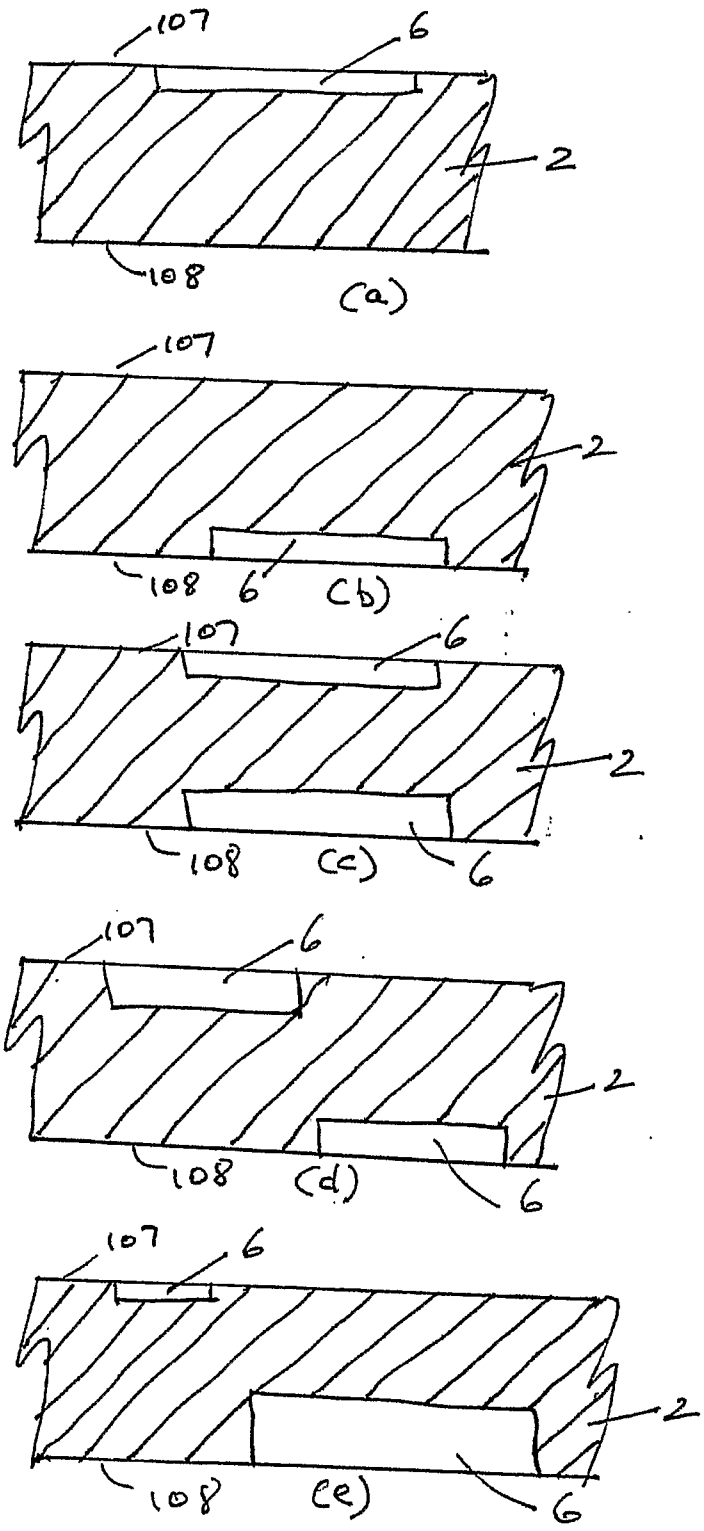


Figure 3 (part)

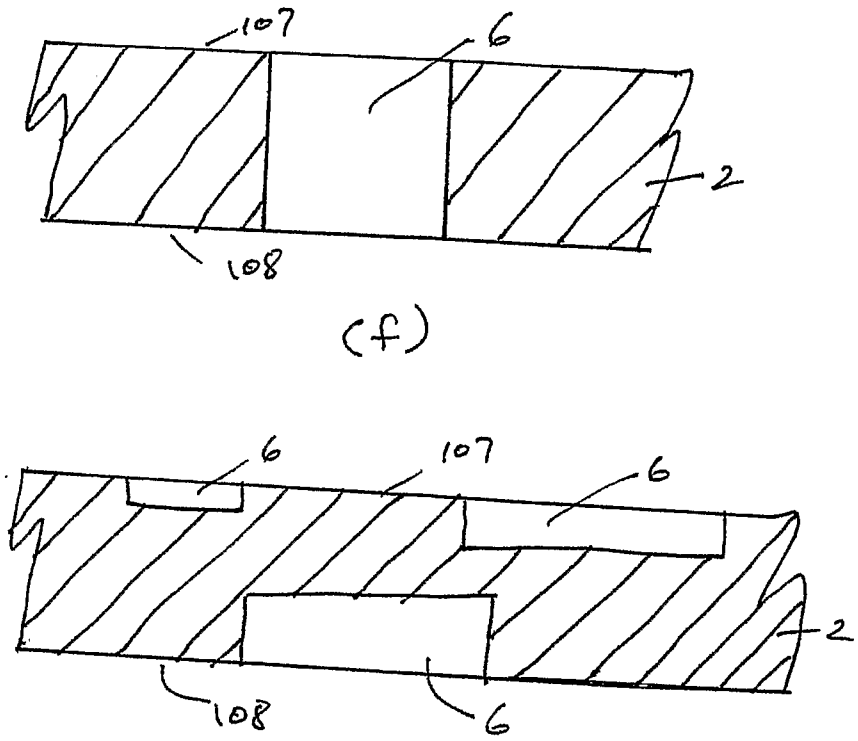


Figure3(conclusion)

