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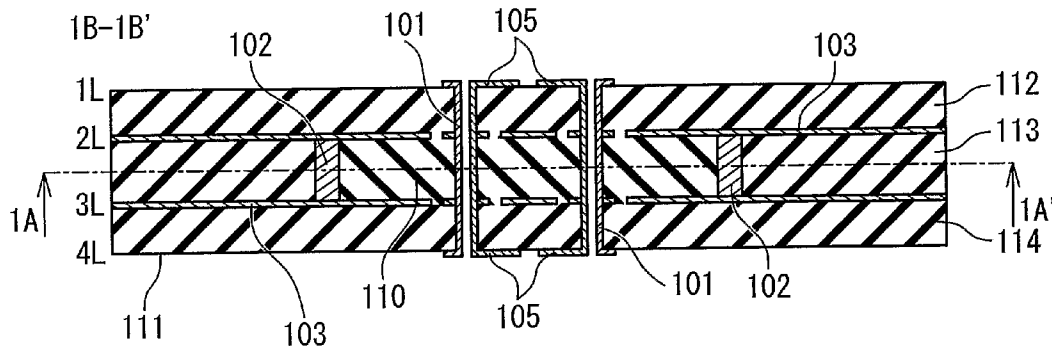
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(54) Title: DIFFERENTIAL-COMMON MODE RESONANT FILTERS

Fig. 1B



(57) Abstract: A filter is provided with a multilayer board incorporating a resonator formed by two ground plates opposed to each other and conductive side walls connected to the ground plates; two signal vias provided through the resonator; and two terminals connected to the signal vias to receive a pair of signals. The resonator has a first face of symmetry vertical to the ground plates. The signal vias are disposed symmetrically with respect to the first face of symmetry on a distance from the first face of symmetry.

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**DESCRIPTION****DIFFERENTIAL-COMMON MODE RESONANT FILTERS****Technical Field**

5           The present invention relates to differential mode and common mode filtering components based on multilayer board technologies for digital, analog or mixed digital and analog systems in communication and computing devices.

**Background Art**

10           Signaling by means of two complementary signals sent on two separate conductors, which is often referred to as differential signaling, is widely-used in modern high-frequency and high-speed digital and analog devices  
15 because of clearly-expressed advantages as compared to single-ended signaling. As for an example, differential signaling can considerably reduce noise in data transmission channels and radiation issues. Also, because differential and common modes (odd and even mode  
20 definition is also used in transmission line theory) are orthogonal ones, then both of these modes can be used in data transmission to increase capacity of the channels. That is why, it is important to control a frequency response for the differential and common modes, or to provide  
25 separation of the differential and common modes, or suppressing one of these modes to make independent their receiving and transmitting.

From this viewpoint, differential-common mode filters are crucial components in analog and digital devices. Also it is important to make the filters as cost-effective components which can be easily integrated  
5 in a multifunctional system using in the devices.

US Patent No. 5,321,373 discloses a combined differential-mode common-mode filter. This filter has a plurality of U-shaped wires passing through a ferrite core.

US Patent No. 6,642,672 discloses an integrated  
10 filter with common-mode and differential-mode functions. This filter comprises a magnetic core, two windings and a frame for installing the windings.

US Patent Application Publication No. 2005/0063127A1 discloses a paired multi-layered  
15 dielectric independent passive component architecture resulting in differential and common mode filtering.

However, proposed common and differential mode filters do not provide selective separation of the differential and common modes in frequency domain and do  
20 not have a system to intensify a loss of the common mode, or the differential mode or both these modes in a predetermined frequency band.

#### Disclosure of Invention

25 Therefore, an object of the present invention is to provide a technique for providing selective separation of the differential and common modes in frequency domain.

In one exemplary embodiment of the present invention, a filter is provided with a multilayer board incorporating a resonator formed by two ground plates opposed to each other and conductive side walls connected to the ground plates; two signal vias provided through the resonator; and two terminals connected to the signal vias to receive a pair of signals. The resonator has a first face of symmetry vertical to the ground plates. The signal vias are disposed symmetrically with respect to the first face of symmetry on a distance from the first face of symmetry.

#### Brief Description of Drawings

The above and other objects, advantages and features of the present invention will be more apparent from the following description of certain exemplary embodiments taken in conjunction with the accompanying drawings, in which:

FIG. 1A is a horizontal cross-sectional view of a differential-common mode resonant filter according to one exemplary embodiment of the present invention;

FIG. 1B is a vertical cross-sectional view of the filter on the face 1B-1B' as shown in FIG.1A;

FIG. 1C is a vertical cross-sectional view of the filter on the face 1C-1C' as shown in FIG. 1A;

FIG. 1D is a top view of the filter;

FIG. 2A is a horizontal cross-sectional view of a

differential-common mode resonant filter according to another exemplary embodiment of the present invention;

FIG. 2B is a vertical cross-sectional view of the filter on the face 2B-2B' as shown in FIG. 2A;

5 FIG. 2C is a vertical cross-sectional view of the filter on the face 2C-2C' as shown in FIG. 2A;

FIG. 2D is a top view of the filter;

FIG. 2E illustrates the geometry of the resonator of the filter;

10 FIG. 3 is a graph illustrating insertion losses of the differential-common mode resonant filter with rectangular arrangement of side walls;

FIG. 4A is a horizontal cross-sectional view of a differential-common mode resonant filter according to  
15 still another exemplary embodiment of the present invention;

FIG. 4B is a vertical cross-sectional view of the filter passing on the face 4B-4B' as shown in FIG. 4A;

20 FIG. 4C is a vertical cross-sectional view of the filter on the face 4C-4C' as shown in FIG. 4A;

FIG. 4D is a top view of the filter;

FIG. 5 is a graph illustrating insertion losses of the differential-common mode resonant filter with square arrangement of side walls;

25 FIG. 6A is a horizontal cross-sectional view of a differential-common mode resonant filter according to still another exemplary embodiment of the present

invention;

FIG. 6B is a vertical cross-sectional view of the filter on the face 6B-6B' as shown in FIG. 6A;

FIG. 6C is a vertical cross-sectional view of the filter on the face 6C-6C' as shown in FIG. 6A;

FIG. 6D is a top view of the filter;

FIG. 7A is a horizontal cross-sectional view of a differential-common mode resonant filter according to still another exemplary embodiment of the present invention;

FIG. 7B is a vertical cross-sectional view of the filter on the face 7B-7B' as shown in FIG. 7A;

FIG. 7C is a vertical cross-sectional view of the filter on the face 7C-7C' as shown in FIG. 7A;

FIG. 7D is a top view of the filter;

FIG. 8A is a horizontal cross-sectional view of a differential-common mode resonant filter according to still another exemplary embodiment of the present invention;

FIG. 8B is a vertical cross-sectional view of the filter on the face 8B-8B' as shown in FIG. 8A;

FIG. 8C is a vertical cross-sectional view of the filter on the face 8C-8C' as shown in FIG. 8A;

FIG. 8D is a top view of the filter;

FIG. 9A is a horizontal cross-sectional view of a differential-common mode resonant filter according to still another exemplary embodiment of the present

invention;

FIG. 9B is a vertical cross-sectional view of the filter on the face 9B-9B' as shown in FIG. 9A;

FIG. 9C is a vertical cross-sectional view of the filter on the face 9C-9C' as shown in FIG. 9A;

FIG. 9D is a top view of the filter;

FIG. 10A illustrates the insertion loss of the common mode for the filter shown in FIGs. 9A - 9D with four metallic tuning elements;

FIG. 10B illustrates the insertion loss of the common mode for the filter shown in FIGs. 9A - 9D with four dielectric tuning elements;

FIG. 11A is a horizontal cross-sectional view of a differential-common mode resonant filter according to still another exemplary embodiment of the present invention;

FIG. 11B is a vertical cross-sectional view of the filter on the face 11B-11B' as shown in FIG. 11A;

FIG. 11C is a vertical cross-sectional view of the filter on the face 11C-11C' as shown in FIG. 11A;

FIG. 11D is a top view of the filter;

FIG. 12 illustrates the insertion losses of the differential and common modes for the filter shown in FIGs. 11A - 1D with tuning elements made of electromagnetic wave absorbing material;

FIG. 13A is a horizontal cross-sectional view of a differential-common mode resonant filter according to

still another exemplary embodiment of the present invention;

FIG. 13B is a vertical cross-sectional view of the filter on the face 13B-13B' as shown in FIG. 13A;

5 FIG. 13C is a vertical cross-sectional view of the filter on the face 13C-13C' as shown in FIG. 13A; and

FIG. 13D is a top view of the filter.

### **Best Mode for Carrying Out the Invention**

10 Hereinafter, differential-common mode resonant filters according to exemplary embodiments of according to the present invention will be described with reference to the attached drawings.

In FIGS. 1A to 1D, an exemplary embodiment of a  
15 differential-common mode resonant filter is shown. The filter is provided with two signal vias 101 disposed through a resonator 110 formed in a multilayer board 111. In this exemplary embodiment, the multilayer board 111 is provided with three isolation substrates 112 to 114 made  
20 of isolating material. It should be noted that the portion of the isolation substrate 113 within the resonator 110 is indicated by a hatching different from that of the remaining portion for illustration purposes only (the same goes for other figures). The isolating material may be  
25 dielectric material, electromagnetic wave absorbing material, or magnetic material. A first conductor layer

1L is provided on the top surface of the isolation substrate 112, a second conductor layer 2L is provided between the isolation substrates 112 and 113, a third conductor layer 3L is provided between the isolation substrates 113 and 114, and a fourth conductor layer L4 is provided on the rear surface of the isolation substrate 114.

The resonator 110 is formed by ground vias 102 and two ground plates 103 opposed to each other. The ground vias 102 form side walls of the resonator 110 and are connected to the ground plates 103. The ground plates 103 are arranged at the second and third conductor layers 2L and 3L, separated by the isolation substrate 113. It should be noted that the portion of the isolation substrate 113 within the resonator 110 is indicated by a different hatching than that indicating the portion outside the resonator 110. In this example, the ground vias 102 are arranged in such way to configure the resonator 110 having two vertical faces of symmetry as B-B' and C-C'. Two signal vias 101, which are disposed on the face B-B' and equally spaced from the face C-C', are connected to two terminals 105 formed here as a microstrip structure. As input signals, differential and common modes are entered in the terminals 105 as shown in FIG. 1D.

It is well-known that two signal conductors disposed in the vicinity of a ground or a power supply conductor can support two orthogonal modes as differential

and common ones (also called mixed modes). These modes can be used as propagating signals carrying information in a system included in a device.

However due to impedance inhomogeneity,  
5 transformation between the differential and common modes can be considerable that can dramatically increase noise in useful signals and also radiation from the device in which signaling on a mixed mode (differential or common one) is applied.

10 Accordingly, providing separated transmitting and receiving of the differential and common modes or cancellation one of these modes is a crucial problem.

Particularly, this problem is solved by the differential-common mode resonant filter of the present  
15 exemplary embodiment. In the present exemplary embodiment, in which the resonator 110 has two faces of symmetry, the signal vias 101 lie on one of the faces and are disposed symmetrically with respect to the other face of symmetry.

20 Signals are propagating from terminals 105 disposed on the top conductor layer 1L of the board 111 to corresponding terminals 105 disposed on the bottom conductor layer 4L of the board. Application of the resonator 110 gives the distinguishing properties of the  
25 proposed filter.

Consider a numerical example of the differential-common mode resonant filter as shown in FIGS. 2A - 2E. In these figures, the filter with a rectangular form of the resonator 210 is formed in a four-conductor-layer board 211 and signal via pads 205 are used as terminals. The four-conductor-layer board 211 is provided with three isolation substrates 212 to 214. The differential mode and common mode are propagating between top and bottom signal via pads 205. The dimensions of both signal vias 201, separated by  $l = 5 \text{ mm}$  in the present example of the filter, are as following:  $d_r = 0.65 \text{ mm}$ ;  $d_p = 0.95 \text{ mm}$ ;  $d_c = 1.65 \text{ mm}$ , where  $d_r$  is the external diameter of the signal vias 201,  $d_p$  is the external diameter of the signal via pads 205, and  $d_c$  is the diameter of the holes provided through the inner conductor layers 203 through which the signal vias 201 are disposed. The resonator 210 is formed between the second and third conductor layers 2L and 3L of the four-conductor-layer board 211 in which the distance between neighboring conductor layers is  $h = h_1 = h_2 = h_3 = 0.75 \text{ mm}$ , the thickness of the top and bottom conductor layers 1L and 4L is  $t_o = 0.055 \text{ mm}$ , and the thickness of the inner conductor layers 203 forming the resonator 210 is  $t_i = 0.035 \text{ mm}$ . Isolating material between the ground plates 203 of the board 211 has  $\epsilon = 4.0$ ,  $\mu = 1.0$  and  $\tan \delta = 0.023$ , where  $\epsilon$  is the relative permittivity,  $\mu$  is the relative permeability and  $\tan \delta$  is dielectric loss tangent.

The resonator 210 is obtained by ground vias 202 forming its side walls which are connected to both inner conductor layers 203 serving as top and bottom conductive boundaries of the resonator 210. These ground via side walls are formed by the ground vias 202 of the diameter of  $d_g = 0.3 \text{ mm}$  which are equally-separated by the distance of  $l_g = 1.0 \text{ mm}$ . The horizontal dimensions of the resonator 210 are  $a = 20 \text{ mm}$  and  $b = 40 \text{ mm}$ . Note that these dimensions are defined as the distance between lines of an imagined contour passing through the center of the ground vias 202.

In FIG. 3, simulation data as the insertion loss ( $|S_{21}|$ -parameter) for the filter shown in FIGS. 2A - 2E having above-mentioned parameters are demonstrated. These results are obtained by the use of the finite-difference time-domain method which is well-established and one of the most accurate numerical methods.

As follows from the presented data, the structure demonstrates clearly-expressed properties of the differential-common mode filter. Moreover, it is important to note that stopbands for differential mode are in different positions if they are compared with common mode stopbands. As for an example, at the frequency about of  $4.2 \text{ GHz}$ , the common mode has a stopband; however, at this frequency, the differential mode passes through the filter without insertion loss practically. On the contrary, at the frequency about  $7.9 \text{ GHz}$ , the differential

mode has a clearly-expressed stopband, but at the same time the common mode is propagating through the filter with a very small loss at this frequency. This is a distinguishing property of the proposed differential-common mode filter of the present exemplary embodiment.

Consider physical mechanisms lying in the basis of the differential-common mode filter using the structure shown in FIGS. 2A - 2E. The electromagnetic field in the position of each signal via 201 within the resonator 210 as  $(x_1, y_1)$  and  $(x_2, y_1)$  can be approximately represented by following equations:

$$\mathbf{E}(1) \sim E_0^{mnp} \cdot \sin\left(\frac{m\pi x_1}{a}\right) \cdot \sin\left(\frac{n\pi y_1}{a}\right) \cdot \cos\left(\frac{p\pi z}{h}\right) \mathbf{z}, \quad \dots(1a)$$

$$\mathbf{E}(2) \sim E_0^{mnp} \cdot \sin\left(\frac{m\pi x_2}{a}\right) \cdot \sin\left(\frac{n\pi y_1}{a}\right) \cdot \cos\left(\frac{p\pi z}{h}\right) \mathbf{z}, \quad \dots(1b)$$

where  $m$ ,  $n$ , and  $p$  give the order of the resonant mode;  $a$  and  $b$  are the side horizontal dimensions of the resonator 210;  $\mathbf{E}(1)$  is the electric field at the signal via 201 positioned at  $(x_1, y_1)$ , and  $\mathbf{E}(2)$  is the electric field at the signal via 201 positioned at  $(x_2, y_1)$ ;  $E_0^{mnp}$  is the amplitude of the resonant mode;  $\mathbf{z}$  is the unit vector of the direction which is perpendicular to the top and bottom ground plates 203 of the resonator 210. It is important to note that frequency  $f_{mnp}$  of the resonant mode can be approximately expressed as:

$$f_{mnp} \approx \frac{c}{2\pi \cdot \sqrt{\mu\epsilon}} \left[ \left( \frac{m\pi}{a} \right)^2 + \left( \frac{n\pi}{b} \right)^2 + \left( \frac{p\pi}{h} \right)^2 \right]^{1/2}, \quad \dots(2)$$

where  $c$  is the velocity of light.

The electromagnetic field of the differential mode at the output of the filter will be proportional to the difference of the fields at the signal vias 201, that is:

$$\mathbf{E}_d^{mnp} \sim (\mathbf{E}(1) - \mathbf{E}(2)). \quad \dots(3)$$

At the same time, the electromagnetic field of the common mode at the output of the filter will be proportional to the sum of the field at the signal vias 201 and can be written as:

$$\mathbf{E}_d^{mnp} \sim (\mathbf{E}(1) + \mathbf{E}(2)). \quad \dots(4)$$

To provide the separation of the differential and common modes, positions of the signal vias 201 are chosen symmetrically with respect to the vertical face of symmetry passing between the signal vias 201. It means that  $x_2 = b - x_1$ . In this case, Eq. (1b) can be written as:

$$\mathbf{E}(2) \sim -E_0^{mnp} \cdot \sin\left(\frac{m\pi x_1}{a}\right) \cdot \sin\left(\frac{n\pi y_1}{a}\right) \cdot \cos\left(\frac{p\pi z}{h}\right) \cdot \cos(m\pi) \cdot \mathbf{z}, \quad \dots(5)$$

As a result, according to Eq. (3) and taking into account Eqs. (1a) and (5), the electromagnetic field  $\mathbf{E}_d^{mnp}$  for the differential mode can be represented as following:

$$\mathbf{E}_d^{mnp} \sim E_0^{mnp} \cdot \sin\left(\frac{m\pi x_1}{a}\right) \cdot \sin\left(\frac{n\pi y_1}{a}\right) \cdot \cos\left(\frac{p\pi z}{h}\right) \cdot (1 + \cos m\pi) \cdot \mathbf{z}, \quad \dots(6)$$

Defined by the similar manner, the electromagnetic field  $\mathbf{E}_c^{mnp}$  of the common mode can be obtained as:

$$\mathbf{E}_c^{mnp} \sim E_0^{mnp} \cdot \sin\left(\frac{m\pi x_1}{a}\right) \cdot \sin\left(\frac{n\pi y_1}{a}\right) \cdot \cos\left(\frac{p\pi z}{h}\right) \cdot (1 - \cos m\pi) \cdot \mathbf{z}, \quad \dots(7)$$

5 Thus, as follows from Eqs. (6) and (7), the differential resonant modes of some orders will be canceled that give the propagation of the differential mode of these orders through the resonator 210 without losses, practically. But simultaneously, the common resonant modes having the  
 10 same orders will be resonating that will lead to a dramatic increase of the losses and forming the stopbands for the common mode at the orders. Also for other orders of resonances, the stopbands will be formed for the differential mode but the common mode will be propagating  
 15 through the resonator 210 with insignificant losses.

As for example, consider FIG. 3 in which insertion losses are presented for the differential and common modes.

The electromagnetic field of the lowest differential mode can be represented by following expression:

$$20 \quad \mathbf{E}_d^{110} \sim E_0^{110} \cdot \sin\left(\frac{\pi x_1}{a}\right) \cdot \sin\left(\frac{\pi y_1}{a}\right) \cdot (1 + \cos\pi) \cdot \mathbf{z} = 0. \quad \dots(8)$$

Eq. (8) means that the differential mode is propagating through the resonator 210 without losses at the resonant frequency of 4.2 GHz which can be also defined according to Eq. (2).

5 At the same time, the electromagnetic field for the common mode can be obtained as:

$$\mathbf{E}_c^{110} \sim E_0^{110} \cdot \sin\left(\frac{\pi x_1}{a}\right) \cdot \sin\left(\frac{\pi y_1}{a}\right) \cdot (1 - \cos\pi) \cdot \mathbf{z} = 2 \cdot E_0^{110} \cdot \sin\left(\frac{\pi x_1}{a}\right) \cdot \sin\left(\frac{\pi y_1}{a}\right) \cdot \dots (9)$$

As follows from Eq. (9), the common mode is resonating and for this mode the stopband is formed around frequency of  
10 4.2 GHz that is agreed with FIG. 3.

At the frequency about 7.9 GHz, the differential mode has a stopband, but simultaneously the common mode is propagating through the resonator. It can be also explained by Eqs. (6) and (7).

15 This is a distinguishing property of the filter of the present exemplary embodiment. Thus, the filter of the present exemplary embodiment effectively achieves cancellation of one group of resonances for one mode (differential or common) that give the propagation of this  
20 mode through the filter at these resonances. At the same time, another mode (common or differential, respectively) will be resonating at these frequencies that lead to forming stopbands at considered frequencies.

Therefore, the separation of the differential and common modes can be obtained in frequency domain.

This is a basis of forming the band pass filter for the differential mode providing band stop characteristics  
5 for the common mode at the same time and vice versa.

Thus, a number of filters can be obtained by the use of the proposed approach including a resonator in a multilayer board having a vertical face of symmetry and a pair of signals vias disposed symmetrically with respect  
10 to this face.

A number of resonators with different arrangements of ground vias forming side walls can be developed. Note such arrangement can be used to control the frequency response of the filter.

15 In FIGS. 4A - 4D, a differential-common mode resonant filter with a square arrangement of ground vias 402 in side walls of a resonator 410 is presented. This filter is formed by a pair of signal vias 401 embedded in the resonator 410 and connected to terminals 405 disposed  
20 on the top and bottom conductor layers 1L and 4L of a four-conductor-layer board 411 including three isolation substrates 412 to 414.

In FIG. 5, the numerical example is presented for structure shown in FIGS. 4A - 4D. Dimensions of the  
25 four-conductor-layer board 411, the signal vias 401, and

the resonator 410 are the same as for FIG.3, but only the resonator 410 is as a square one with the side of  $a = 20$  mm. As follows from simulation results, this type of filters also demonstrate separation of the differential and common modes for which the stopband is in different positions (for common mode, the central frequency of the stopband is about 5.3GHz, but for differential mode this frequency is about 8.7GHz). Also, these data show that form of arrangement of ground vias in side walls (this form can be simple one like circular, elliptical, or more complicate one which is dictated by a concrete application) is effective approach to control frequency response.

It is important to emphasize that proposed filters can be used not only as integrated elements for in-board applications and also as independent devices.

In FIGs. 6A - 6D, a differential common mode filter is presented. In this exemplary embodiment, side conductor plates 604 are used instead of ground vias to form the side walls of a resonator 610.

More specifically, this resonator 610 is formed by ground planes 603 formed within a four-conductor-layer board 611 incorporating three isolation substrates 612 to 614 and side conductor plates 604 formed on the sides of the four-conductor-layer board 611. Signal vias 601 disposed symmetrically with respect to the vertical face 6C-6C' are connected to terminals 605 at the top and bottom

conductor layers 1L and 4L of the four-conductor-layer board 611. Such type of differential-common resonant filters is applicable as an independent device.

Although the filters in the aforementioned  
5 exemplary embodiments have two faces of symmetry, it is well-understandable that providing the separation of the differential and common modes can be achieved in a differential-common mode resonant filter with a resonator having one face of symmetry in which signal vias will be  
10 disposed symmetrically with respect to this face. In FIGS. 7A - 7D, another exemplary embodiment of the differential-common mode resonant filter is presented. This filter is provided with signal vias 701, a resonator 710 and terminals 705 which are placed on top and bottom  
15 conductor layers 1L and 6L of a multilayer board 711 incorporating five isolation substrates 712 to 716. The resonator 710 is formed by ground vias 702 connected to ground planes 703 and arranged in such way that a trapezoidal contour of side walls is obtained. In this  
20 structure, signal vias 701 are symmetrical with respect to the face 7C-7C'.

In another exemplary embodiment of the present invention, a differential-common resonant filter may incorporate tuning elements embedded in the resonator.  
25 Such filters can not only provide the shift of the stopband but also widening of the stopband.

In FIGs. 8A - 8D, a differential-common resonant filter with two tuning elements is shown. This filter is provided with two signal vias 801 embedded in a resonator 810 and connected to terminals 805. The resonator 810 is formed by ground planes 803 and ground via walls 802 connected to these ground planes. The filter is based on a four-conductor-layer board 811 incorporating three isolation substrates 812 to 814. As a distinguishing characteristic of this filter, tuning elements 816 are embedded in the resonator 810. These tuning elements 816 are disposed through the resonator 810, affecting on the position and the Q-factor of the resonances. In the shown exemplary embodiment, the tuning elements 816 are disposed symmetrically with respect to the signal vias 801 to provide the same effect on the signal vias 801.

The tuning elements 816 may be made of material to give a required property of the filter. This material may be metal, dielectric, or electromagnetic wave absorbing material (for example, ferrite). It should be noted that the tuning elements 816 may be formed in forms of hollow tubes instead of solid structures; the tuning elements 816 may be formed as metallizations formed on the side walls of holes passing through the resonator 810. Also, the number and dimensions of tuning elements 816 may be modified to achieve the required property.

In FIGs. 9A - 9D, a differential-common mode filter with four tuning elements 916 is presented. This filter is provided with a multilayer board 911 including three isolation substrates 912 to 914. Formed within the  
5 multilayer board 911 is a resonator 910 with a square arrangement of ground vias 902 connected to ground planes 903. The ground vias 902 form side walls of the resonator 910. Within the resonator 910, signal vias 901 are embedded.

10 To demonstrate the effect of the tuning elements 916 on the electrical performance of the filter, the structure and dimensions of the filter and board material are chosen the same as in numerical example shown in FIG. 5. The four same tuning elements 916 are disposed  
15 symmetrically with respect to the signal vias 901 with following dimensions according to notation of FIGs. 9A - 9D. Thus,  $d_t = 2 \text{ mm}$ ;  $l_t = 5 \text{ mm}$ ; and  $c_t = 5 \text{ mm}$ .

In FIG. 10A, the insertion loss of the common mode for the filter shown in FIGs. 9A - 9D with four metallic  
20 tuning elements 916 is presented. Also, the insertion loss of the same filter but without tuning elements is demonstrated for comparison in this figure. As follows from the presented data, the application of four metallic tuning elements gives a shift of the resonance frequency  
25 to a higher value. This result can be explained by reduction of the effective horizontal dimensions of the

resonator 910 which are responsible for the position of the resonance frequency.

In FIG.10B, the insertion loss for the common mode of the filter with dielectric tuning elements 916 is shown. The structure and dimensions of the filter are the same as for FIG.10A, but only the four tuning elements 916 are made of dielectric material with a relative permittivity of 40, instead of metal. It should be noted that the relative permittivity of the dielectric material of the tuning elements 916 is higher than that of the isolating material of the isolation substrate 912 to 914 within the multilayer board 911. As one can see in FIG.10B, the use of the dielectric material with the higher permittivity than the isolating material of the multilayer board 911 leads to the shift of the resonance frequency to the lower frequency if it is compared with the same filter but without tuning elements. This property of the filter can be traced by considering Eq. (2).

The tuning elements 916, made of material for which the relative permittivity is higher than the board material permittivity, give higher effective permittivity of the resonator 910 and this, as a result, shifts the resonance frequency to a lower value.

Also, preferable properties of the differential-common mode resonant filter can be obtained by the use of electric absorbing material as the tuning

elements 916. Introduction of such material in the resonator 910 of the filter can give widening the resonance line that can be explained by the following expression:

$$\frac{\Delta f}{f_0} \approx \tan \delta_{eff}, \quad \dots(10)$$

5 where  $\Delta f$  is the bandwidth,  $f_0$  is the resonance frequency, and  $\tan \delta_{eff}$  is the effective loss tangent of the composite material of the resonator 910 which is obtained from loss tangents of the tuning elements 916 and the materials of the multilayer board 911.

10 Taking into account distinctive properties of the differential and common modes and also using absorbing material in the tuning elements 916, a differential-common mode resonant filter with an increased frequency band of suppression of the common mode can be designed.

15 It should be noted that the electromagnetic field of the differential mode will be concentrated between signal vias if the distance between these vias will be small enough. At the same time, the electromagnetic field of the common mode for these signal vias will be extended to the  
20 side ground via walls of the resonator.

Applying tuning elements of electromagnetic wave absorbing material on a distance from the signal vias 901, suppressing the common mode can be obtained. It should be noted that simultaneously the differential mode will

be propagating with a considerably lower loss. The distance on which the tuning elements 916 can be placed can be obtained by simulations in which step-by-step position and number of tuning elements 916 are changed for  
5 given electromagnetic wave absorbing material.

In FIGS. 11A - 11D, still another exemplary embodiment of such filter is presented. The filter shown in FIGS. 11A - 11D is provided with two signal vias 1101 which are connected to terminals 1105. These signal vias  
10 1101 are embedded in a resonator 1110 which is formed in a multilayer board 1111 by ground plates 1103 and ground vias 1102 connected to the ground plates 1103. In this exemplary embodiment, the multilayer board 1111 is provided with three isolation substrates 1112 to 1114. A  
15 number of tuning elements 1116 are disposed in the resonator 1110 in the vicinity of signal vias 1101 to suppress the common mode in the wide frequency band.

Note that the resonator 1110 plays an important role in this filter because it increases considerably loss of  
20 the common mode propagating through the resonator 1110.

Consider a numerical implementation of the filter. In this implementation, the structure and dimensions of the filter are the same as for FIG. 3 but only the distance between the signal vias 1102 is  $l = 2 \text{ mm}$ , and the number  
25 of the tuning elements 1116 is sixteen. These tuning elements 1116 are disposed symmetrically with respect to

the signal vias 1101 as shown in FIGs. 11A - 11D. The dimensions of the tuning elements 1116 are as follows:  $d_t = 2 \text{ mm}$ ;  $l_t = 5 \text{ mm}$ ; and  $c_t = 5 \text{ mm}$ .

As one can see in this numerical example, the distance between the signal vias 1101 is smaller compared with aforementioned numerical examples. This provides propagation of the differential mode through the resonator 1110 with a small effect of the resonator 1110 on this differential mode. It should be noted that the effect of the resonator 1110 on the common mode will be large in this case. In the present numerical example, the 16 tuning elements 1116 are filled with absorbing material with a relative permittivity  $\epsilon = 40$ , the relative permeability  $\mu = 1.2$ , the dielectric loss tangent  $\tan \delta = 0.26$ , and the magnetic loss tangent  $\tan \delta_m = 1.5$ .

In FIG. 12, simulated insertion losses for the differential and common modes are presented for the structure shown in FIG. 11A - 11D. As shown in FIG. 12, in the frequency bands from about 2.3 GHz to about 3.7 GHz and also from about 8 GHz to 15 GHz, losses of the common mode are considerably higher than losses of the differential mode. This implies that in these frequency bands such structure suppresses effectively the common mode and has a small effect on the differential mode. This type of filters is especially important for digital applications.

It is important to emphasize that material filling in the resonator of the differential-common mode resonant filter can be used to define predetermined properties of this resonator.

5 It would be well-understandable that differential-common mode resonant filters may be formed in a multilayer board having a different number of ground plates. FIGs. 13A - 13D show a differential-common mode resonant filter disposed within a six-conductor-layer  
10 board 1311 incorporating five isolation substrates 1312 to 1316, in still another exemplary embodiment of the present invention.

This filter is provided with two signal vias 1301 embedded in the six-conductor-layer board 1311. The  
15 signal vias 1301 are disposed within a resonator 1310 which is formed by ground vias 1302 and ground plates 1303. The ground vias 1302 are used as side walls of the resonator 1310. A distinguishing characteristic of this filter is a round arrangement of ground vias 1302. In this exemplary  
20 embodiment, any face vertical to the ground plates 1303 and passing through the center of the resonator 1310 will be a vertical face of symmetry. Such property of the round in-board resonator is useful if a predetermined  
orientation of the pair of the signal vias 1301 will be  
25 necessary, because in this resonator, any orientation of the pair of the signal vias 1301 disposed symmetrically with respect to the center of the resonator 1310 can provide

the separation of the differential and common modes in the frequency domain.

In the filter shown in FIGS. 13A - 13D, another  
5 important feature of the differential-common mode resonant filter is presented. In this exemplary embodiment, the material disposed between the ground plates 1303 forming the resonator 1310, which has a relative permittivity of  $\epsilon_2$  and a relative permeability  
10 of  $\mu_2$ , is different from the material filled in the space between the ground plates 1303 and ground plates 1306, which has a relative permittivity of  $\epsilon_1$  and a relative permeability of  $\mu_1$ . The relative permittivity  $\epsilon_1$  is different from the relative permittivity of  $\epsilon_2$ , and/or the  
15 relative permeability of  $\mu_1$  is different from the relative permeability of  $\mu_2$ . In a specific implementation, such structure is important because the material of  $\epsilon_2$  and  $\mu_2$  may be chosen to provide a desired resonant frequency of the resonator 1310 and, as a result, the desired central  
20 frequency of the stopband of the filter. Moreover, the use of the material of  $\epsilon_2$  and  $\mu_2$  with a considerable loss can give widening the stopband in the filter for the differential mode or the common mode.

Thus, it is well-understandable that  
25 differential-common mode resonant filters can be formed in a multilayer board having a different number of ground plates and which are separated by materials having

different constitutive parameters. It should be also noted that the resonator may be provided at any position in the multilayer board.

Although the present invention has been described  
5 above in connection with several exemplary embodiments thereof, it would be apparent to those skilled in the art that those exemplary embodiments are provided solely for illustrating the present invention, and should not be relied upon to construe the appended claims in a limiting  
10 sense.

## CLAIMS

1. A filter comprising:

a multilayer board incorporating a resonator formed by two ground plates opposed to each other and  
5 conductive side walls connected to said ground plates;

two signal vias provided through said resonator;

and

two terminals connected to said signal vias to receive a pair of signals,

10 wherein said resonator has a first face of symmetry vertical to said ground plates, and

wherein said signal vias are disposed symmetrically with respect to said first face of symmetry on a distance from said first face of symmetry.

15

2. The filter according to claim 1, wherein said ground plates are separated by first isolating material.

3. The filter according to claim 2, wherein a relative  
20 permittivity of said first isolating material is different from that of second isolating material disposed in other parts of said multilayer board.

4. The filter according to claim 2 or 3, wherein a  
25 relative permeability of said first isolating material is different from that of second isolating material disposed in other parts of said multilayer board.

5. The filter according to any of claims 2 to 4, wherein first isolating material is dielectric material.

5 6. The filter according to any of claims 2 to 4, wherein first isolating material is electromagnetic wave absorbing material.

7. The filter according to any of claims 2 to 4, wherein  
10 first isolating material is magnetic material.

8. The filter according to any of claims 1 to 7, wherein said resonator additionally has a second face of symmetry vertical to said ground plates, and  
15 wherein said signal vias are equally spaced from said second face of symmetry.

9. The filter according to claim 8, wherein said signal vias lie on said second face of symmetry.

20

10. The filter according to any of claims 1 to 9, wherein said side walls include ground vias connected to said ground plates within said multilayer board.

25 11. The filter according to any of claims 1 to 9, wherein said side walls include a side conductor plate disposed on a side of said multilayer board and connected to said

ground plates.

12. The filter according to any of claims 1 to 11,  
wherein said side walls are arranged so as to form a  
5 rectangular resonator.

13. The filter according to claims 1 to 11, wherein said  
side walls are arranged so as to form a square resonator.

10 14. The filter according to claims 1 to 11, wherein said  
side walls are arranged so as to form a circular resonator.

15. The filter according to claim 14, said two signal  
vias are disposed symmetrically with respect to the center  
15 of said circular resonator.

16. The filter according to any of claims 1 to 15,  
further comprising tuning elements formed through said  
resonator.

20

17. The filter according to claim 16, wherein said  
tuning elements made of metal.

18. The filter according to claim 16, wherein said  
25 tuning elements made of dielectric material.

19. The filter according to claim 16, wherein said

tuning elements made of magnetic material.

20. The filter according to claim 16, wherein said tuning elements made of electromagnetic wave absorbing material.

21. The filter according to any of claims 16 to 20, wherein said tuning elements are formed symmetrically with respect to said first face of symmetry.