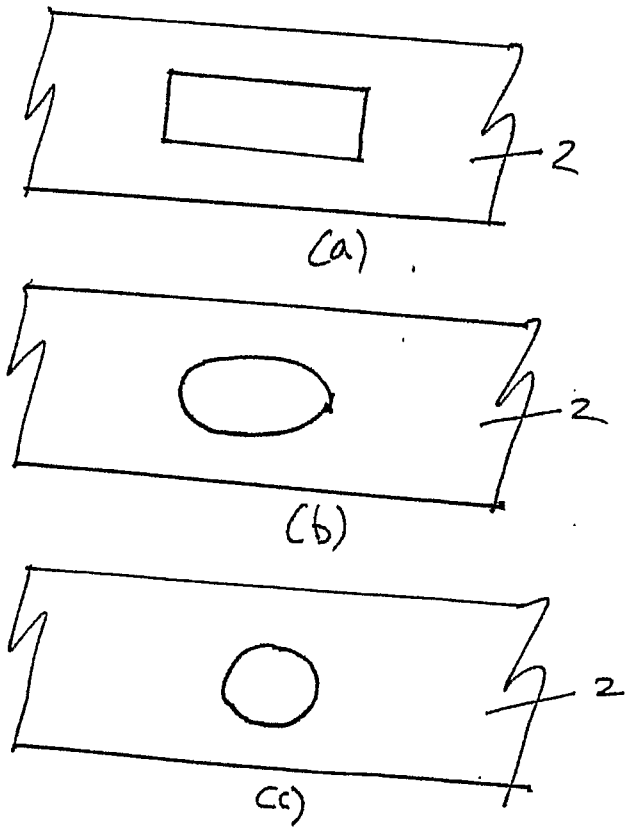


Figure 4

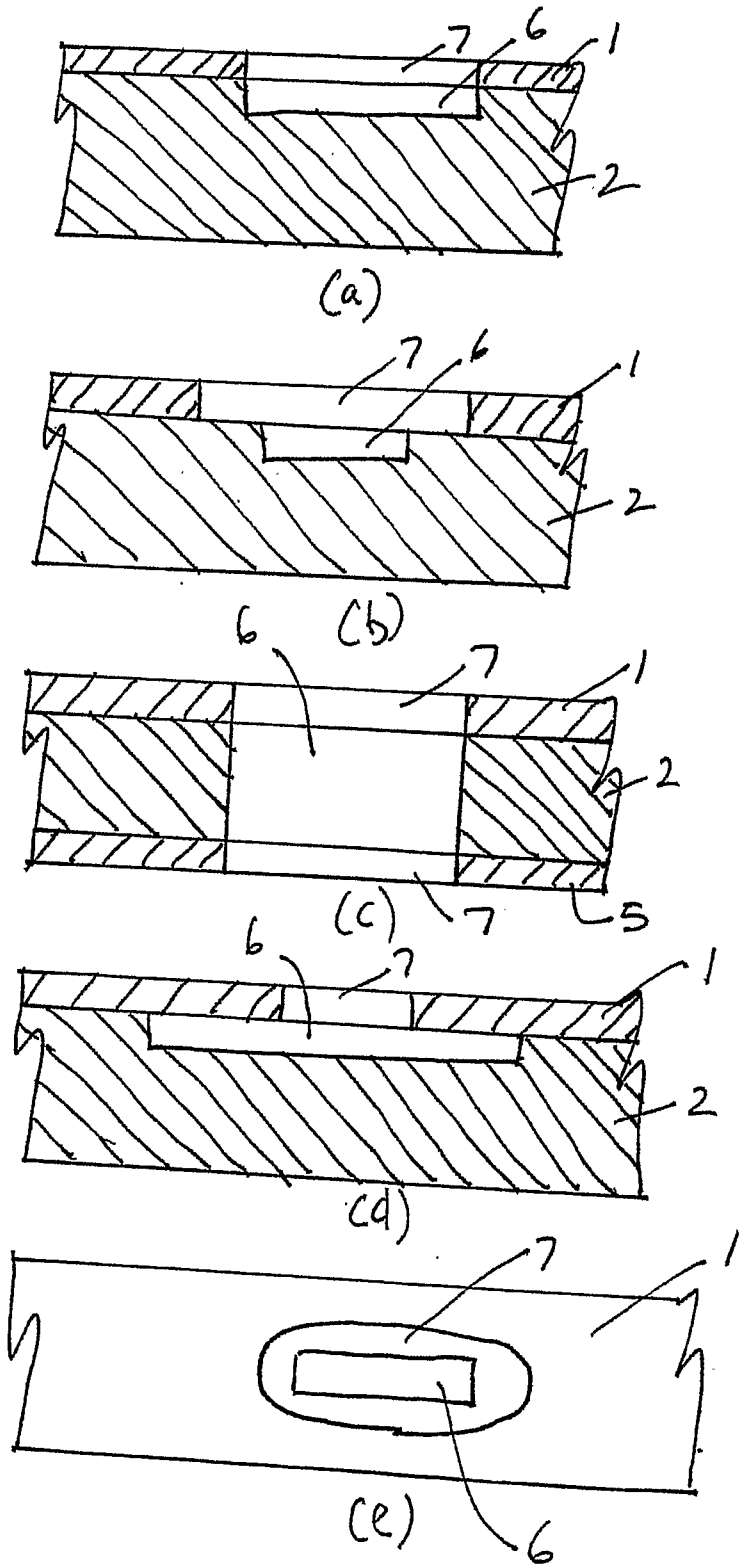


Figure 5

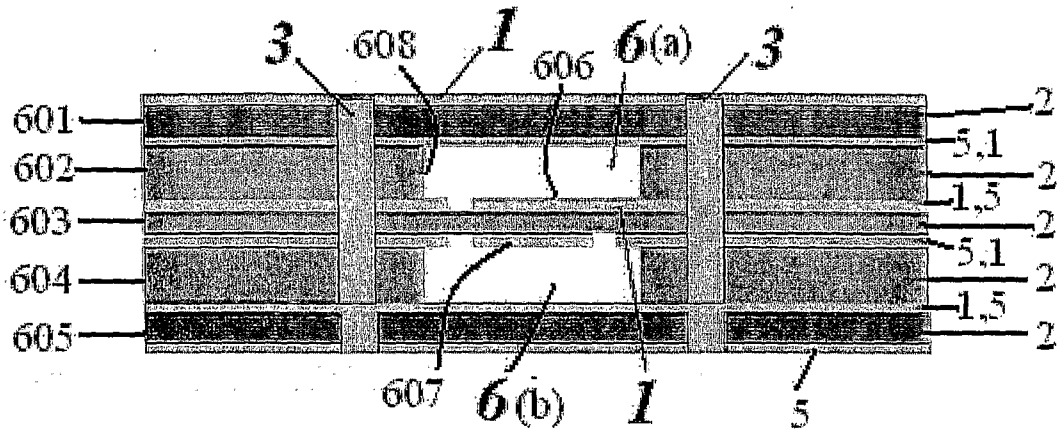


Figure 6

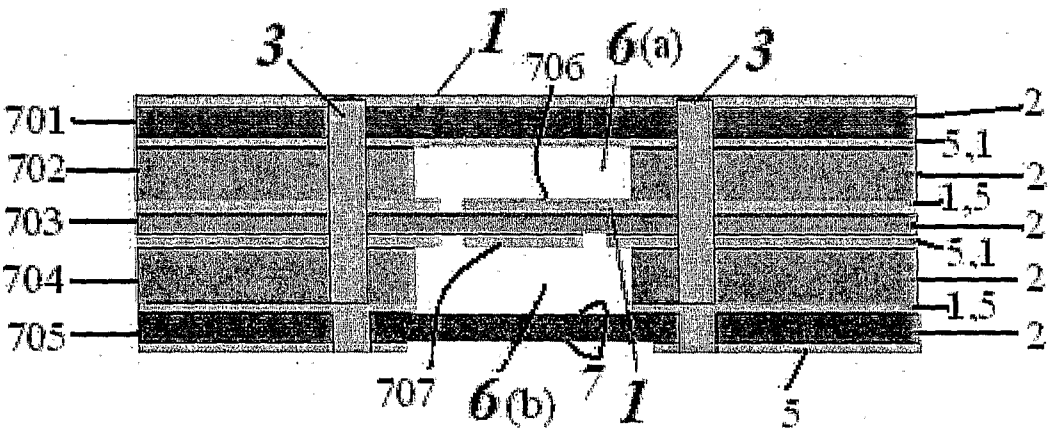