10

22. The filter according to any of claims 16 to 21, wherein the number, positions, materials and dimensions of said tuning elements are chosen to provide a predetermined shift of a resonance frequency of said resonator.

15

23. The filter according to any of claims 16 to 21, wherein the number, positions, materials and dimensions of said tuning elements are chosen to provide reduction of the common mode.

20

24. The filter according to any of claims 16 to 21, wherein the number, positions, materials and dimensions of said tuning elements are chosen to provide reduction of the common mode in a predetermined frequency band, keeping the level of the differential mode on a required level in said predetermined frequency band.

25

25. A method of separation of differential and common modes in a frequency domain, comprising:

providing a resonator having a face of symmetry;

5 and

providing a pair of signal conductors disposed through said resonator symmetrically with respect to said face of symmetry.

10 26. A method of suppressing the common mode, comprising:

providing a resonator having a face of symmetry;

and

15 providing a pair of signal conductors disposed through said resonator symmetrically with respect to said face of symmetry; and

providing tuning elements disposed through said resonator, said tuning elements being made of electromagnetic wave absorbing material.

20

27. A method of controlling the resonance frequency of a resonator-including filter, comprising:

providing a resonator incorporating conductor plates opposed to each other and a side wall connected to  
25 said conductor plates;

providing a pair of signal conductors disposed through said resonator; and

providing tuning elements disposed through said resonator symmetrically with respect to said signal conductors.

5 28. The method according to claim 27, wherein said tuning elements are made of metal.

29. The method according to claim 27, wherein said tuning elements are made of dielectric material.

10

30. The method according to claim 27, wherein said tuning elements are made of magnetic material.

**AMENDED CLAIMS****received by the International Bureau on 14 April 2009 (14.04.2009)**

1. (Amended) A filter comprising:

a resonator formed by two horizontal conductor plates opposed to each other and vertical conductive side walls connected to said horizontal conductor plates;

two signal conductors provided through said resonator in the vertical direction and isolated from said horizontal conductor plates; and

two terminals connected to said signal conductors to receive a pair of signals,

wherein said resonator establishes a resonant effect on said signal conductors at predetermined frequencies by means of horizontal dimensions of said resonator and a material disposed between said horizontal conductor plates,

wherein said resonator has a first face of symmetry vertical to said horizontal conductor plates, and

wherein said signal conductors are disposed symmetrically with respect to said first face of symmetry on a distance from said first face of symmetry.

2. (Amended) The filter according to claim 1, wherein said resonator is incorporated in a multilayer board, wherein said horizontal conductor plates are formed in ground layers of said multilayer board and separated by first isolating material, and wherein said signal

conductors are constructed as signal vias.

3. The filter according to claim 2, wherein a relative permittivity of said first isolating material is different  
5 from that of second isolating material disposed in other parts of said multilayer board.

4. The filter according to claim 2 or 3, wherein a relative permeability of said first isolating material is  
10 different from that of second isolating material disposed in other parts of said multilayer board.

5. The filter according to any of claims 2 to 4, wherein first isolating material is dielectric material.

5

6. The filter according to any of claims 2 to 4, wherein first isolating material is electromagnetic wave absorbing material.

10 7. The filter according to any of claims 2 to 4, wherein first isolating material is magnetic material.

8. (Amended)- The filter according to any of claims 1 to 7, wherein said resonator additionally has a second face of symmetry vertical to said horizontal conductor plates, and

wherein said signal vias are equally spaced from said second face of symmetry.

20 9. The filter according to claim 8, wherein said signal vias lie on said second face of symmetry.

10. (Amended) The filter according to any of claims 2 to 9, wherein said side walls include ground vias connected to said horizontal conductor plates within said multilayer board.

11. (Amended) The filter according to any of claims 1 to 9, wherein said side walls include a side conductor

plate connected to said horizontal conductor plates.

12. The filter according to any of claims 1 to 11,  
wherein said side walls are arranged so as to form a  
5 rectangular resonator.

13. The filter according to claims 1 to 11, wherein said  
side walls are arranged so as to form a square resonator.

10 14. The filter according to claims 1 to 11, wherein said  
side walls are arranged so as to form a circular resonator.

15 15. The filter according to claim 14, said two signal  
vias are disposed symmetrically with respect to the center  
15 of said circular resonator.

16. The filter according to any of claims 1 to 15,  
further comprising tuning elements formed through said  
resonator.

20

17. The filter according to claim 16, wherein said  
tuning elements made of metal.

18. The filter according to claim 16, wherein said  
25 tuning elements made of dielectric material.

19. The filter according to claim 16, wherein said

25. A method of separation of differential and common modes in a frequency domain, comprising:

providing a resonator having a face of symmetry;

5 and

providing a pair of signal conductors disposed through said resonator symmetrically with respect to said face of symmetry.

10 26. A method of suppressing the common mode, comprising:

providing a resonator having a face of symmetry;

and

15 providing a pair of signal conductors disposed through said resonator symmetrically with respect to said face of symmetry; and

providing tuning elements disposed through said resonator, said tuning elements being made of electromagnetic wave absorbing material.

20

27. (Amended) A method of controlling the resonance frequency of a resonator including filter, comprising:

25 providing a resonator incorporating horizontal conductor plates opposed to each other and a vertical conductive side wall connected to said horizontal conductor plates;

providing a pair of signal conductors disposed through said resonator; and

providing tuning elements disposed through said resonator symmetrically with respect to said signal conductors.

5 28. The method according to claim 27, wherein said tuning elements are made of metal.

29. The method according to claim 27, wherein said tuning elements are made of dielectric material.

10

30. The method according to claim 27, wherein said tuning elements are made of magnetic material.

31. (Added) The filter according to any of claims 1 to  
15 24, wherein said resonant effect has a predetermined magnitude of the quality factor.

32. (Added) The filter according to claim 31, wherein said predetermined magnitude of the quality factor is  
20 equal to 0.5 or higher than 0.5.

**STATEMENT UNDER ARTICLE 19 (1)**

The amendments of the claims are directed to emphasize salient characteristics of the applied invention.

Particularly, a resonator comprised in a differential-common mode resonant filter is one of the key points of invented structures and is included in all claims. The resonator provides the resonant effect on both signal conductors, disposed symmetrically with respect to the resonator symmetry face, to suppress required common mode or differential mode at desired frequencies by means of appropriate choice of dimensions and material of the resonator. This can be realized to obtain the differential-common resonant filter as an independent device or as a component integrated in a multilayer board. Generalized structure of the filter is presented in the amended claim 1.

The resonator produces oscillations which can be characterized by the quality factor. Note that the quality factor is one of the main characteristics of the resonator which shows its difference from other structures such as signal paths, waveguides, transmission lines, and so on. Claims 31 and 32 are added to emphasize on this characteristic. Note that the quality factor, which is equal to 0.5, is the critical value identifying the resonator.