Figure 7

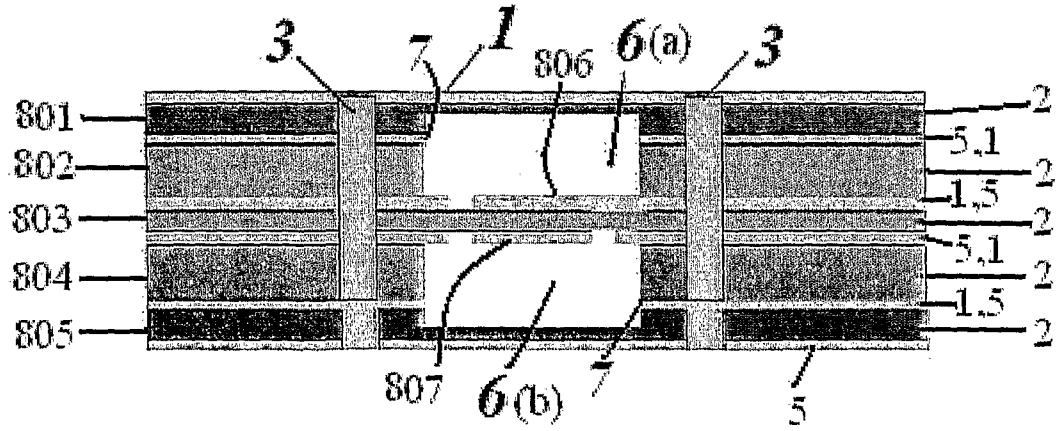


Figure 8

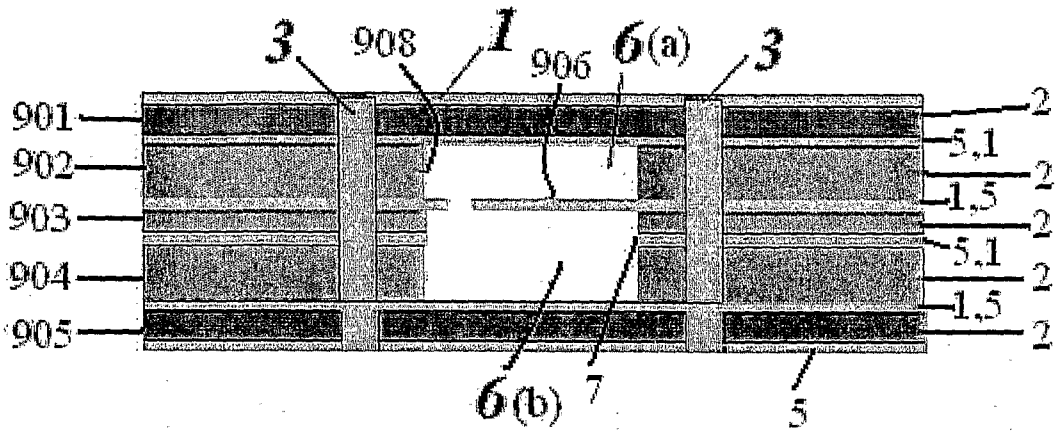


Figure 9

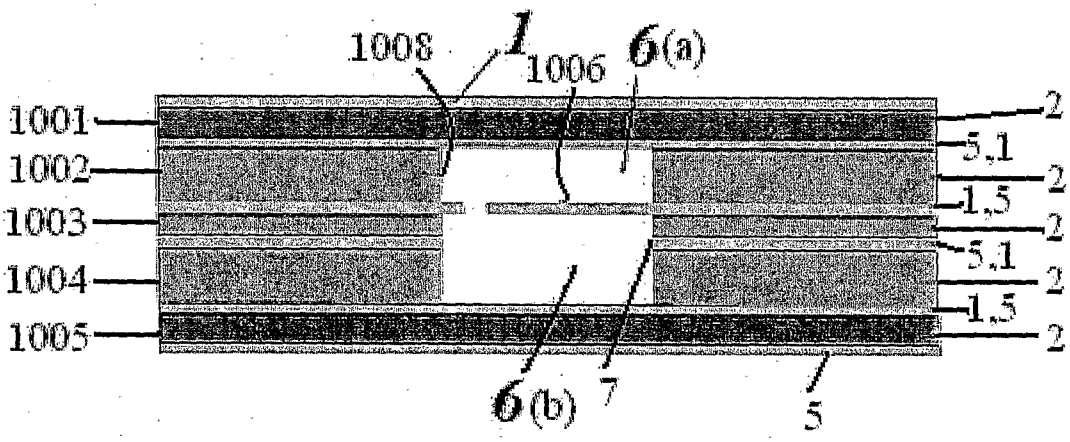


Figure 10

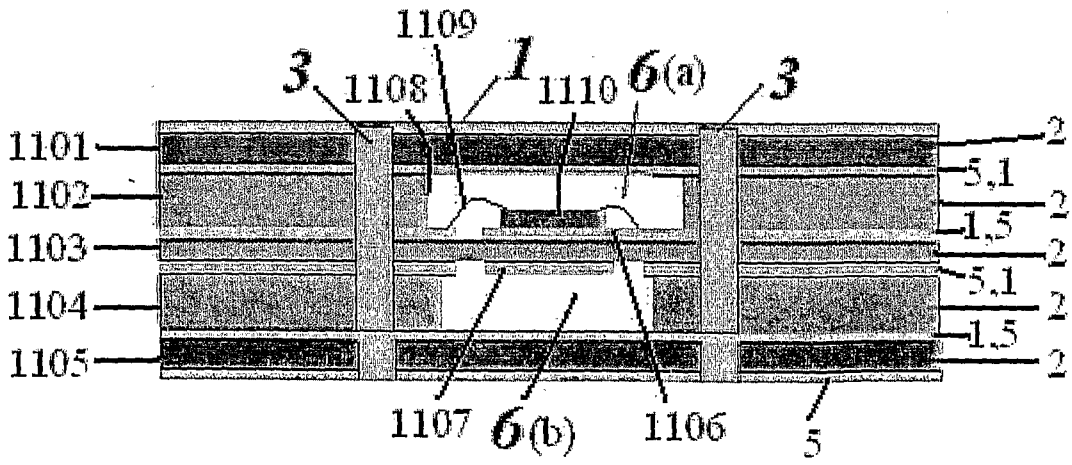


Figure 11

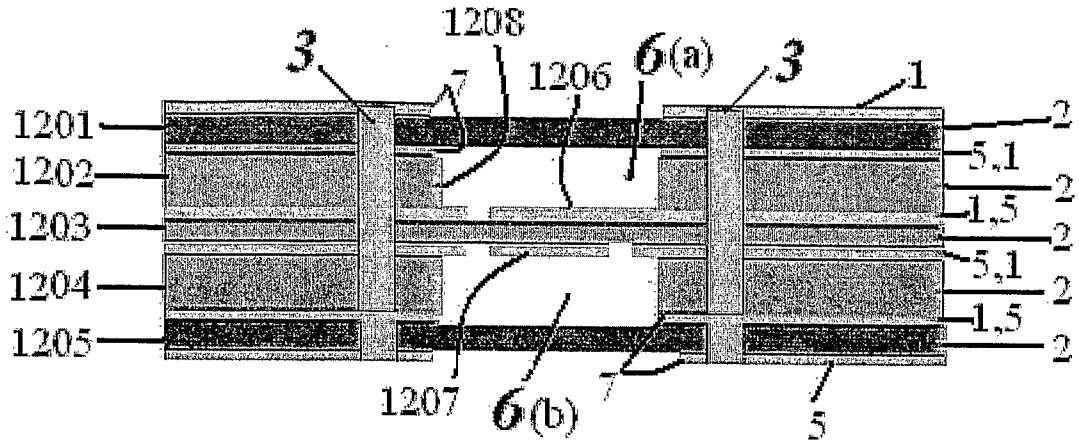


Figure 12

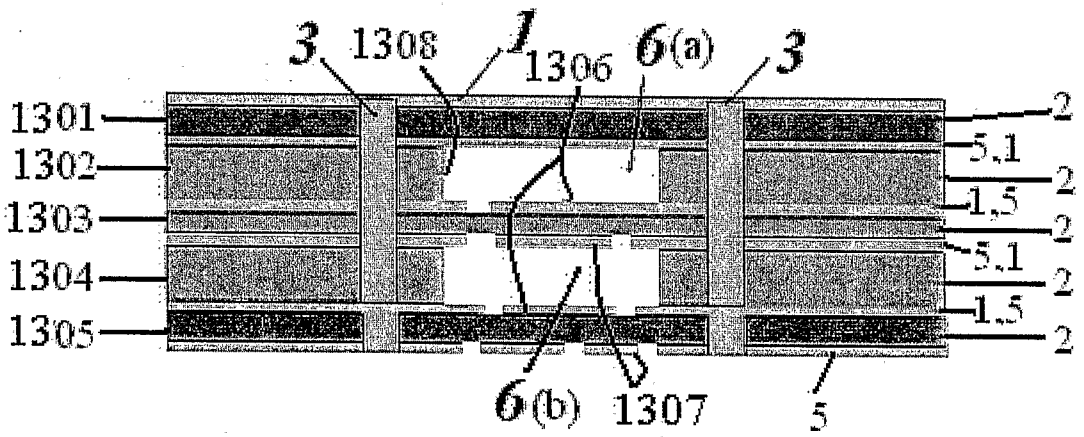


Figure 13

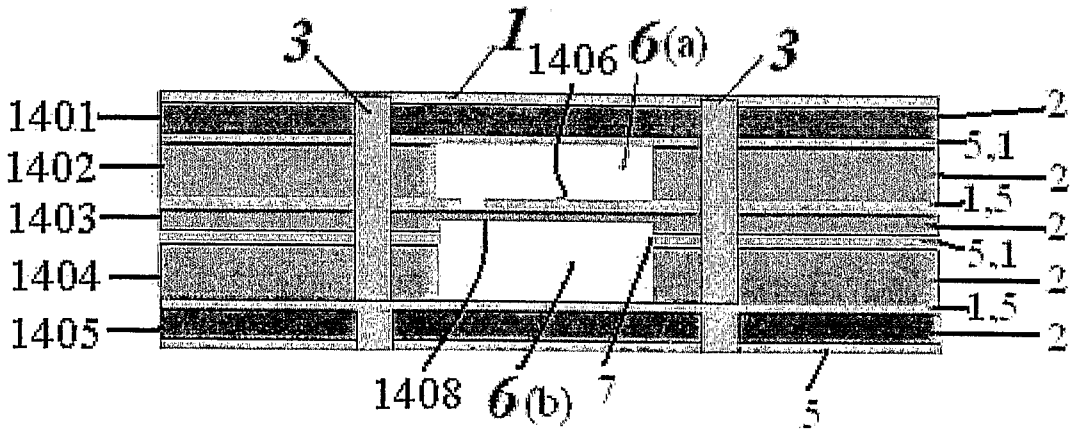


Figure 14