Fig. 1A

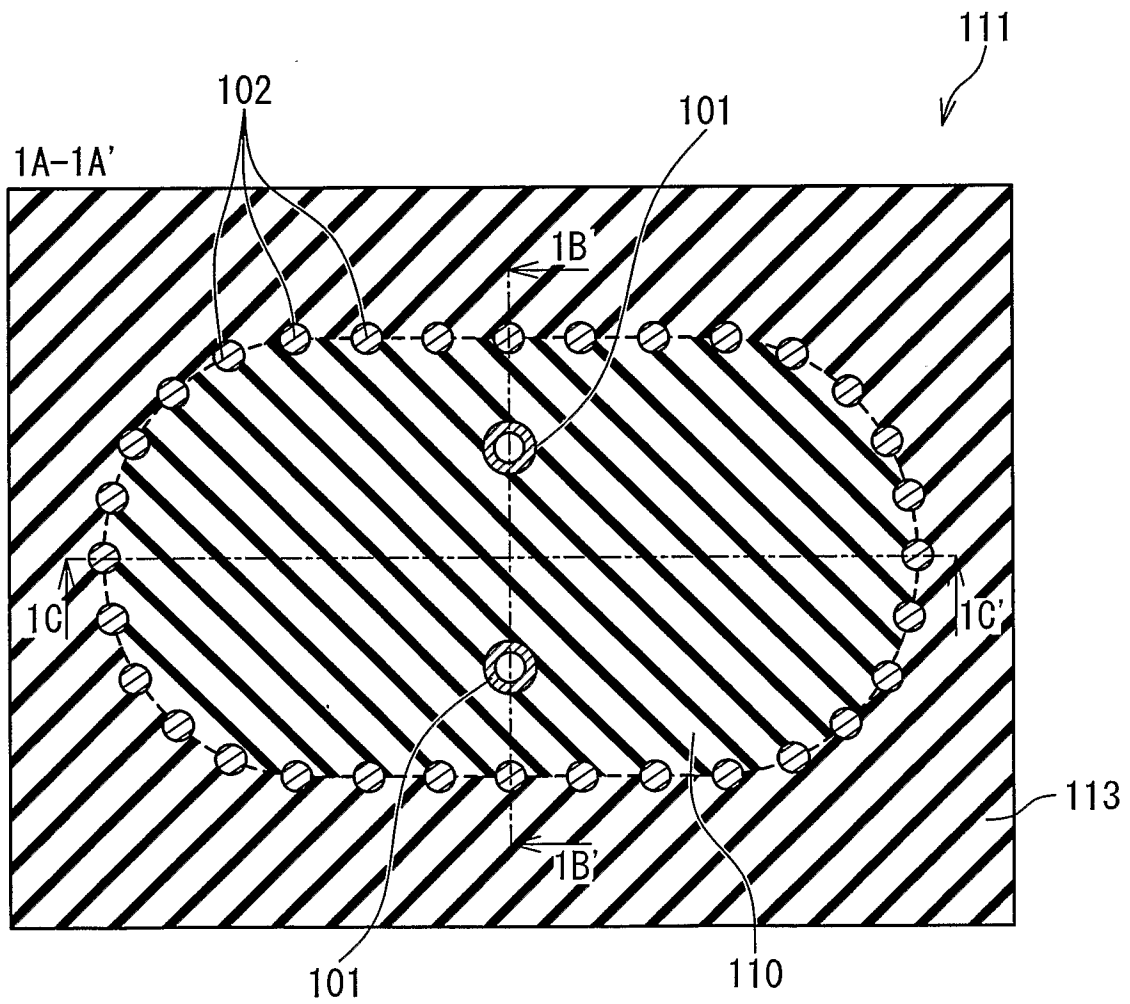


Fig. 1B

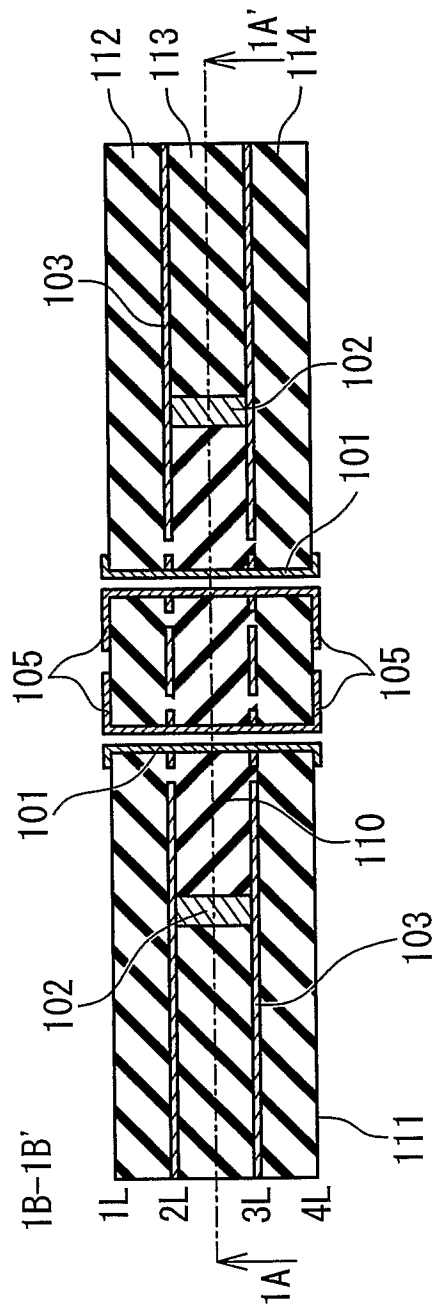


Fig. 1C

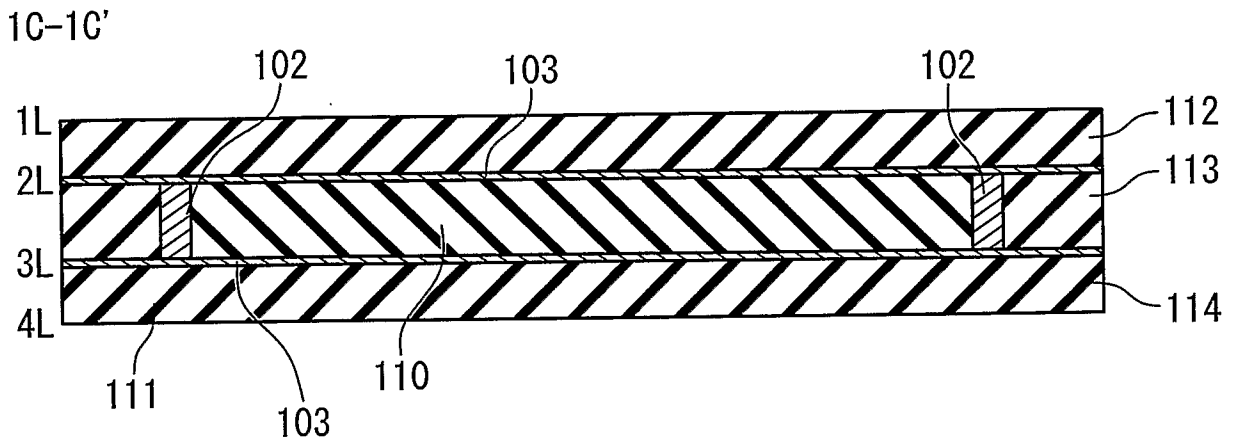


Fig. 1D

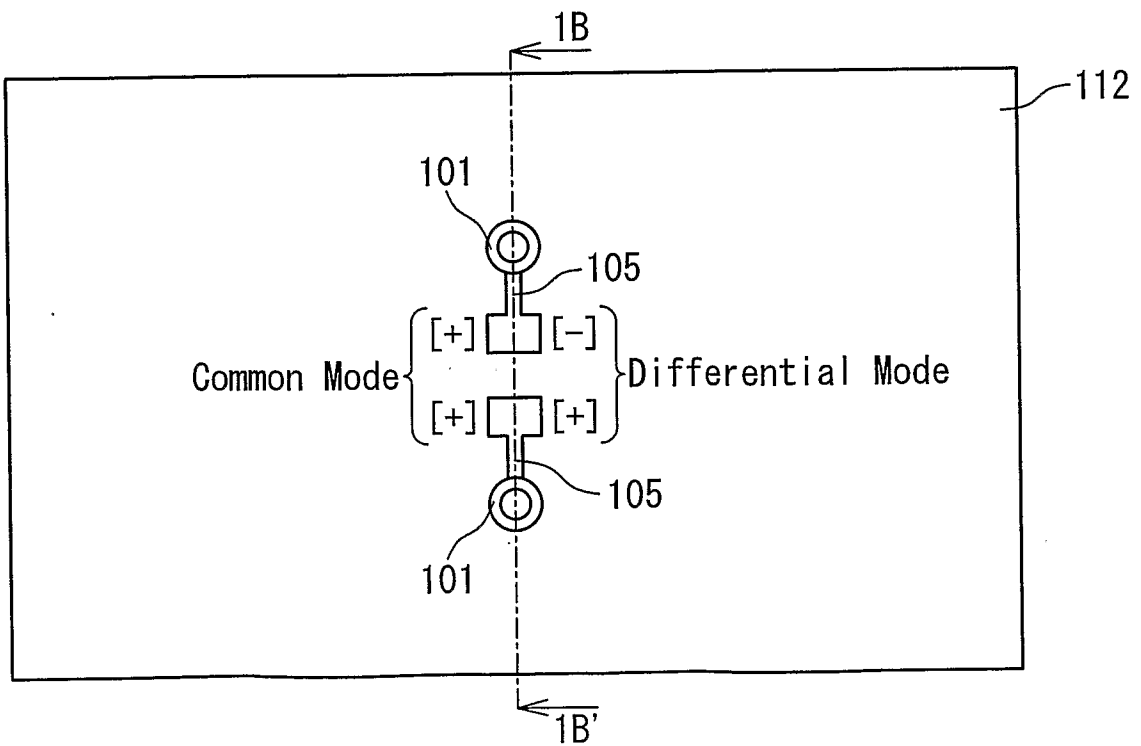


Fig. 2A

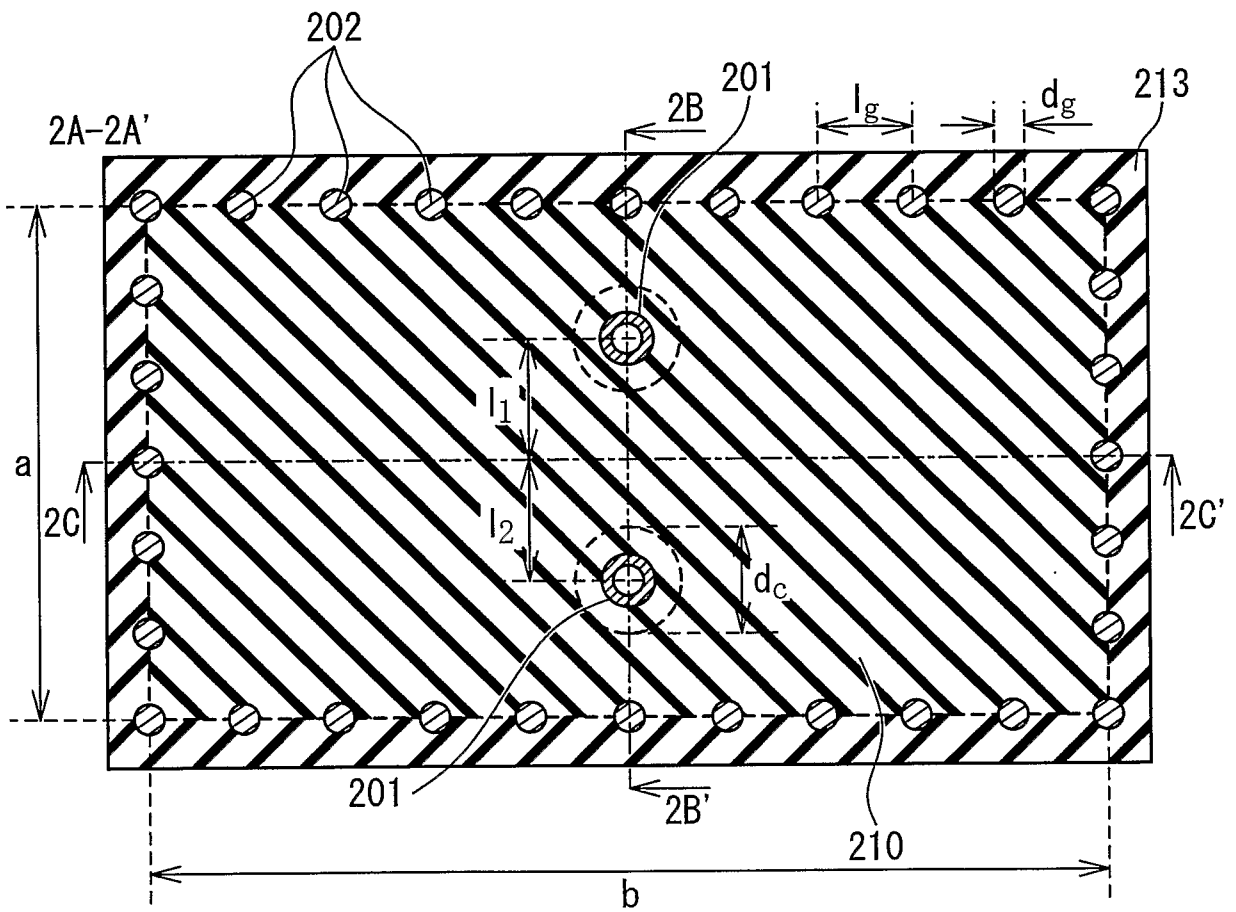


Fig. 2B

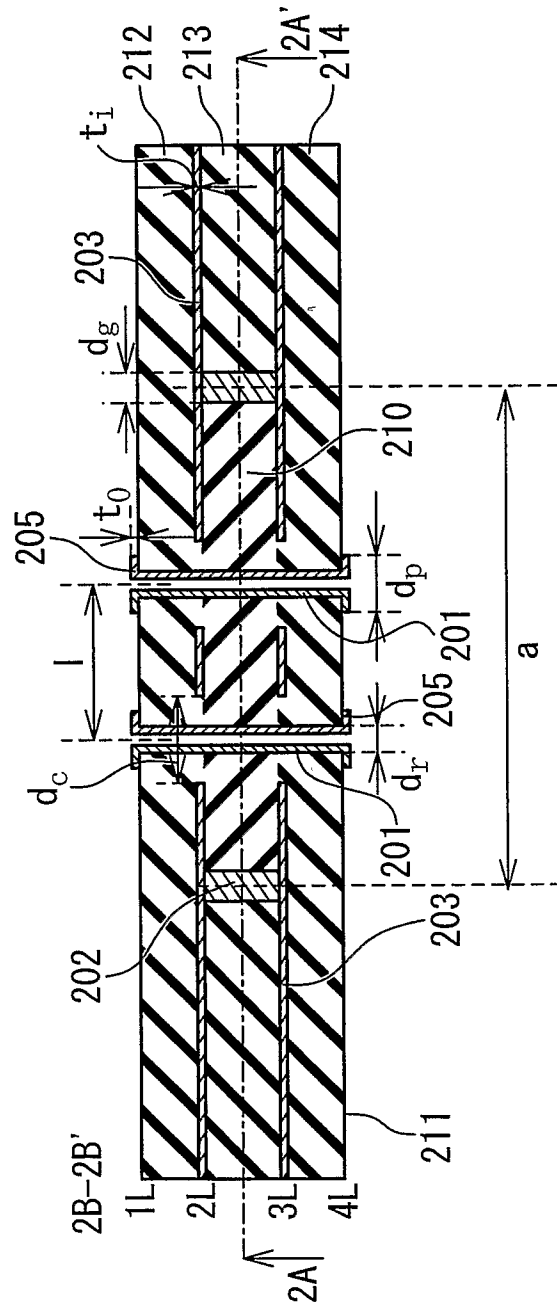


Fig. 2C

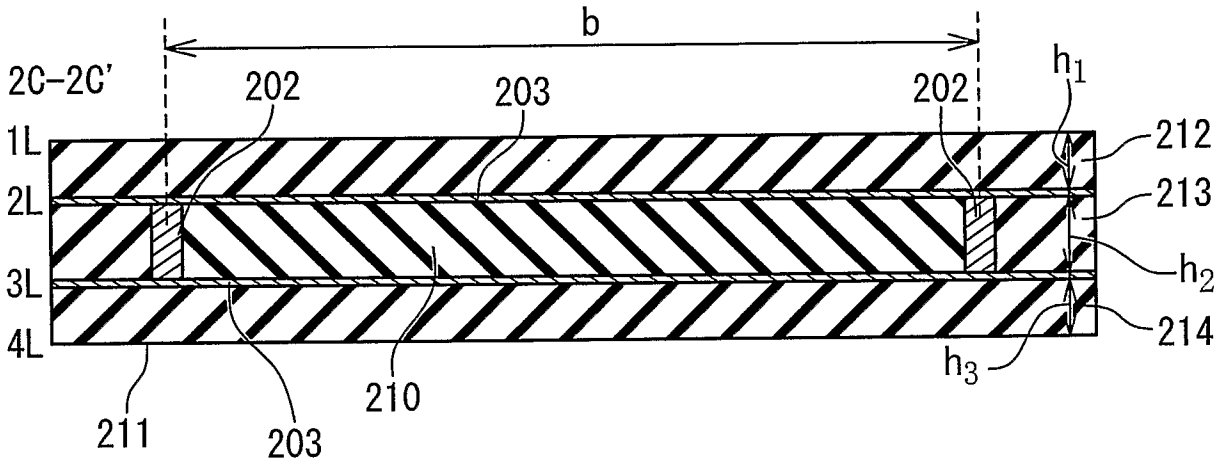


Fig. 2D

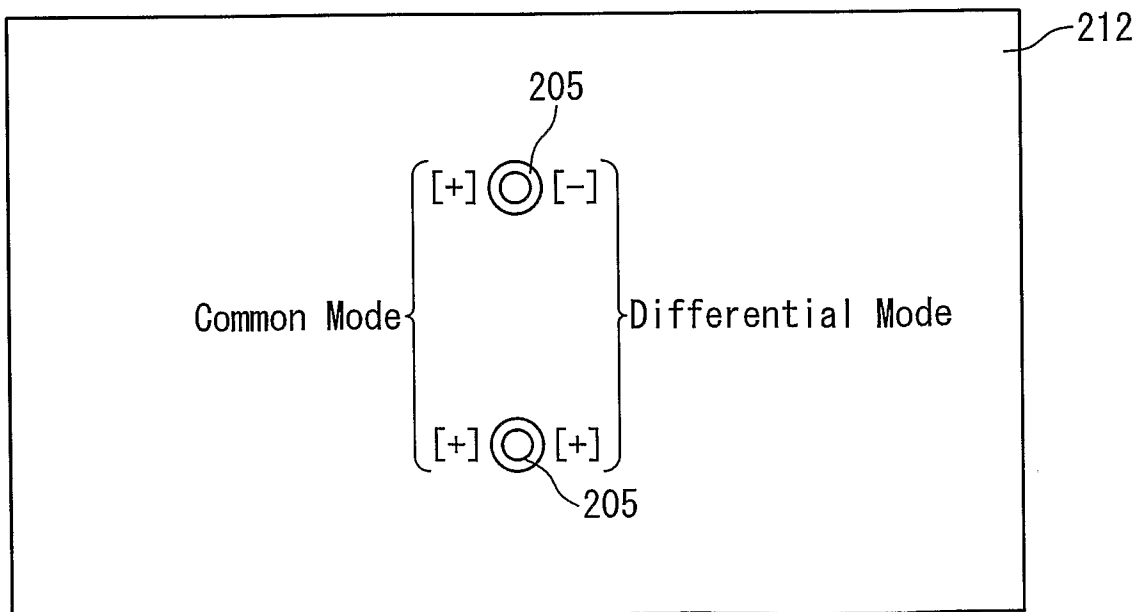


Fig. 2E

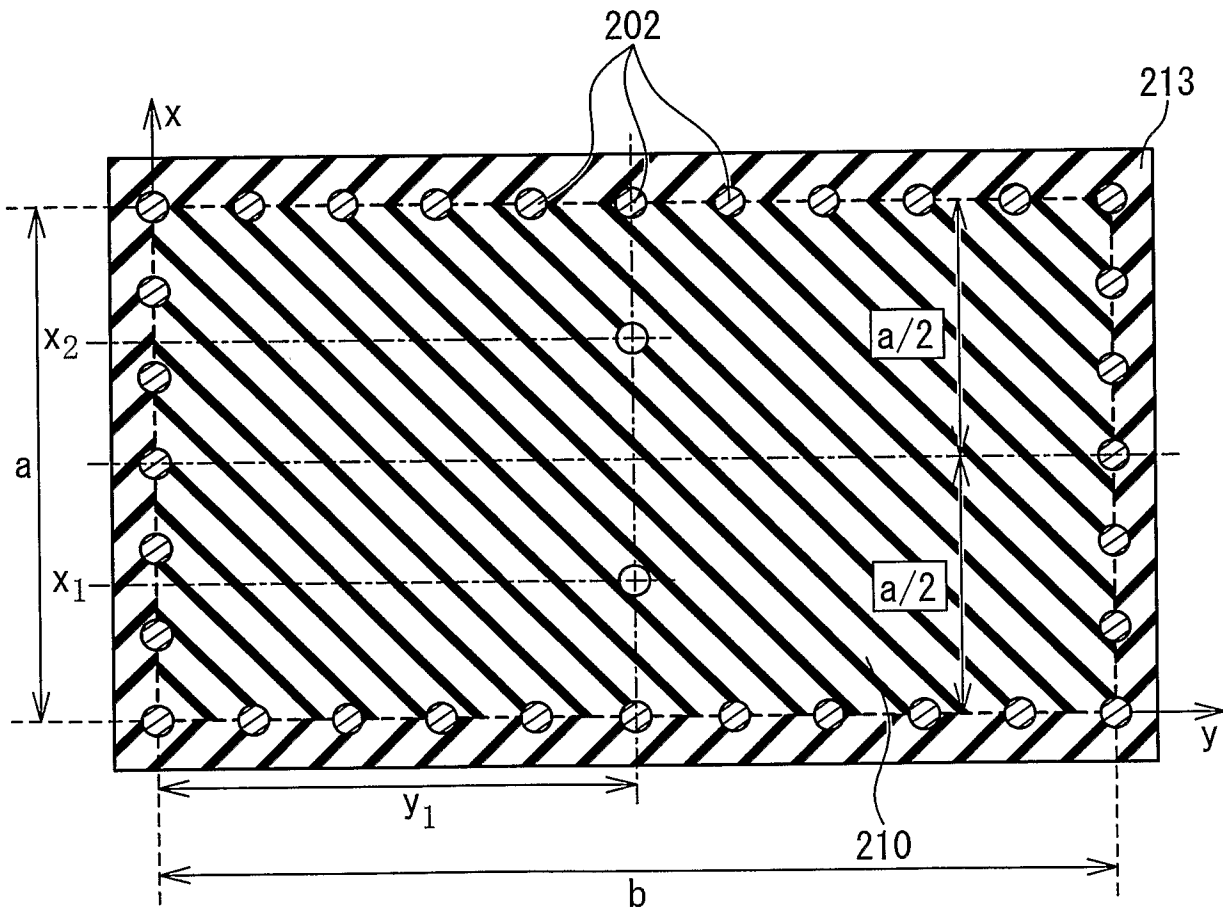


Fig. 3

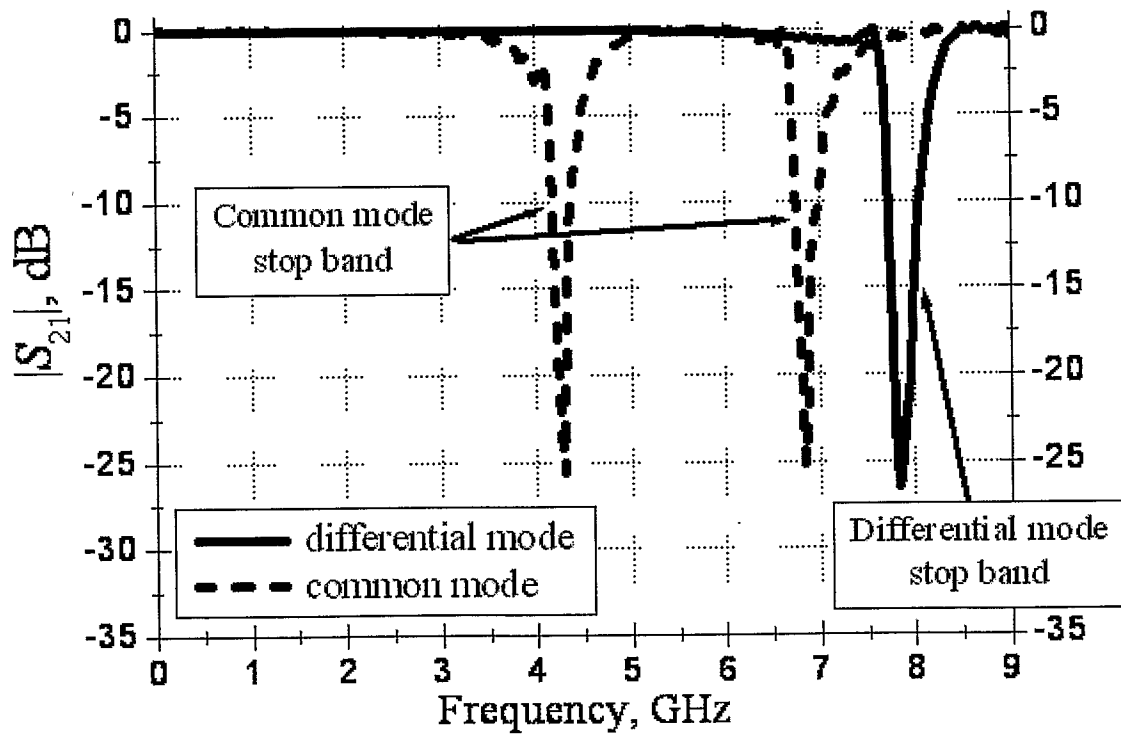


Fig. 4A

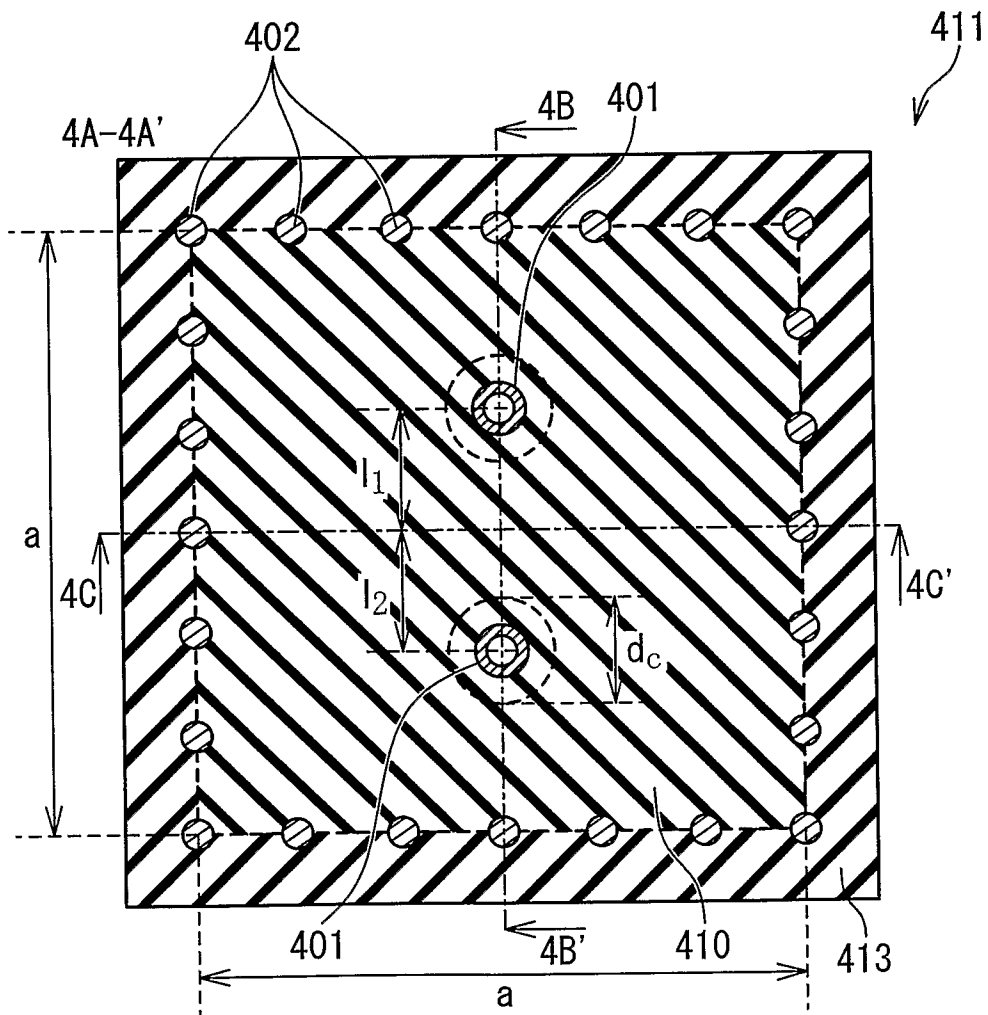


Fig. 4B

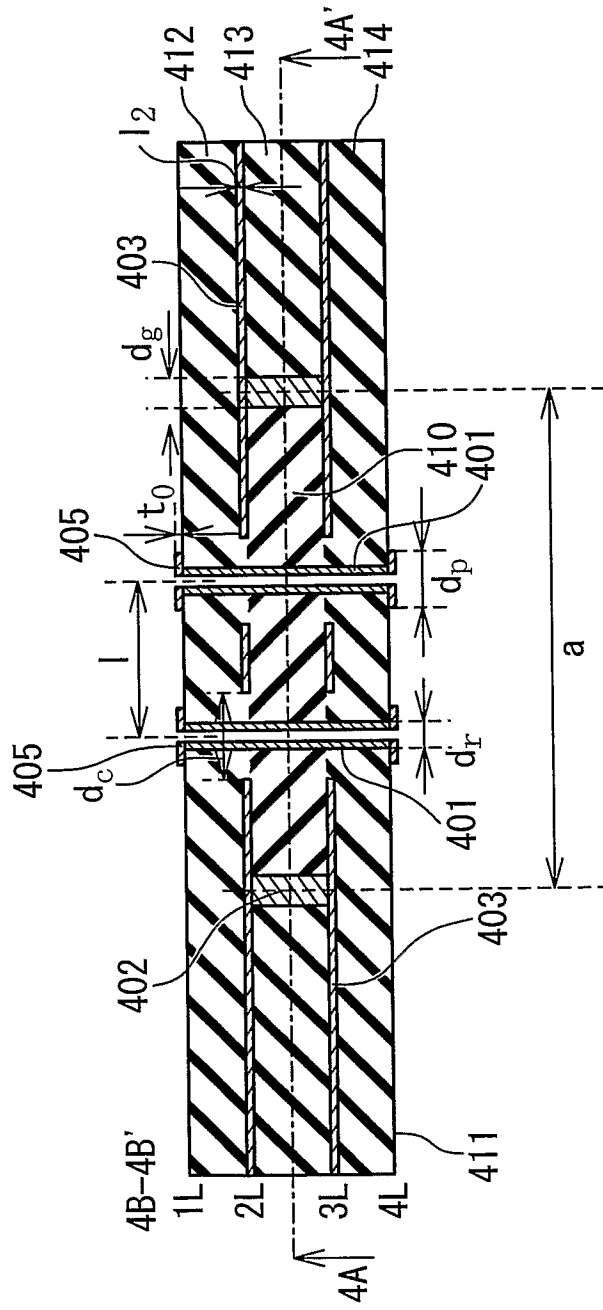


Fig. 4C

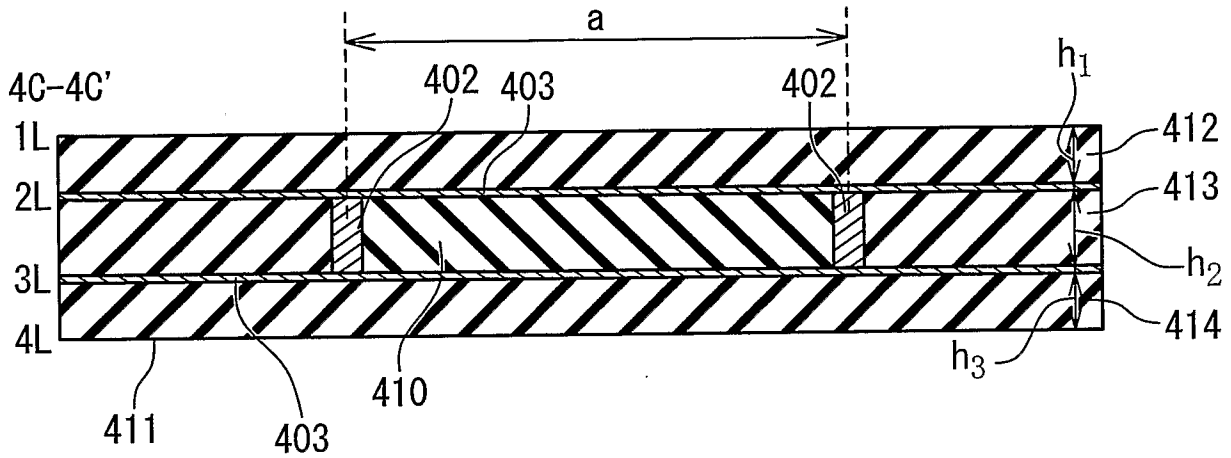


Fig. 4D

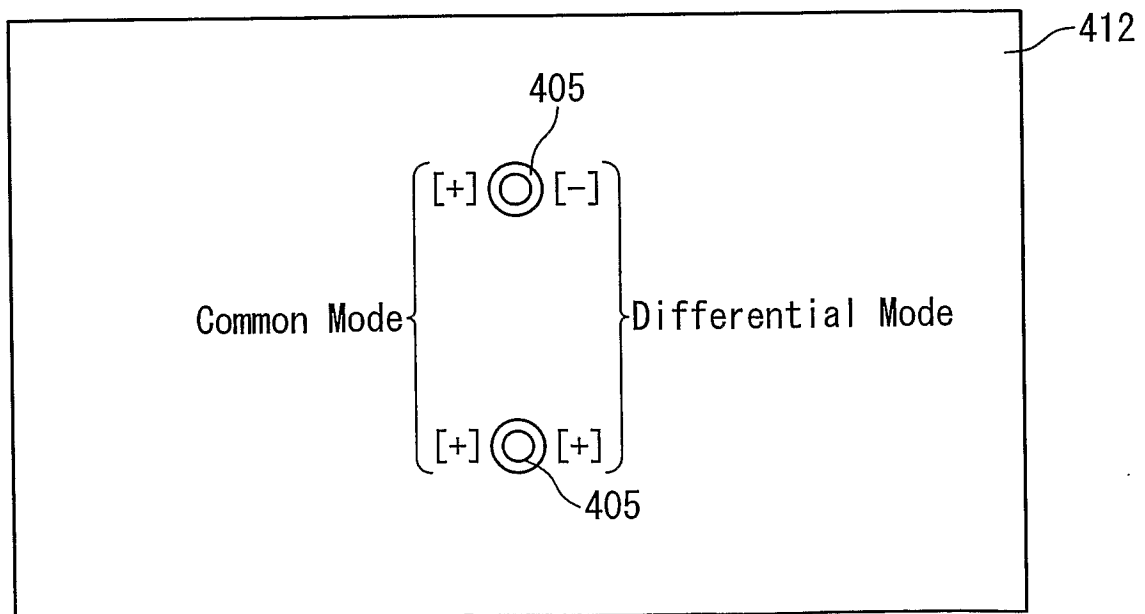


Fig. 5

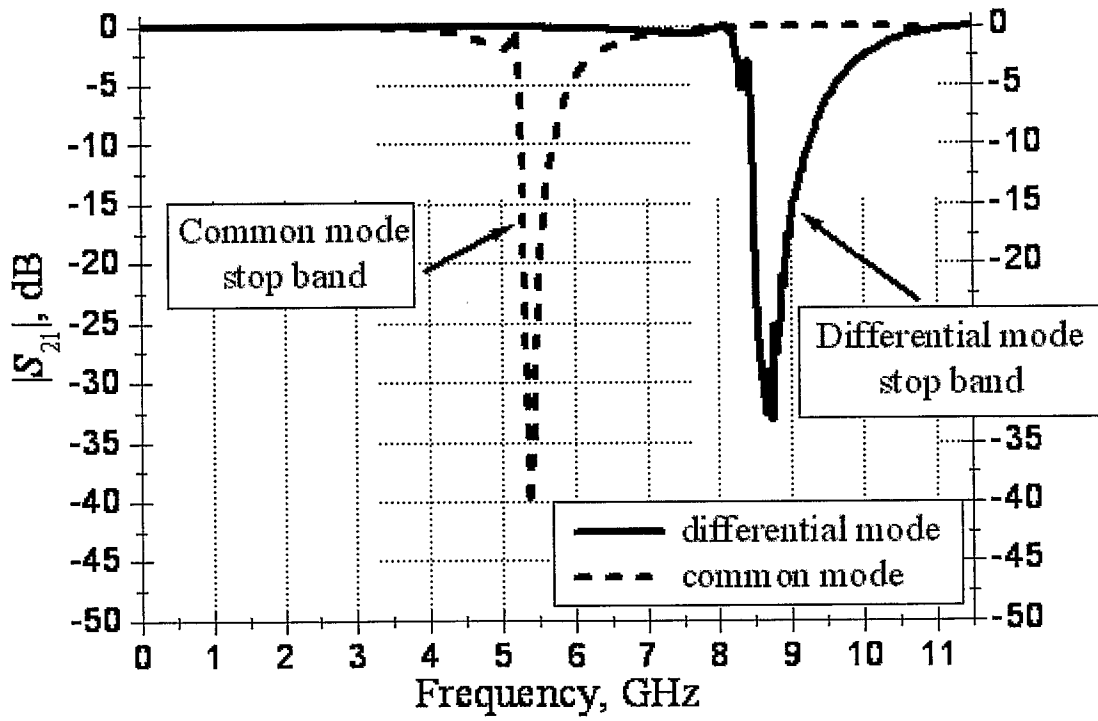


Fig. 6A

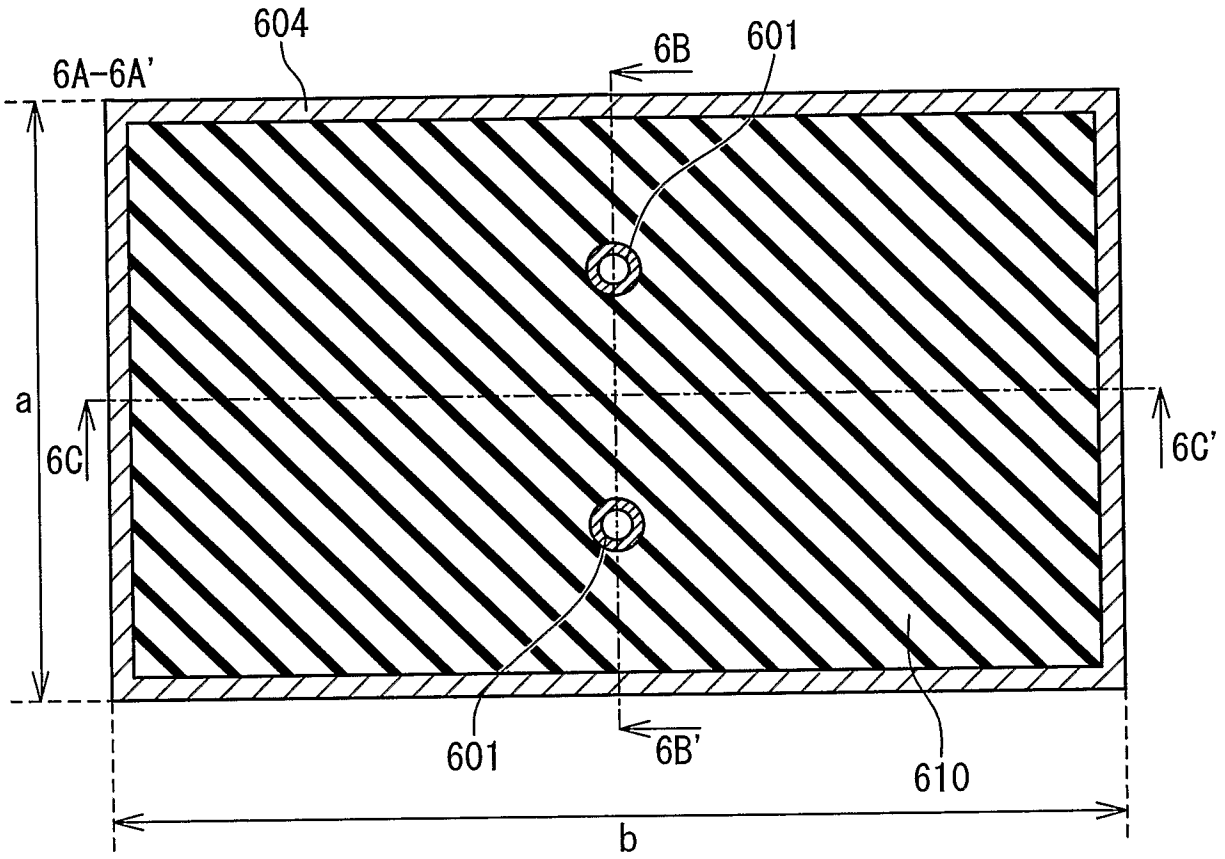


Fig. 6B

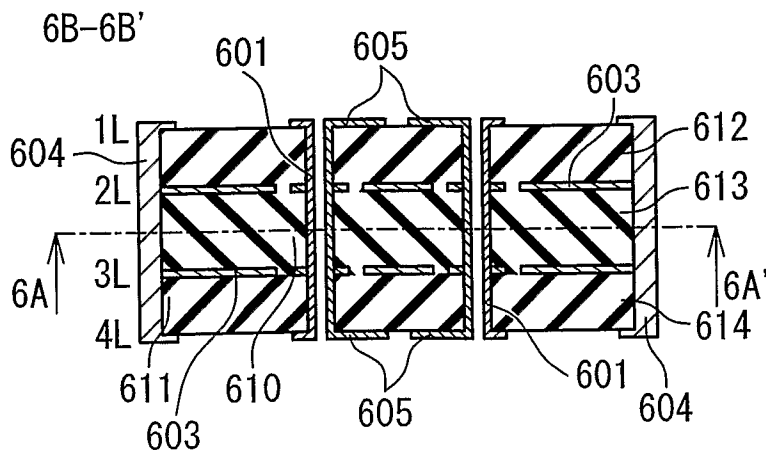


Fig. 6C

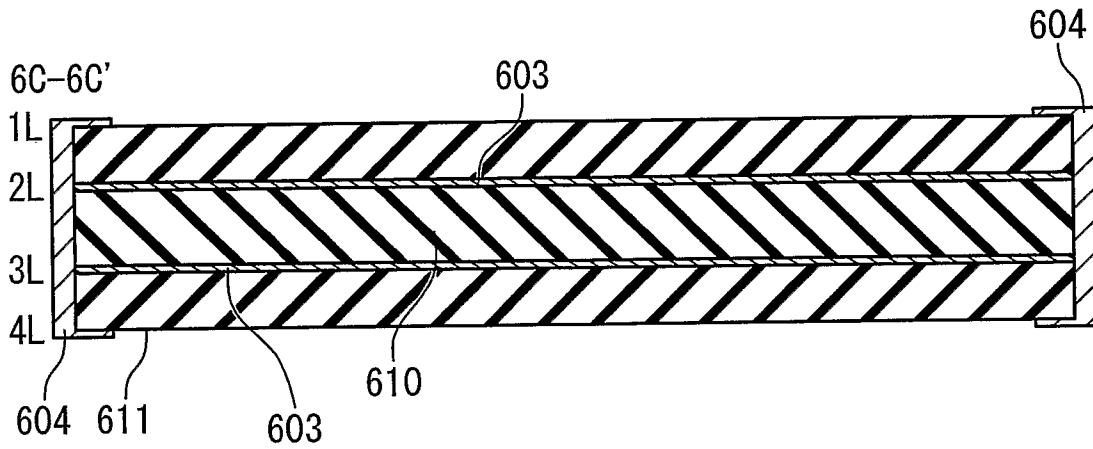


Fig. 6D

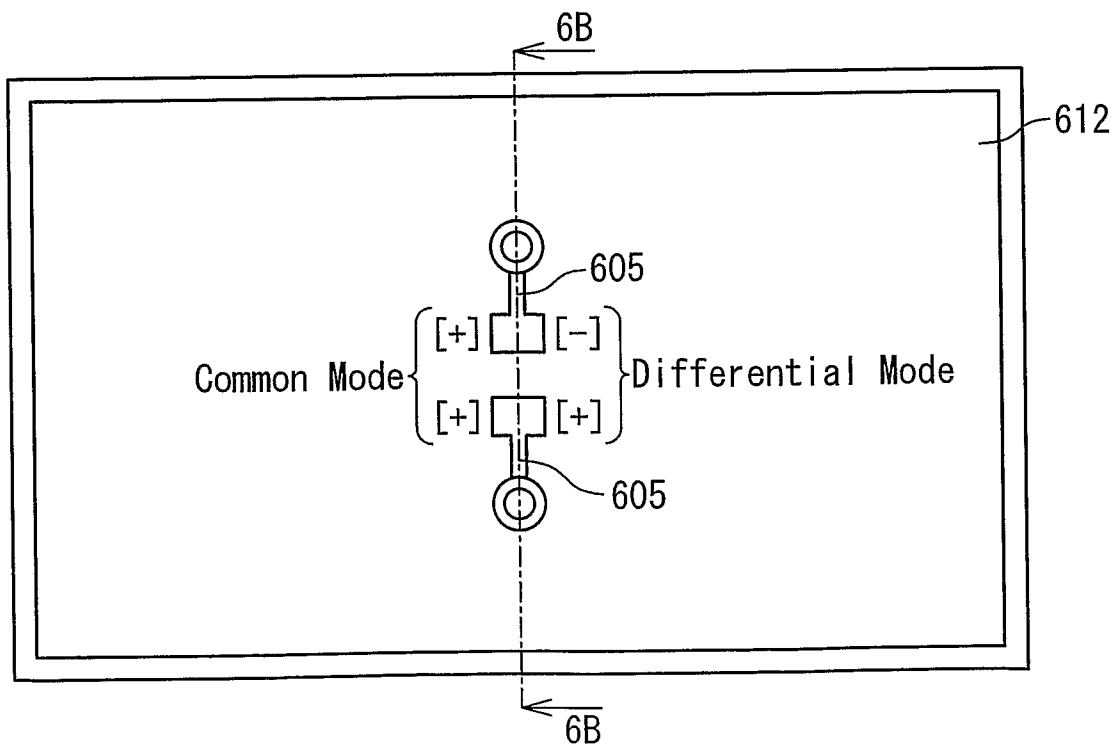


Fig. 7A

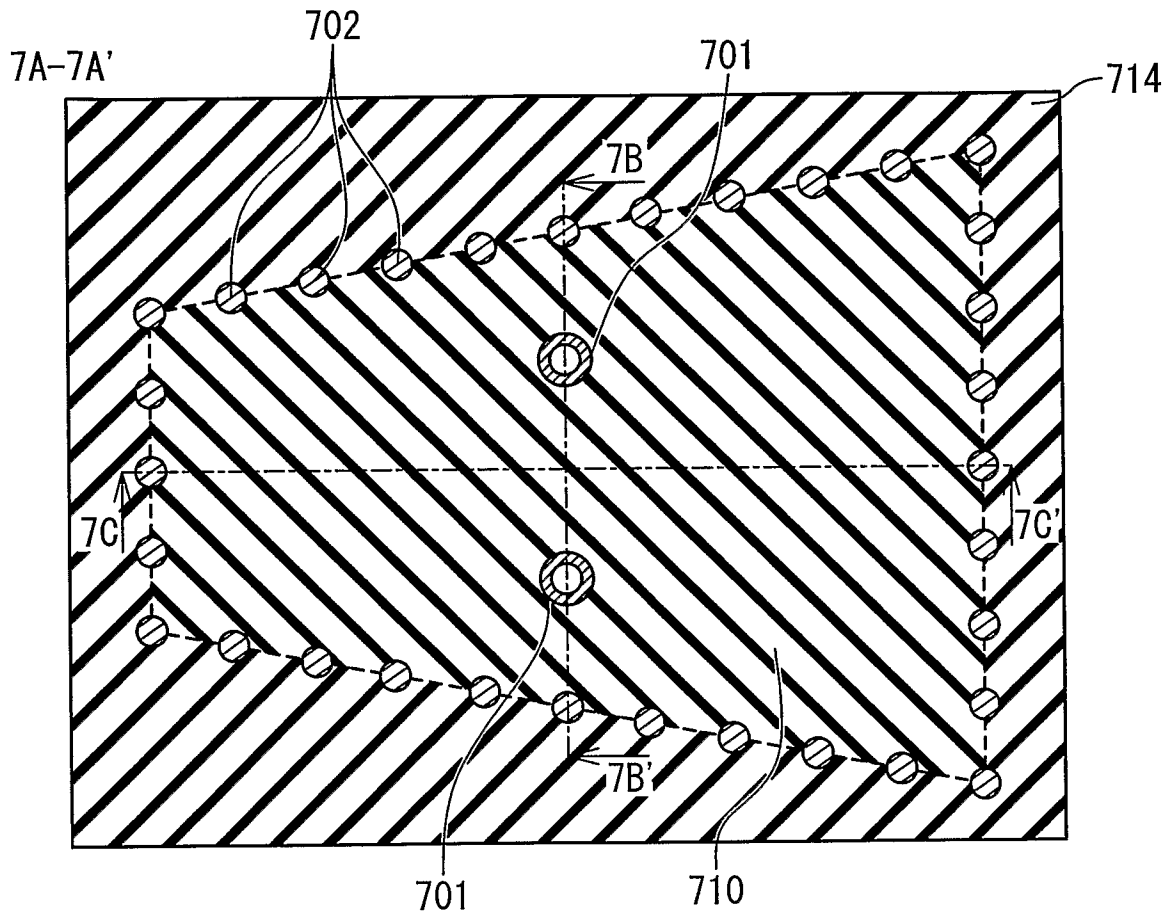


Fig. 7B

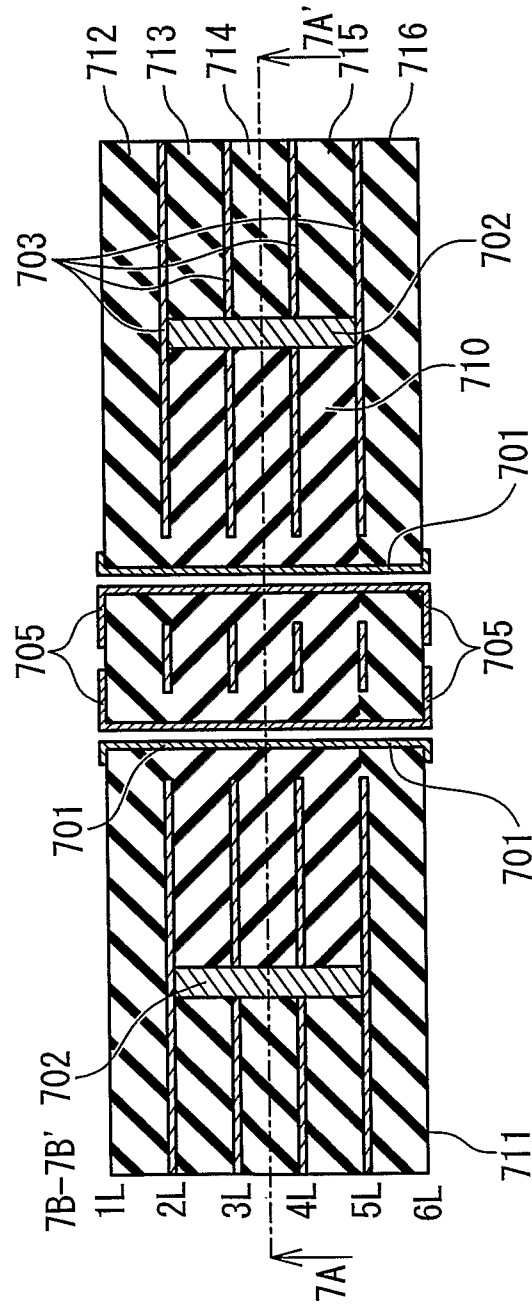


Fig. 7C

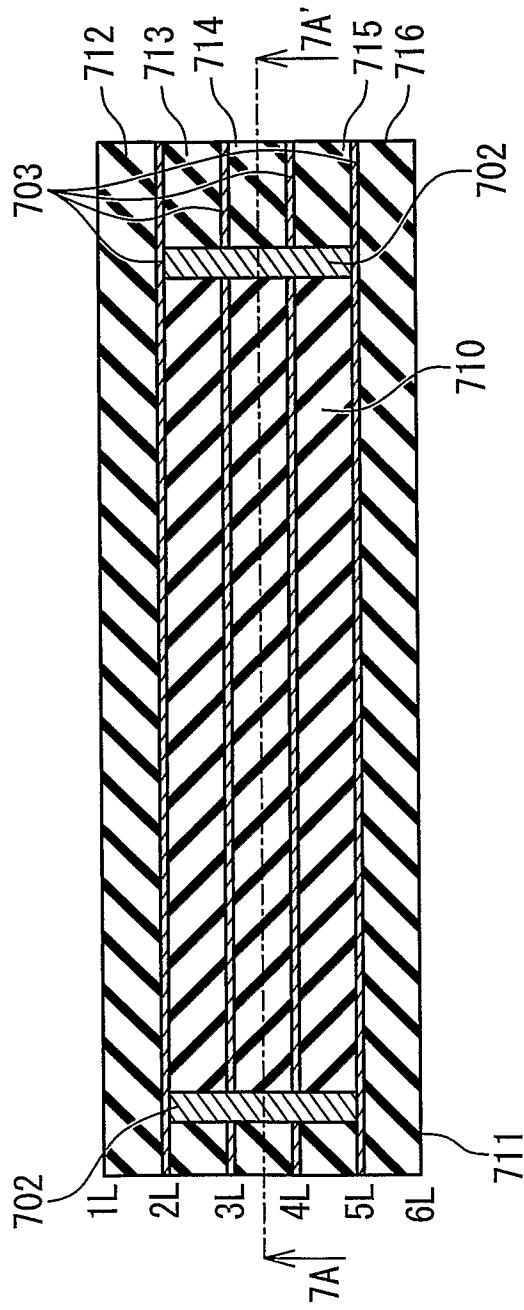


Fig. 7D

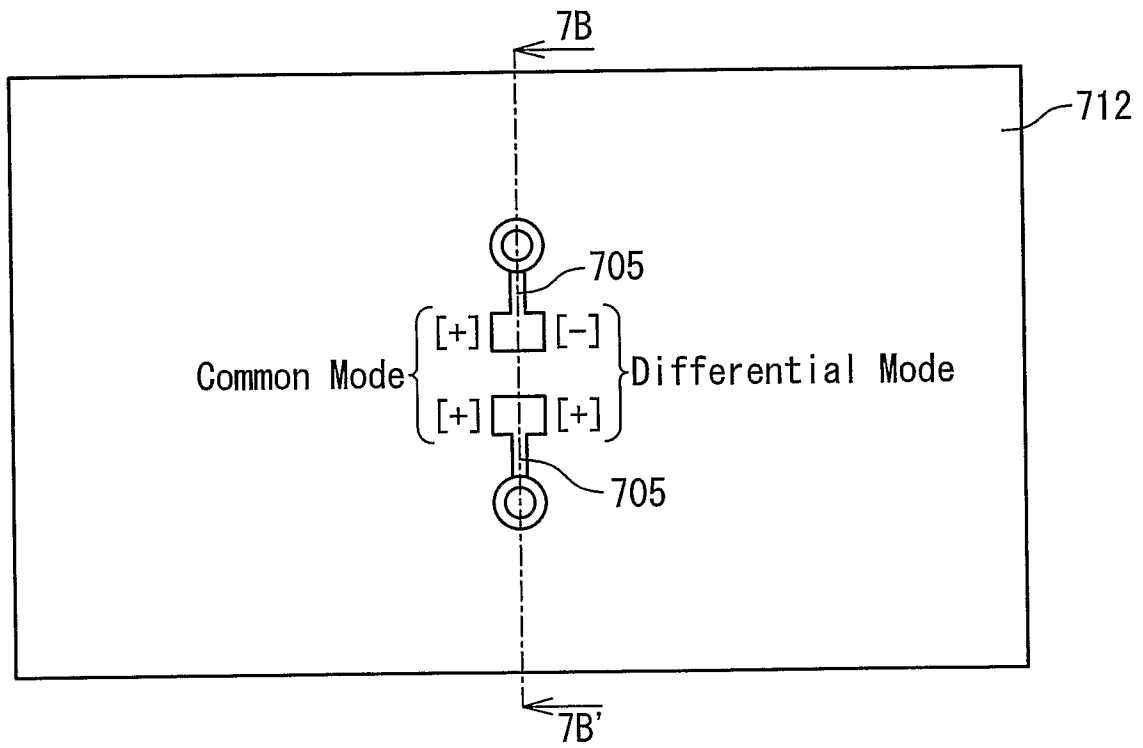


Fig. 8A

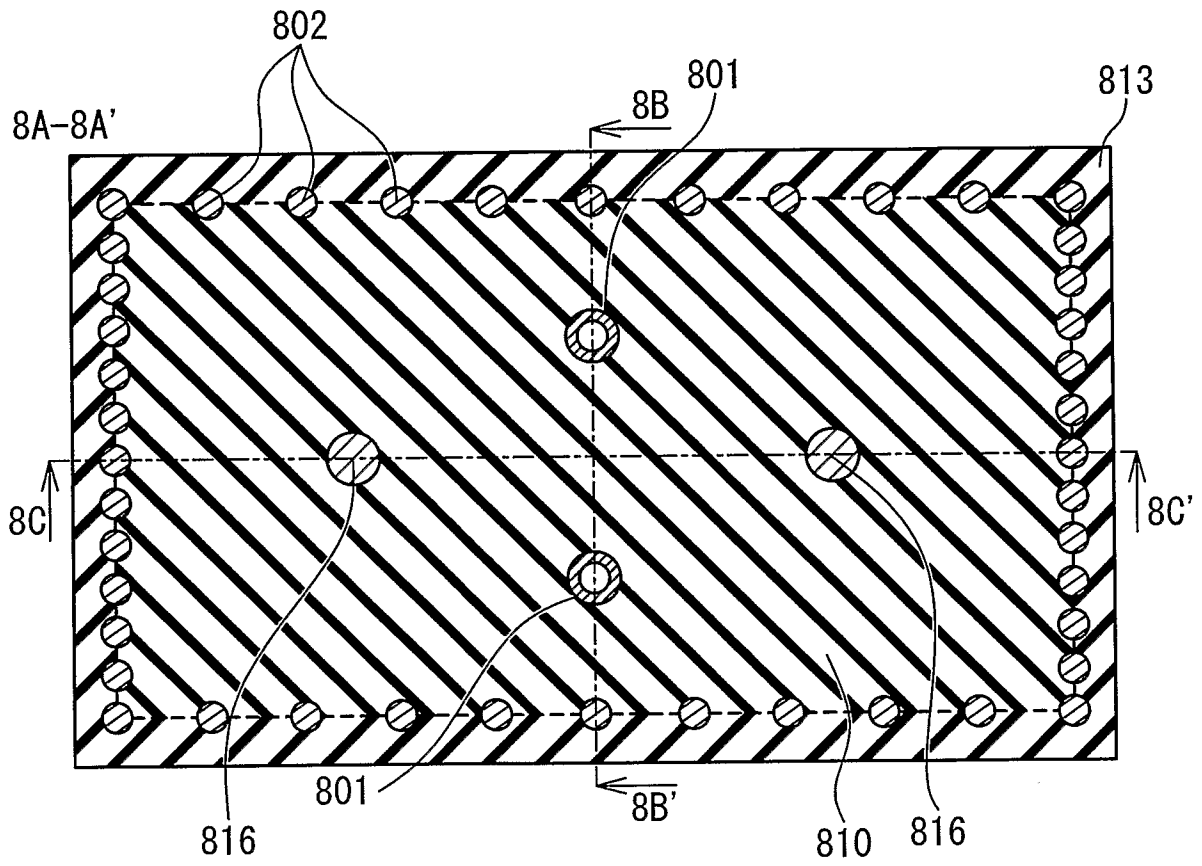


Fig. 8B

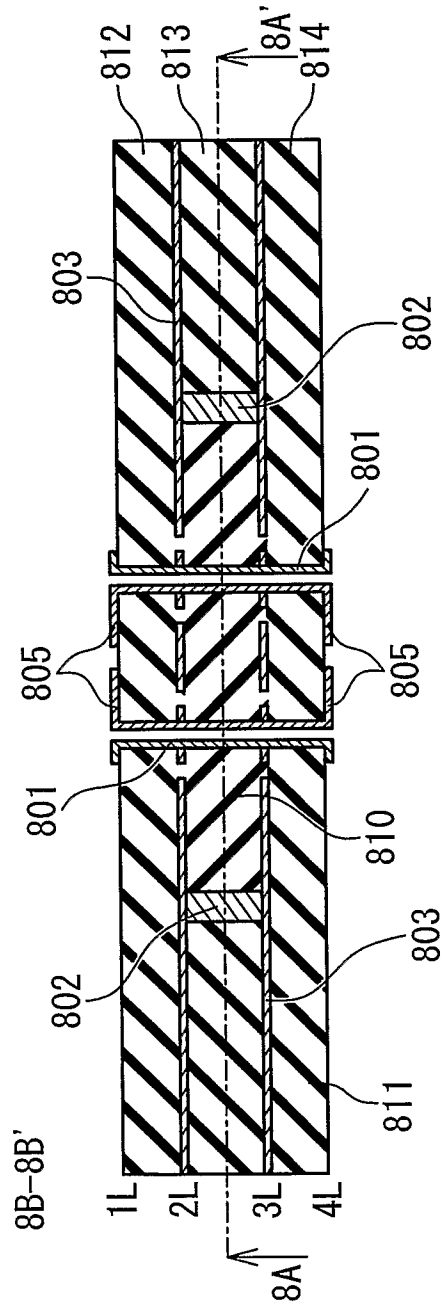


Fig. 8C

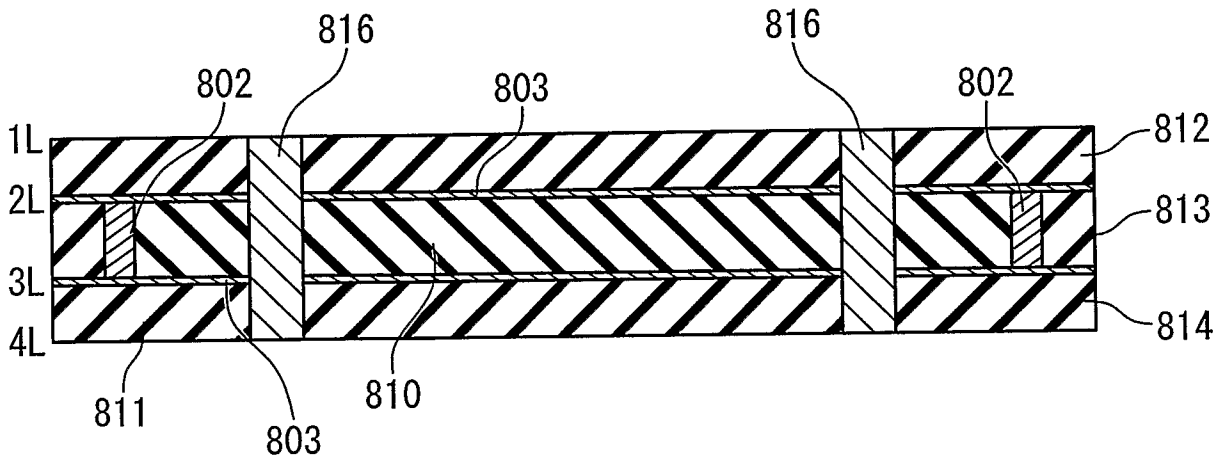


Fig. 8D

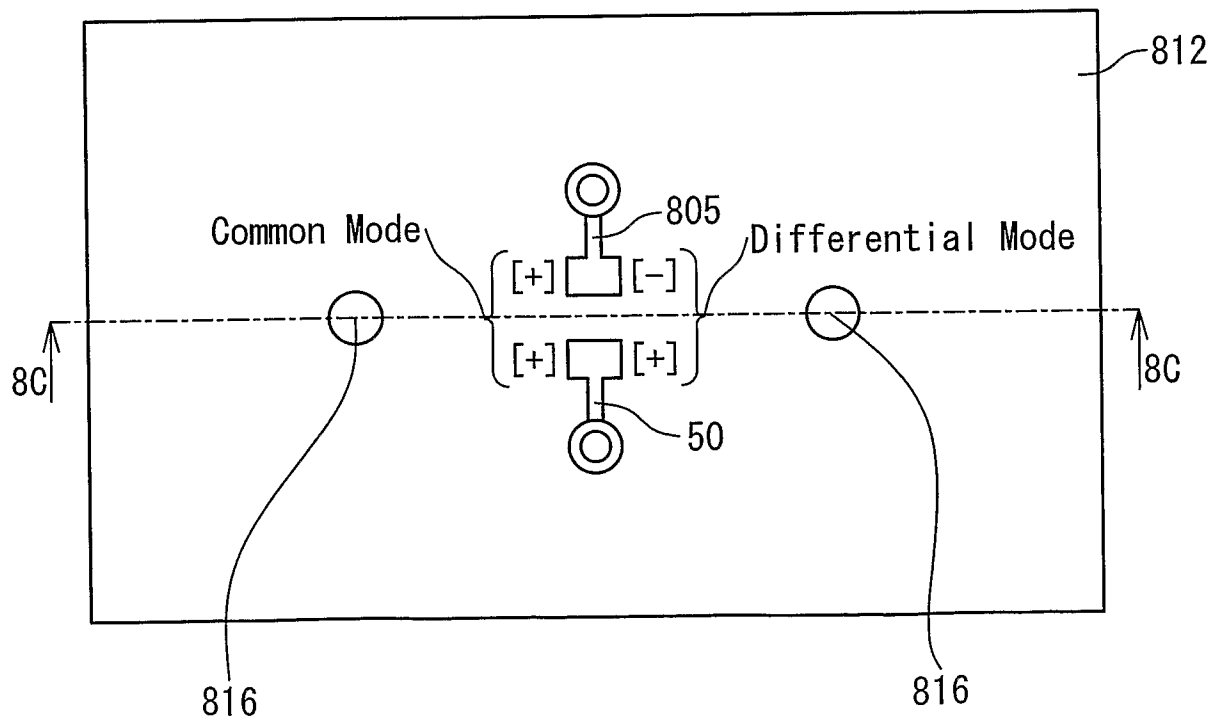
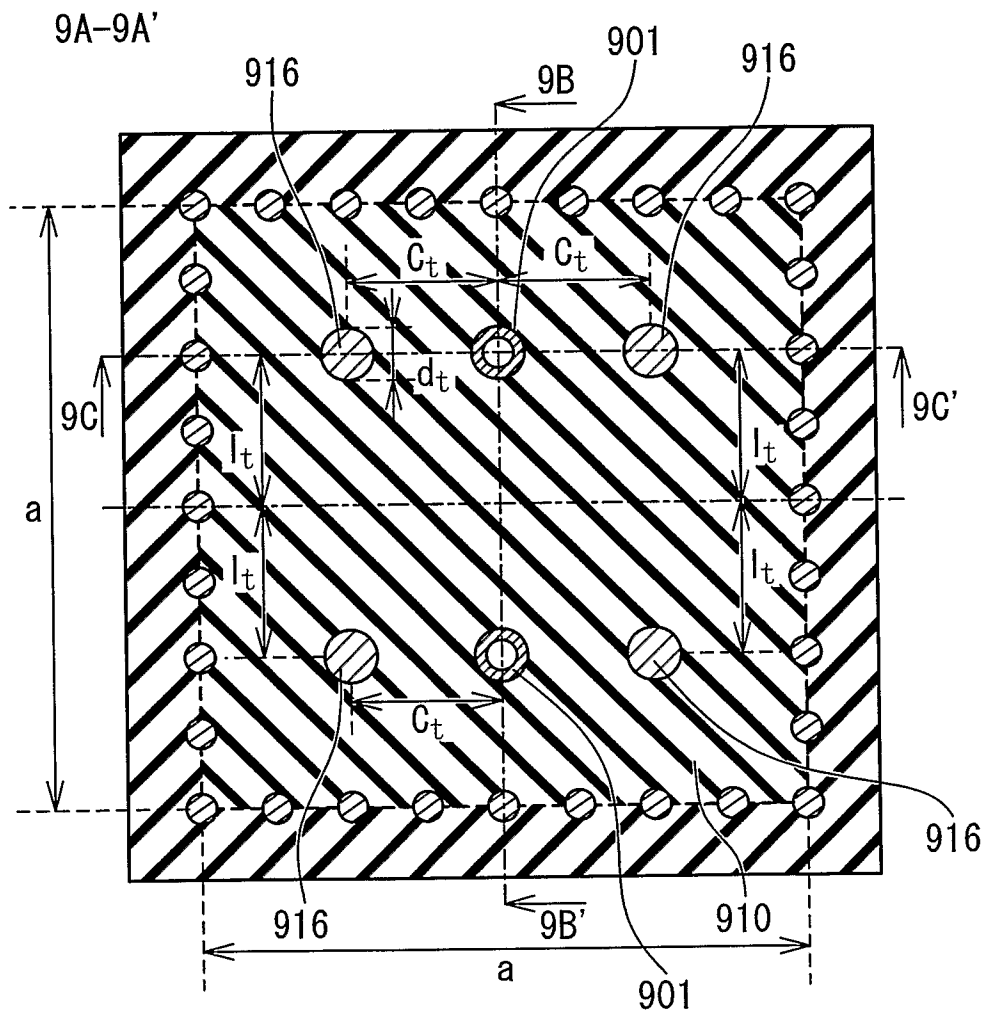
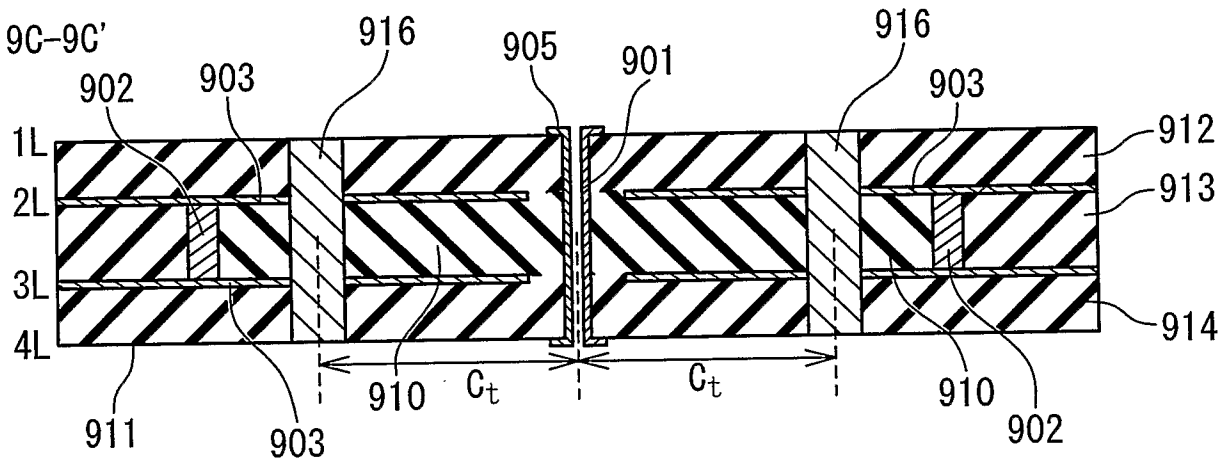


Fig. 9A





# Fig. 9C



# Fig. 9D

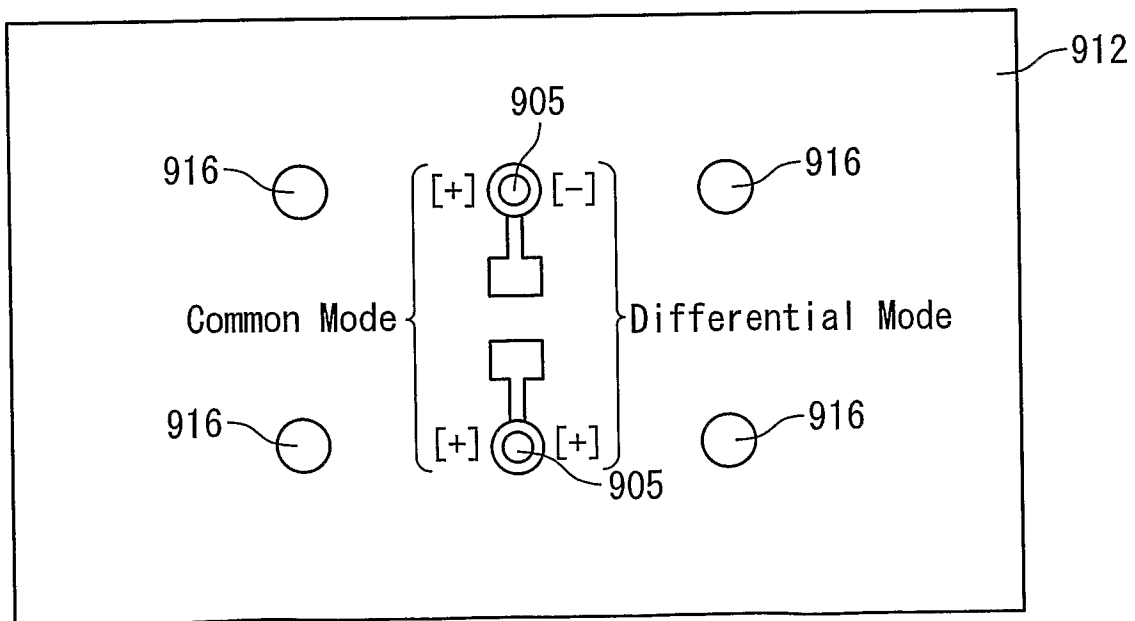
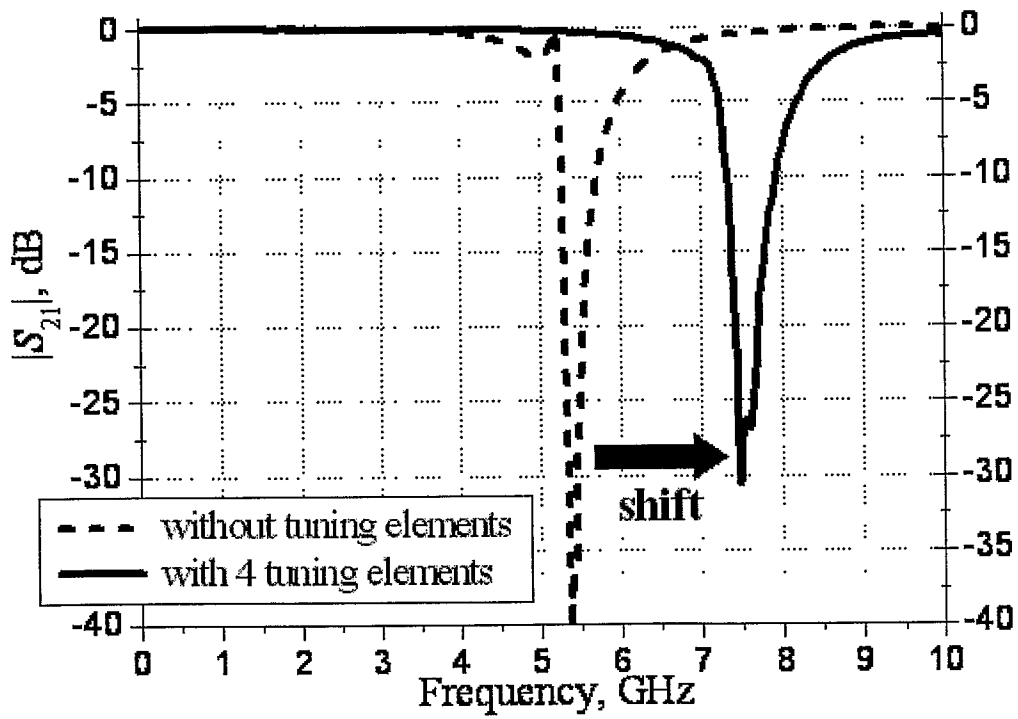


Fig. 10A



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Fig. 10B

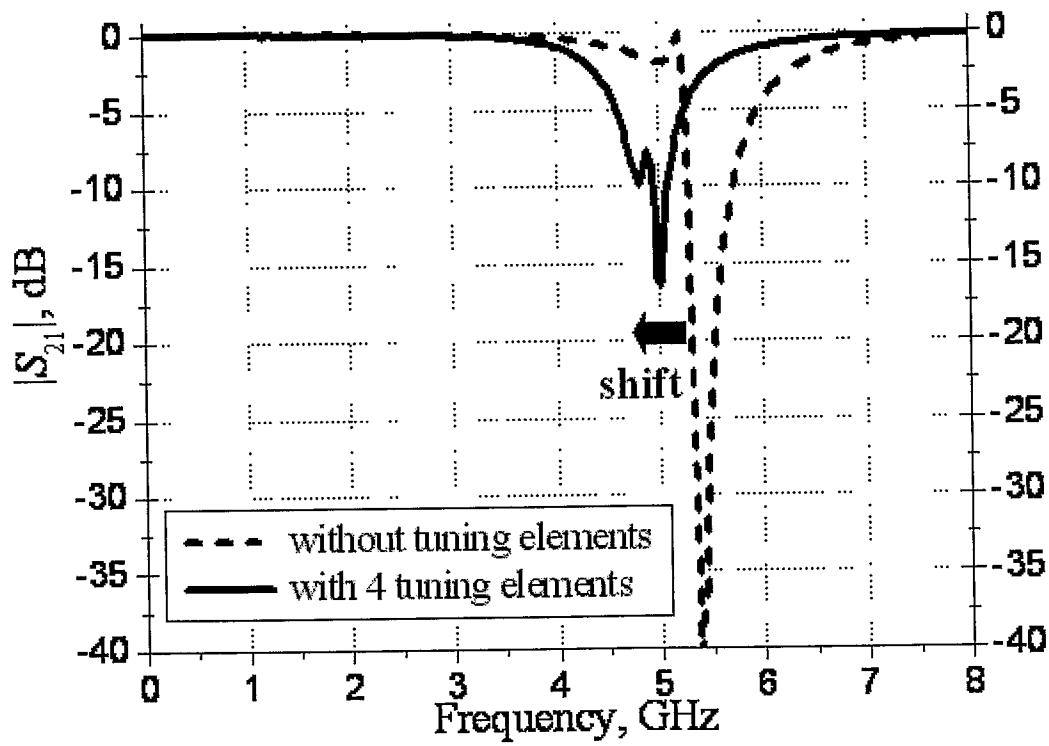




Fig. 11B

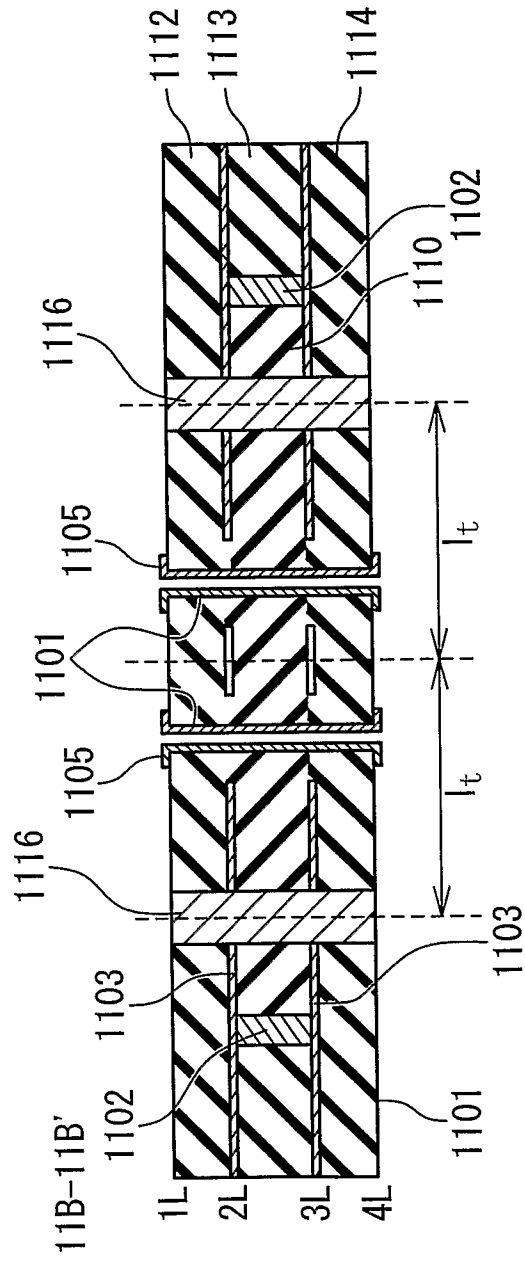


Fig. 110C

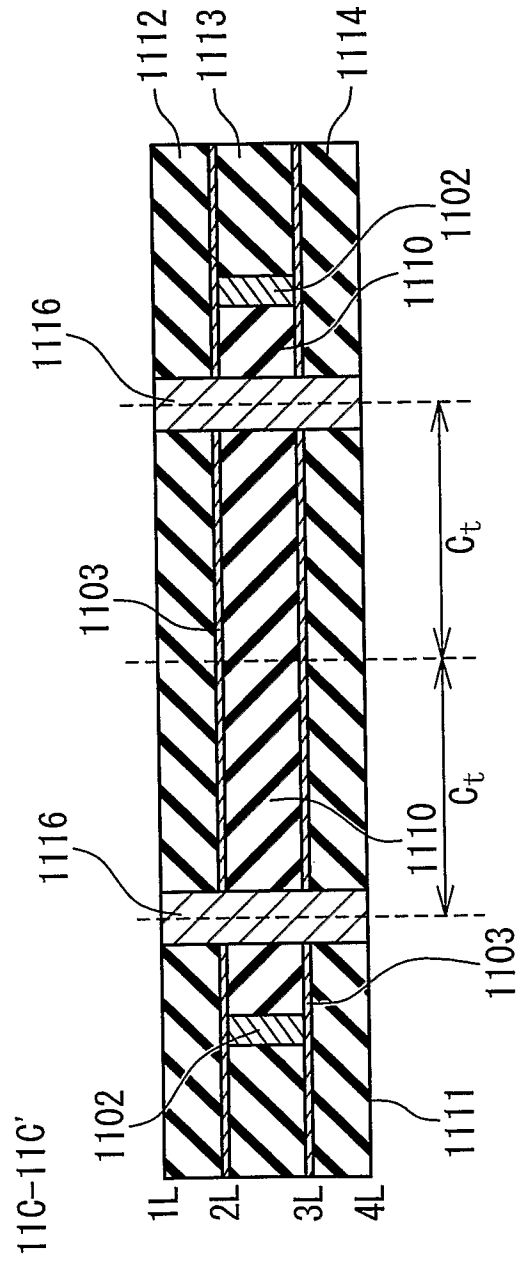
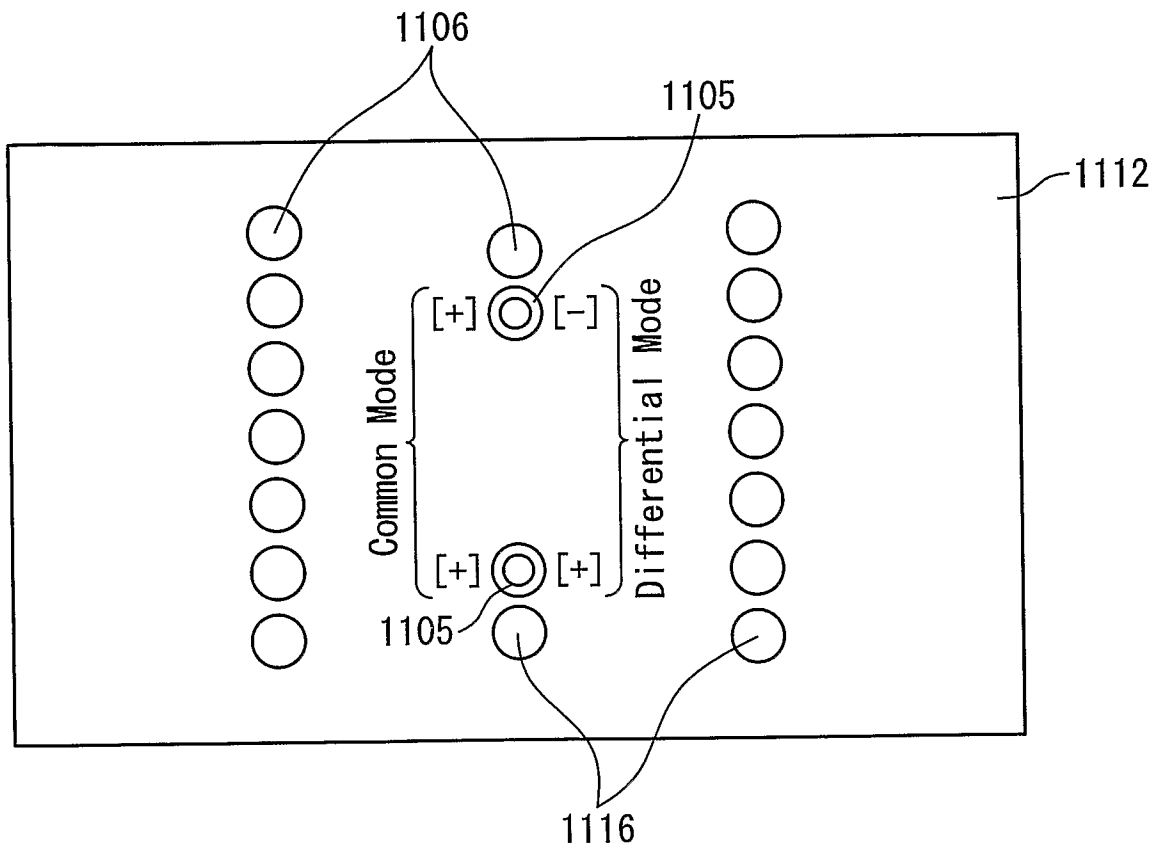


Fig. 11D



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Fig. 12

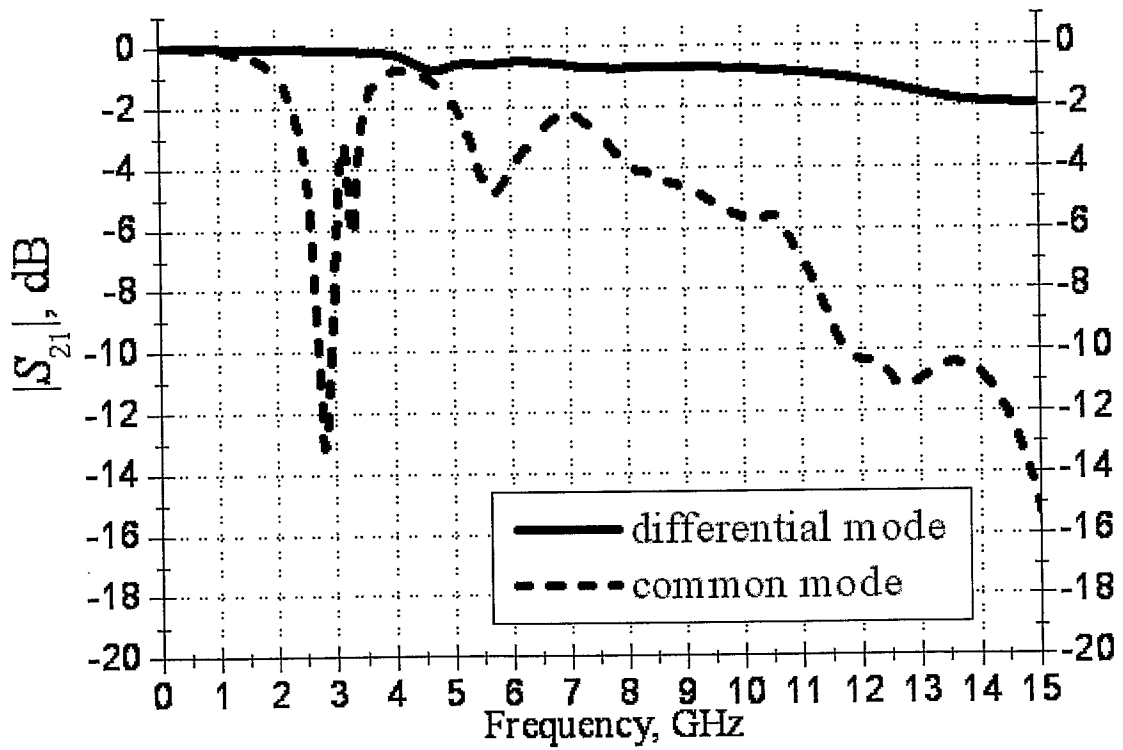


Fig. 13A

13A-13A'

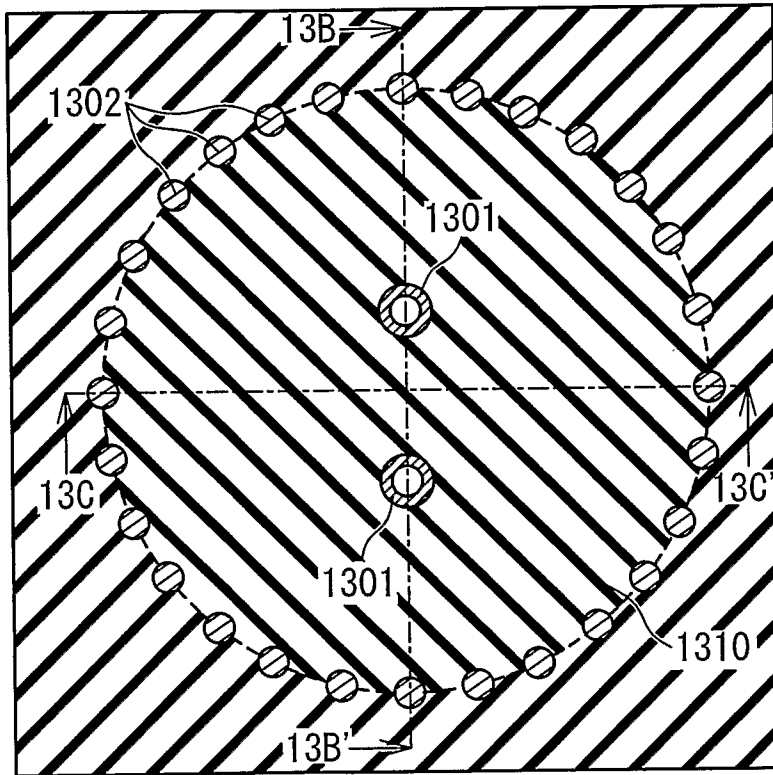


Fig. 13B

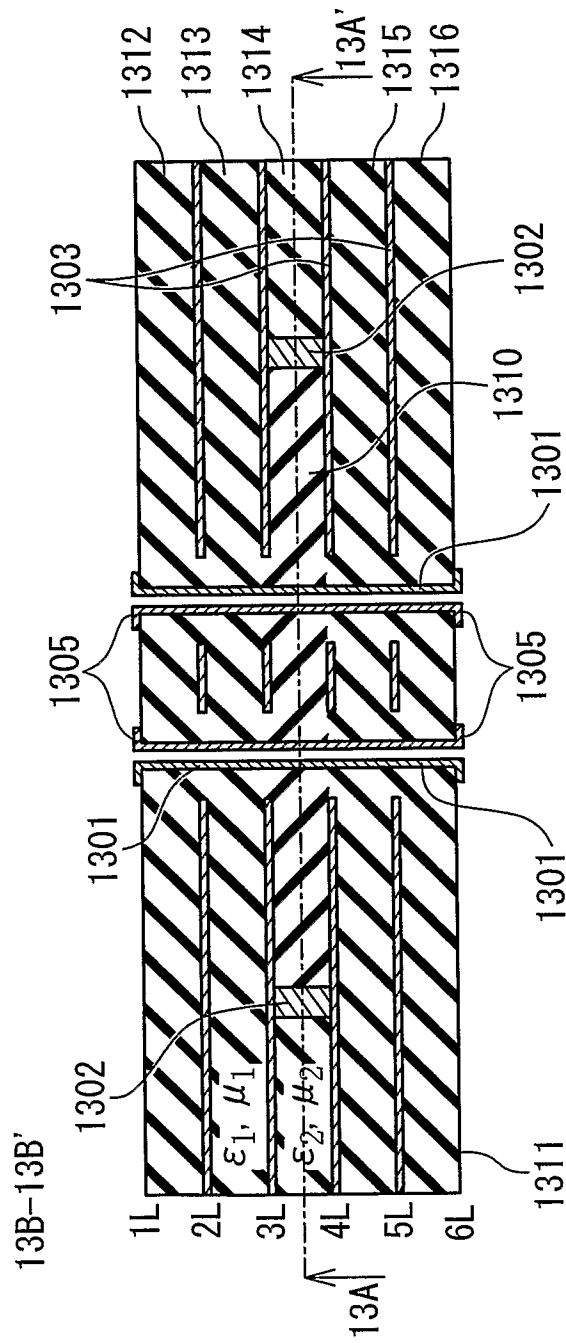


Fig. 13C

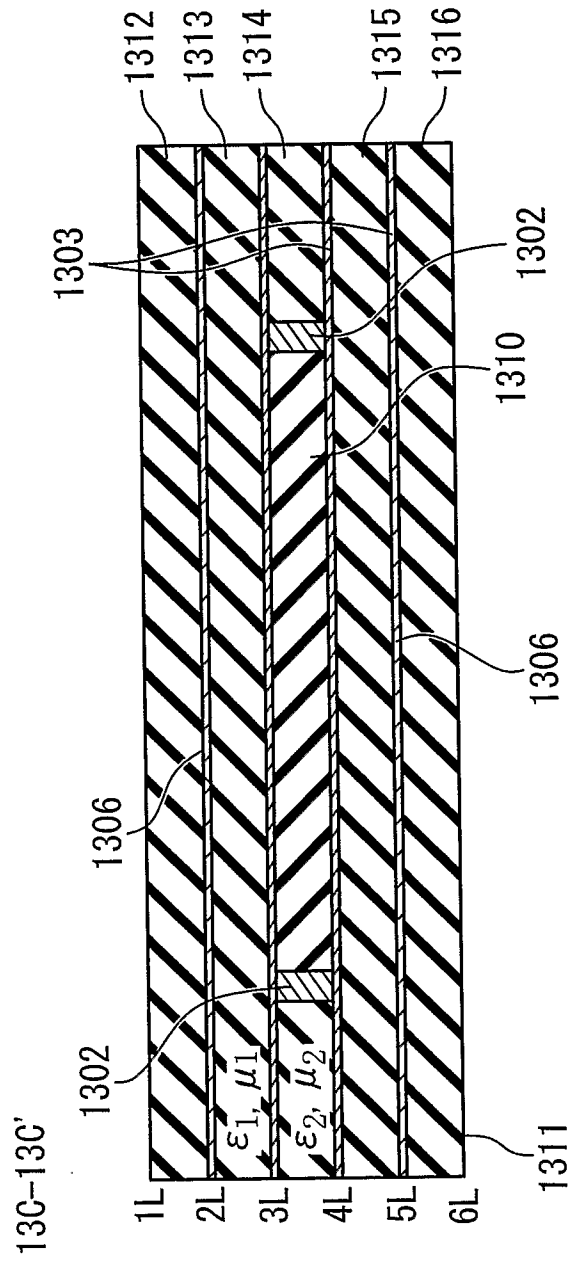
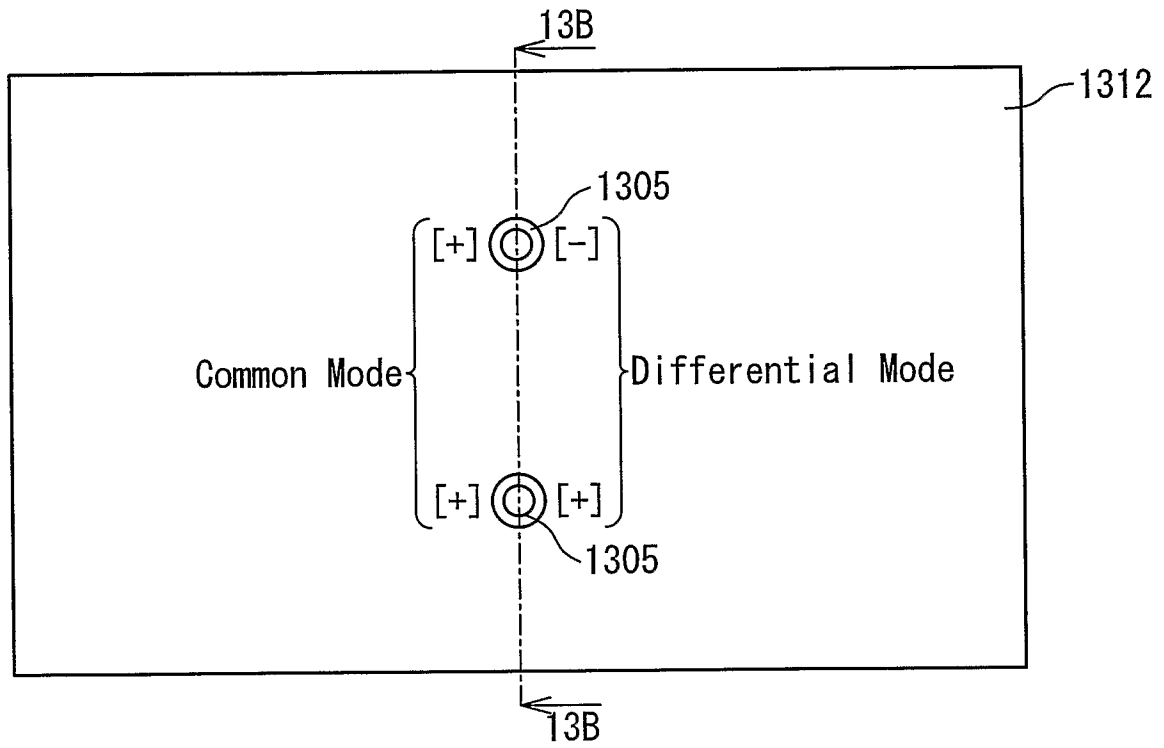


Fig. 13D



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2007/075358

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>		
Int.Cl. H01P1/20(2006.01)i, H01P1/207(2006.01)i, H01P7/06(2006.01)i, H01P7/10(2006.01)i		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols)		
Int.Cl. H01P1/20, H01P1/207, H01P7/06, H01P7/10		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Published examined utility model applications of Japan 1922-1996 Published unexamined utility model applications of Japan 1971-2008 Registered utility model specifications of Japan 1996-2008 Published registered utility model applications of Japan 1994-2008		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007/046271 A1 (NEC Corporation) 2007.04.26, [0132]-[0144], Figs.15A-17 (No Family)	1, 8-15, 25
Y		2-7, 16-24, 26-30
Y	JP 10-303618 A (Kyocera Corporation) 1998.11.13, [0026]-[0030], Fig.8 (No Family)	2-5
Y	JP 9-246821 A (Murata Manufacturing Co., Ltd.) 1997.09.19, [0013], Fig.6 (No Family)	6
Y	JP 2003-37022 A (Soshin Electric CO., LTD.) 2003.02.07, Full text; all drawings (No Family)	7
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> 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
14.03.2008		25.03.2008
Name and mailing address of the ISA/JP		Authorized officer
<b>Japan Patent Office</b>		FUJII, Hiroshi
3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan		5T 3663
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## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/JP2007/075358

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2003-78312 A (Murata Manufacturing Co., Ltd.) 2003.03.14, [0022]-[0023], Fig.5 & US 006020800 A1	16, 21-24, 26, 27
Y	JP 11-88007 A (Alps Electric CO., LTD) 1999.03.30, [0026] & DE 019842218 A	17-19, 28-30
Y	JP 62-92601 A (ANT Nachrichtentechnik GmbH) 1987.04.28, Full text; all drawings & US 004731593 A1 & EP 000218807 A2	20