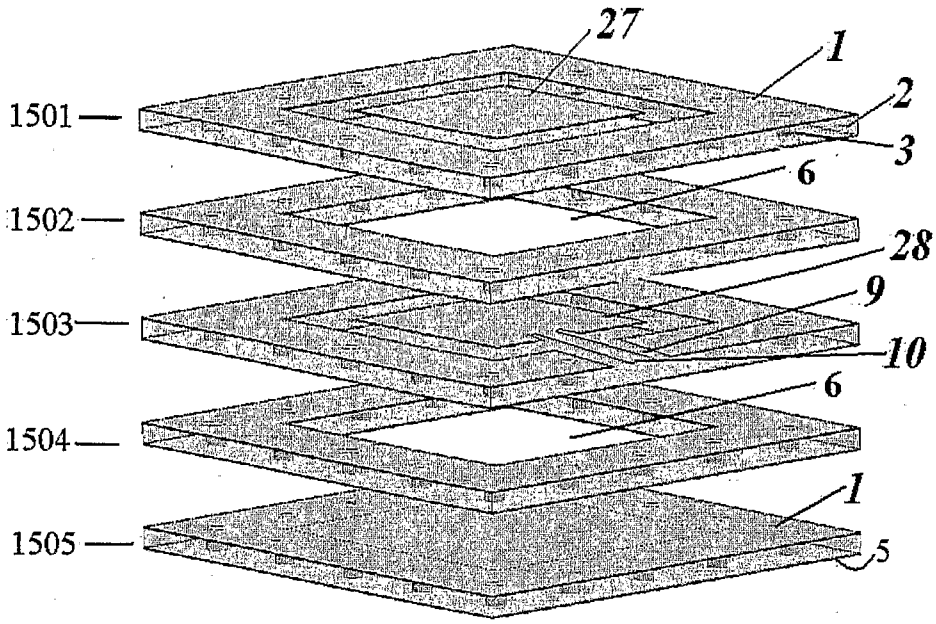


Figure 15

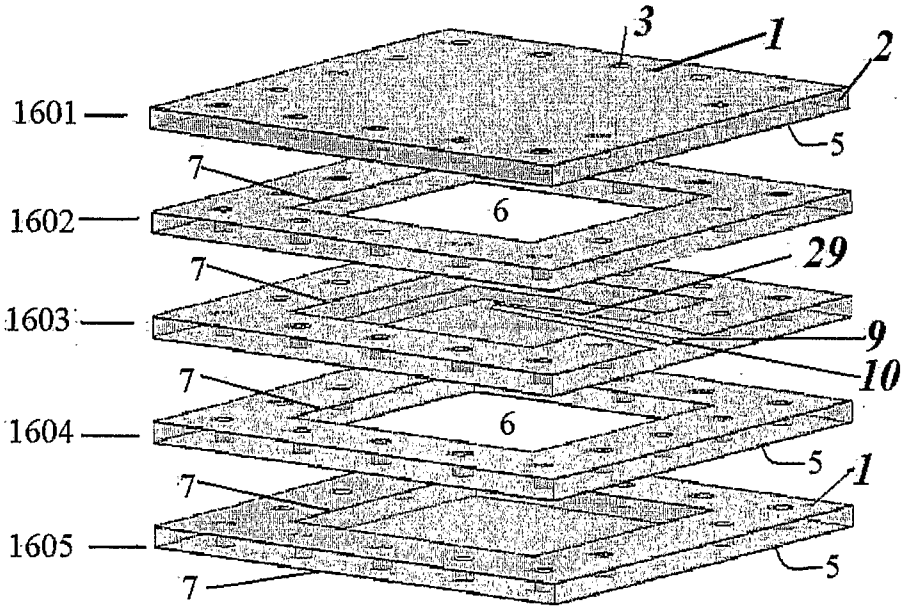


Figure 16

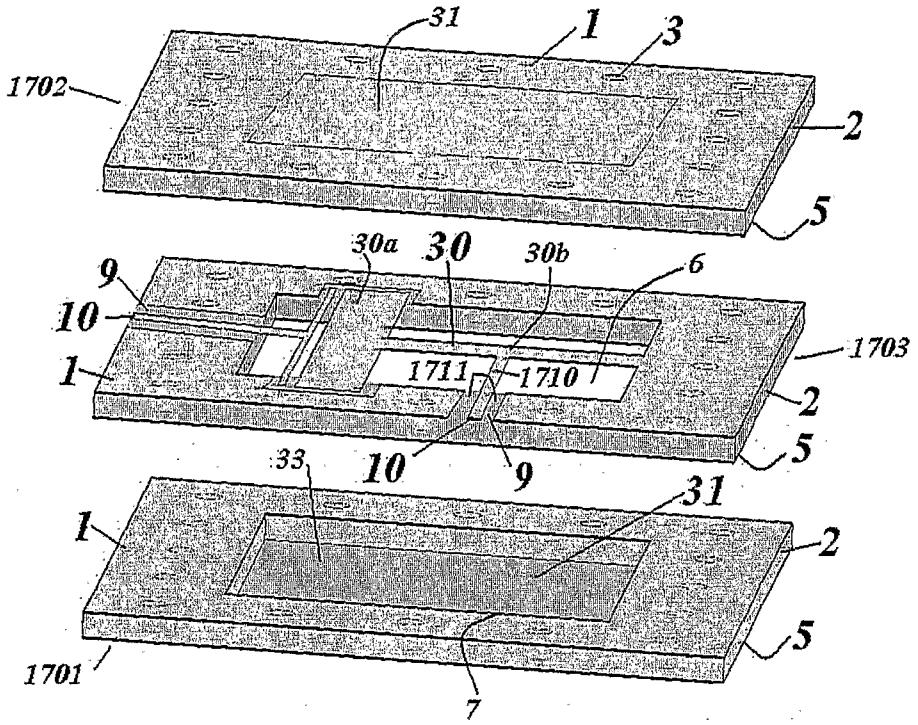


Figure 17

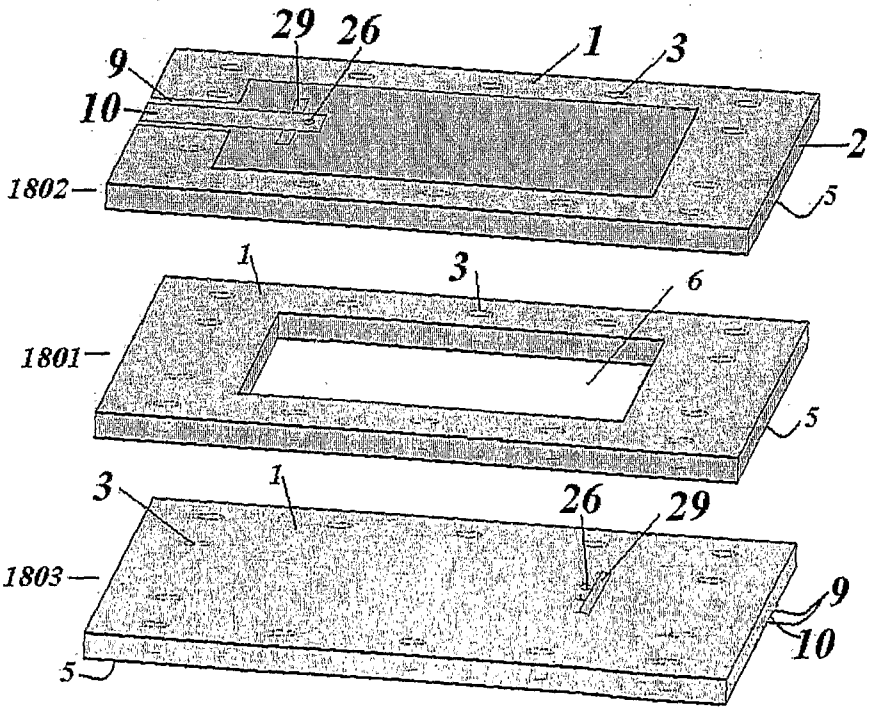


Figure 18

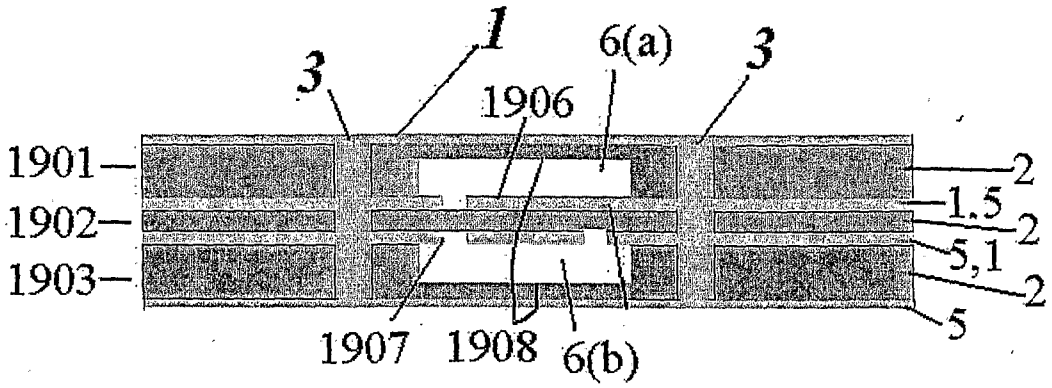


Figure 19

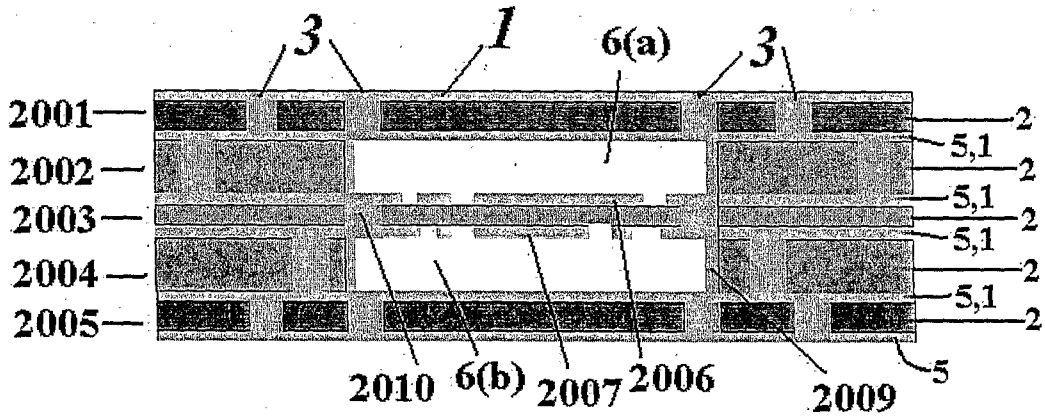
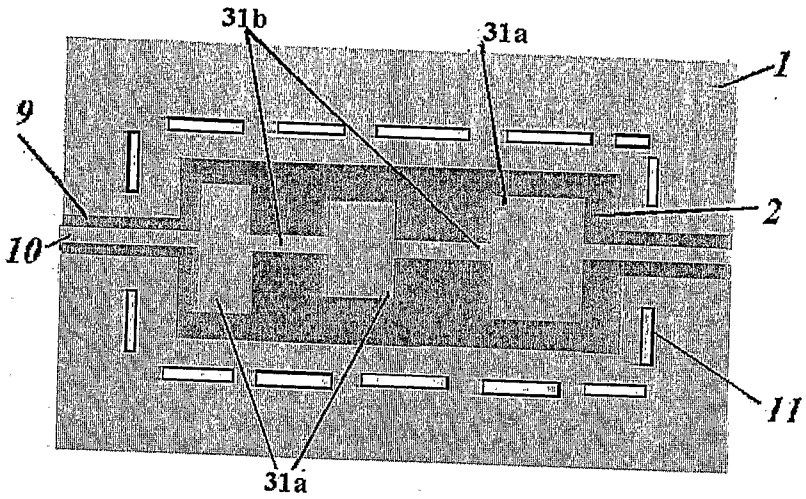
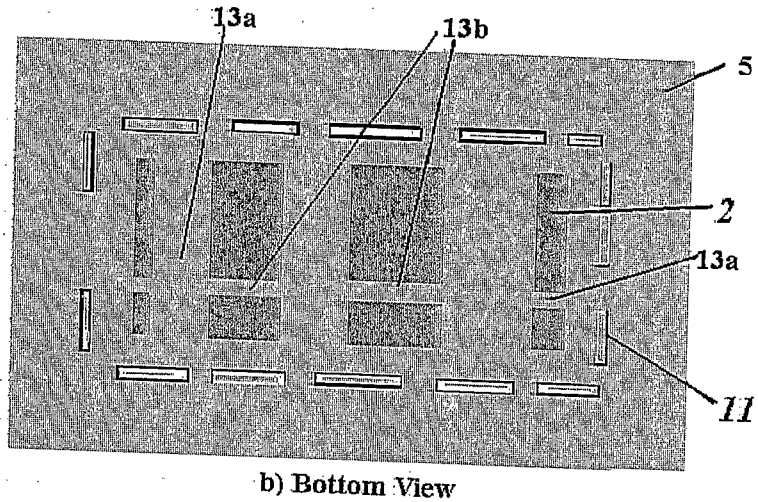


Figure 20



a) Top View



b) Bottom View

Figure 21

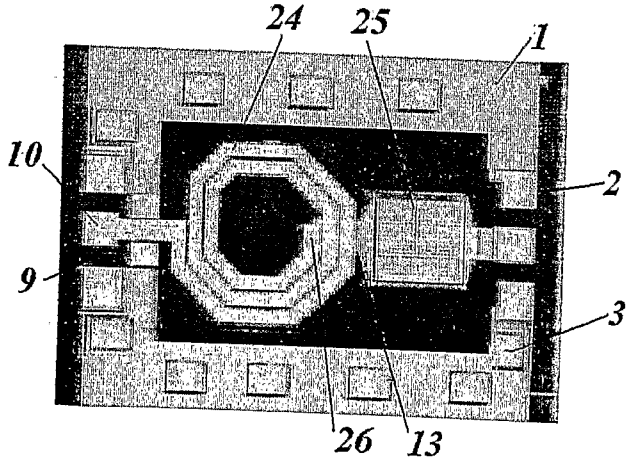


Figure 22

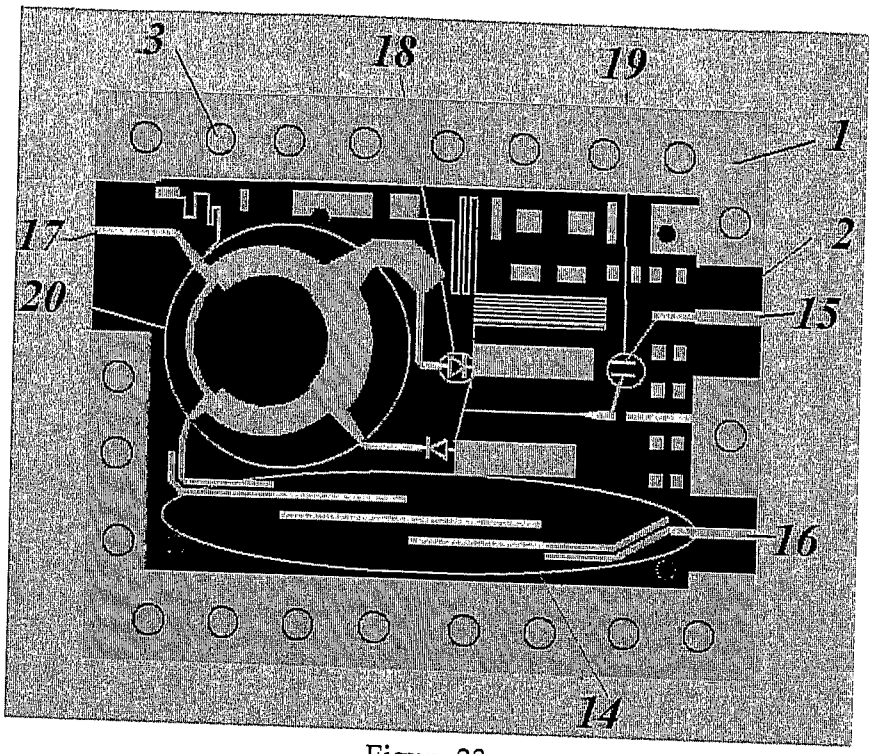


Figure 23

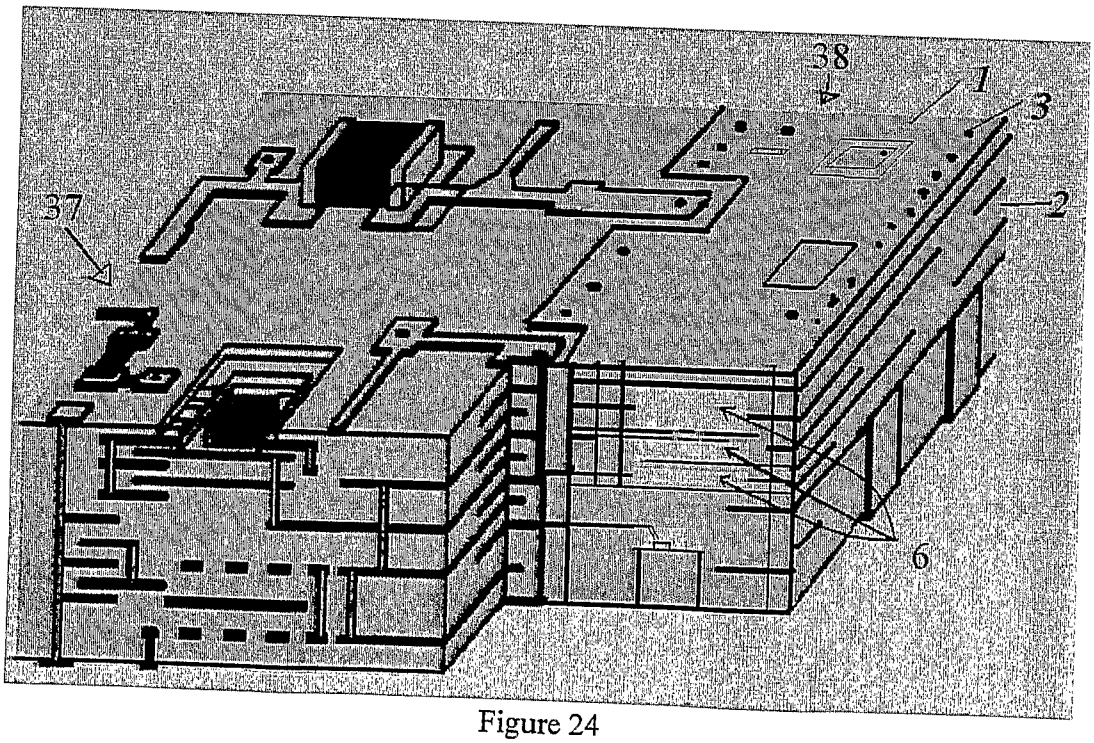


Figure 24

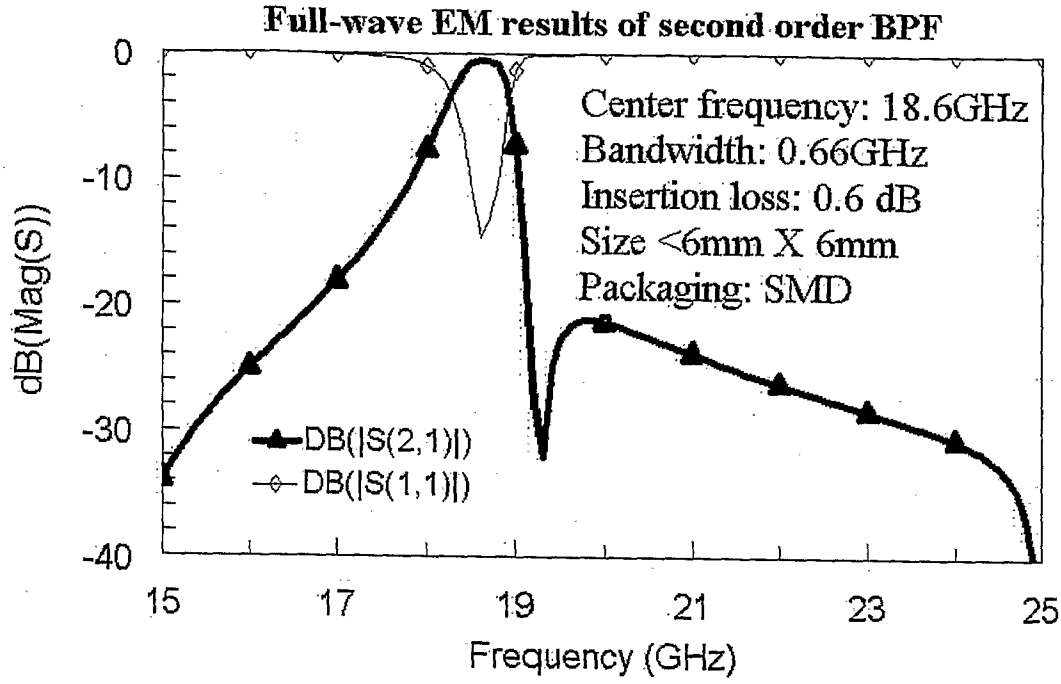


Figure 25

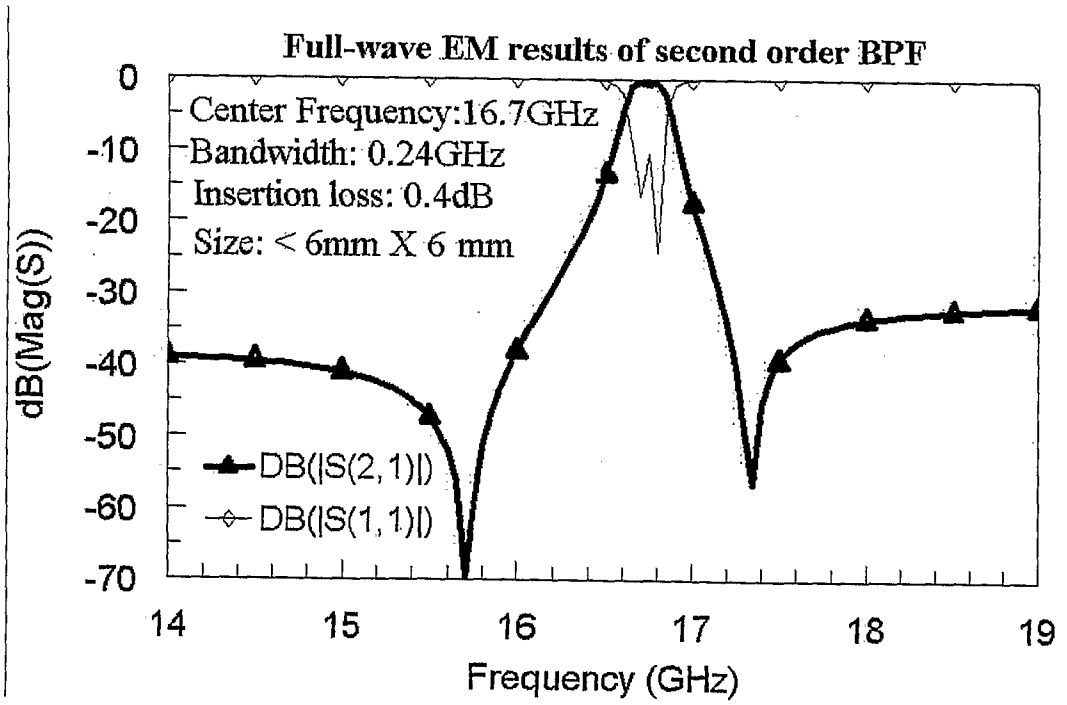


Figure 26

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2006/000166

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

H01P 1/20 (2006.01) ***H01L 23/58*** (2006.01) ***H01Q 13/10*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI, ESP@CE, USPTO with keywords: quasi, microstrip, waveguide, substrate, metal, layer & similar terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0963001 A2 (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.) 8 December 1999 Whole document particularly sections [0012] to [0013]	1- 35
X	US 2004/0174314 A1 (BROWN) 9 September 2004 Whole document particularly the abstract and figures 1A to 2B	1- 35
A	US 2004/0017267 A1 (KANE et al) 29 January 2004 Whole document	1- 35
A	US 4211987 A (PAN) 8 July 1980 Whole document	1- 35

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 September 2006	15 SEP 2006
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer **SOOSA GNANASINGHAM** Telephone No : (02) 6283 2172

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2006/000166

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0817275 B1 (MURATA MANUFACTURING CO., LTD) 7 January 1998 Whole document	1-35

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/SG2006/000166

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
EP	0963001	CN	1273436	JP	11346103	JP	2000323713
		US	6225878	US	6307450	US	6309917
		US	6420760	US	6549105	US	6778041
		US	2001020879	US	2002004260	US	2002017663
		US	2003206083				
US	2004174314	AU	2003304082	US	6975276	WO	2004099707
		WO	2005093902				
US	2004017267	AU	2003259214	US	6822532	WO	2004012297
US	4211987						
EP	0817275	JP	10022302	US	5889297		

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX