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(54) RADIO-FREQUENCY MODULE AND COMMUNICATION DEVICE

(71) Applicant: **Murata Manufacturing Co., Ltd.**, Kyoto (JP)

(72) Inventors: **Yukiya Yamaguchi**, Kyoto (JP); **Shogo Yanase**, Kyoto (JP); **Yuto Aoki**, Kyoto (JP); **Takanori Uejima**, Kyoto (JP)

(73) Assignee: **MURATA MANUFACTURING CO., LTD.**, Kyoto (JP)

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H03H 9/145 (2006.01)
(Continued)

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CPC ***H04B 1/0053*** (2013.01); ***H03H 9/145*** (2013.01); ***H03H 9/25*** (2013.01); ***H03H 9/64*** (2013.01)

(58) **Field of Classification Search**
CPC H04B 1/0053; H04B 1/006; H04B 1/00; H04B 1/38; H03H 9/145; H03H 9/25; H03H 9/64; H03H 9/02102; H03H 9/02834; H03H 9/0542; H03H 9/0552; H03H 9/17; H03H 9/54; H01L 25/04; H01L 25/18
See application file for complete search history.

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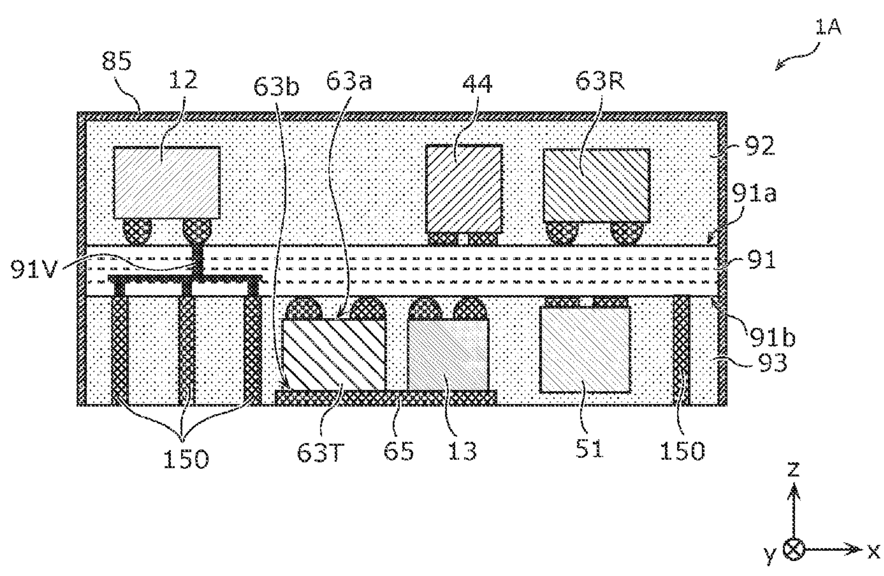
Primary Examiner — Davetta W Goins
(74) *Attorney, Agent, or Firm* — McDonald Hopkins LLC

(57) **ABSTRACT**

A radio-frequency module includes a module substrate having main surfaces facing each other, a transmission filter that has a bottom surface and a top surface facing each other and passes a radio-frequency signal, and an external connection terminal disposed on the main surface. The bottom surface faces the main surface and is disposed closer to the main surface than the top surface. The radio-frequency module further includes a metal electrode joined to the top surface.

19 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

H03H 9/25	(2006.01)
H03H 9/54	(2006.01)
H03H 9/64	(2006.01)
H04B 1/00	(2006.01)

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FIG. 1

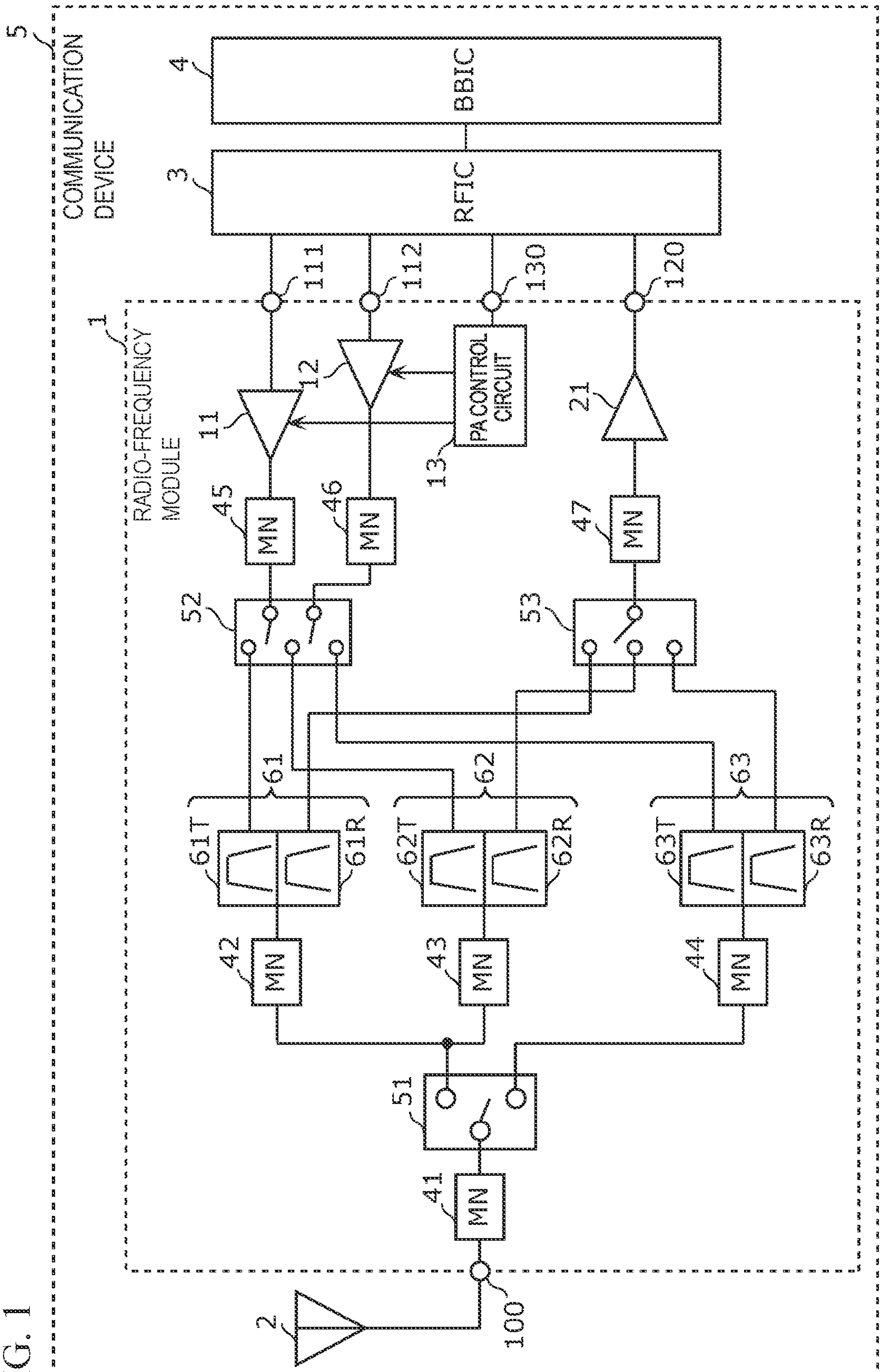

5
COMMUNICATION DEVICE
4
BBIC
3
RFIC
111
112
130
120
1
RADIO-FREQUENCY MODULE
PA CONTROL CIRCUIT
11
12
13
21
45
46
47
MN
52
53
61
62
63
61T
61R
62T
62R
63T
63R
42
43
44
51
41
2
100

FIG. 2AA

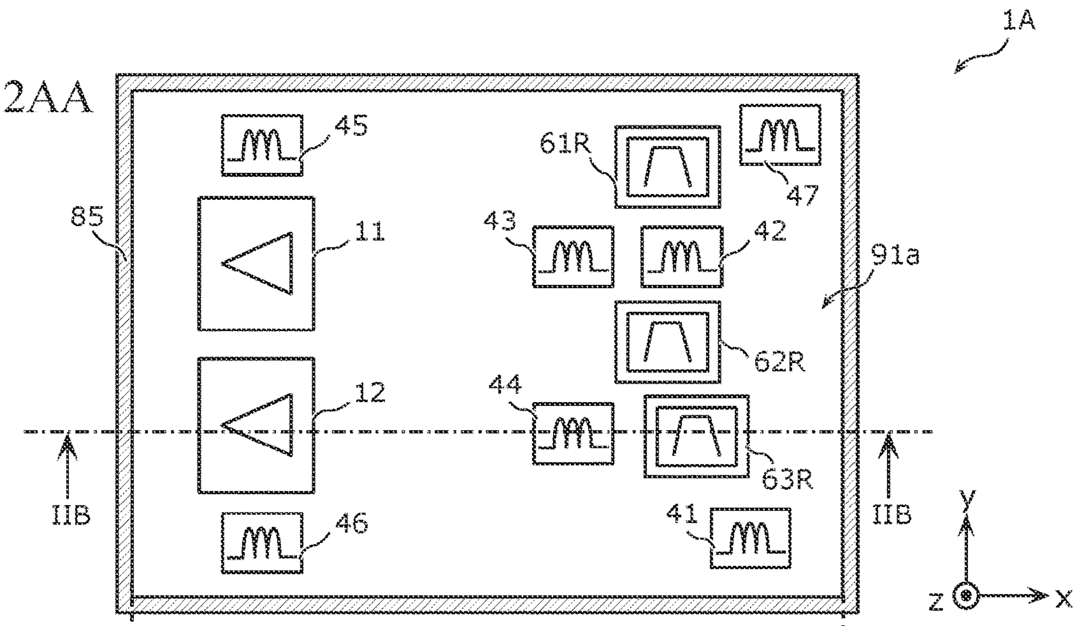


FIG. 2AB

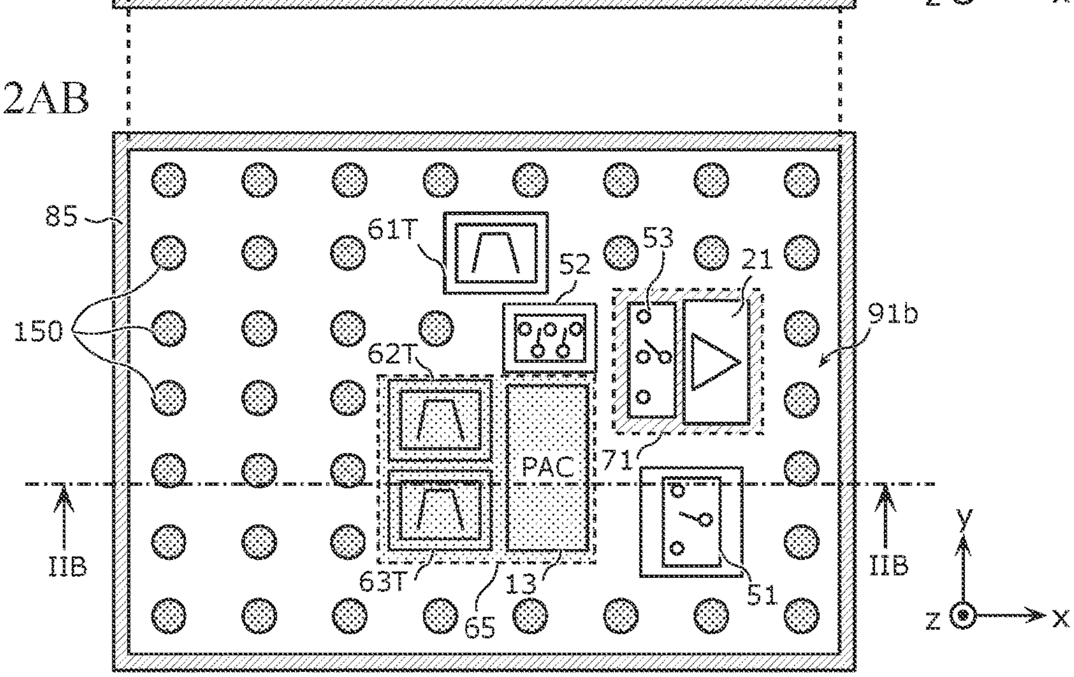
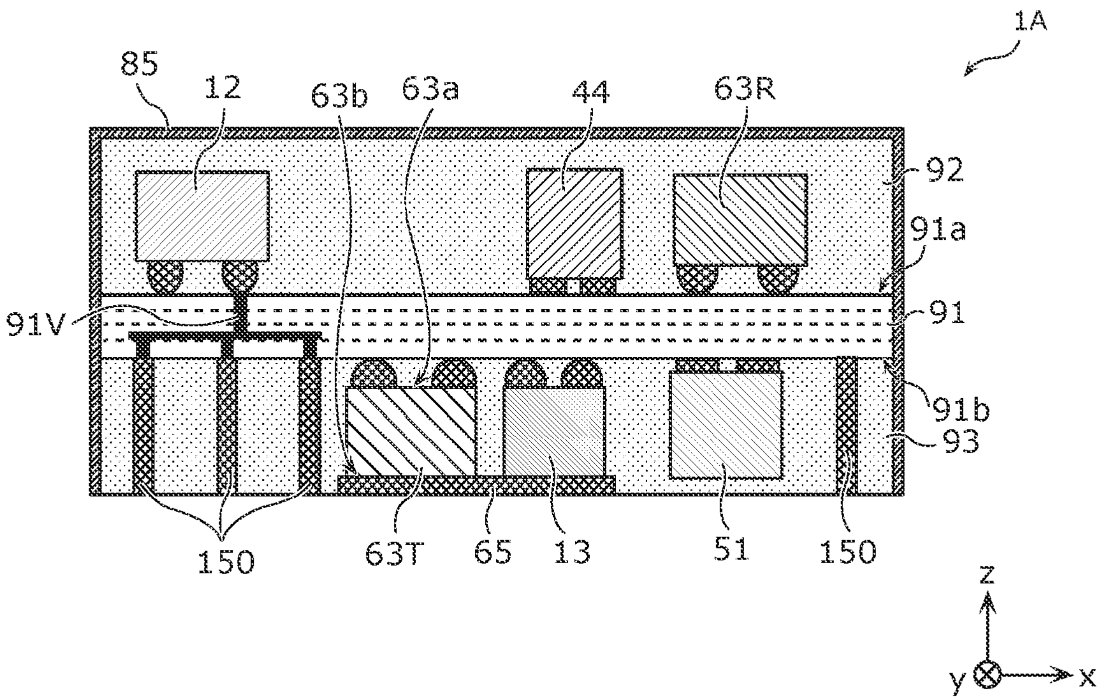


FIG. 2B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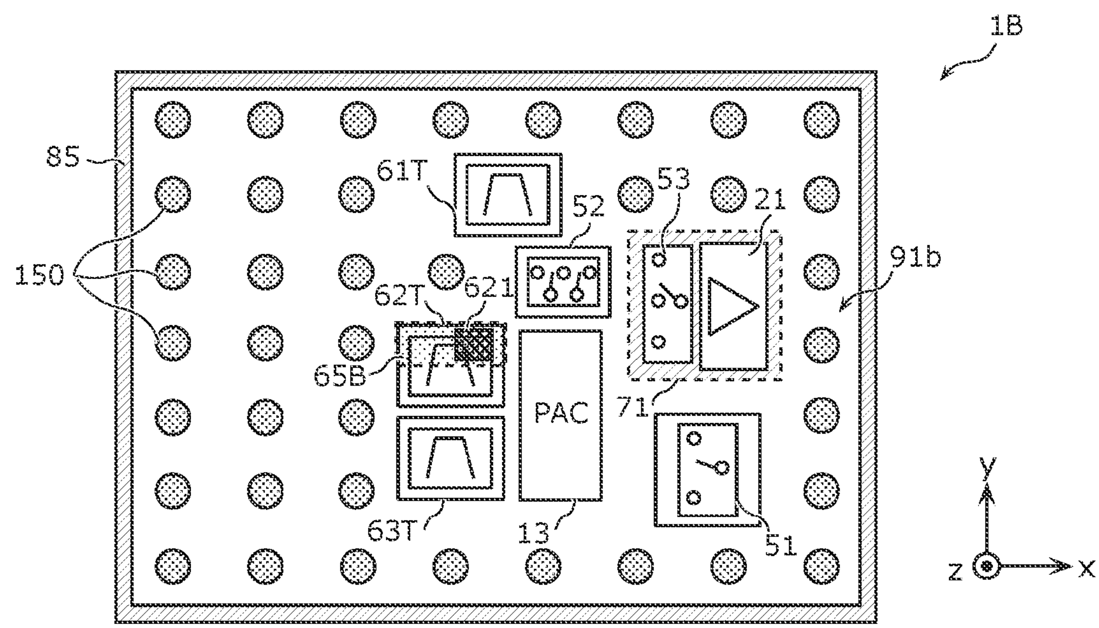
12
63b
63a
44
63R
92
91a
91V
91
91b
93
150
63T
65
13
51
150
z
y
x

FIG. 2C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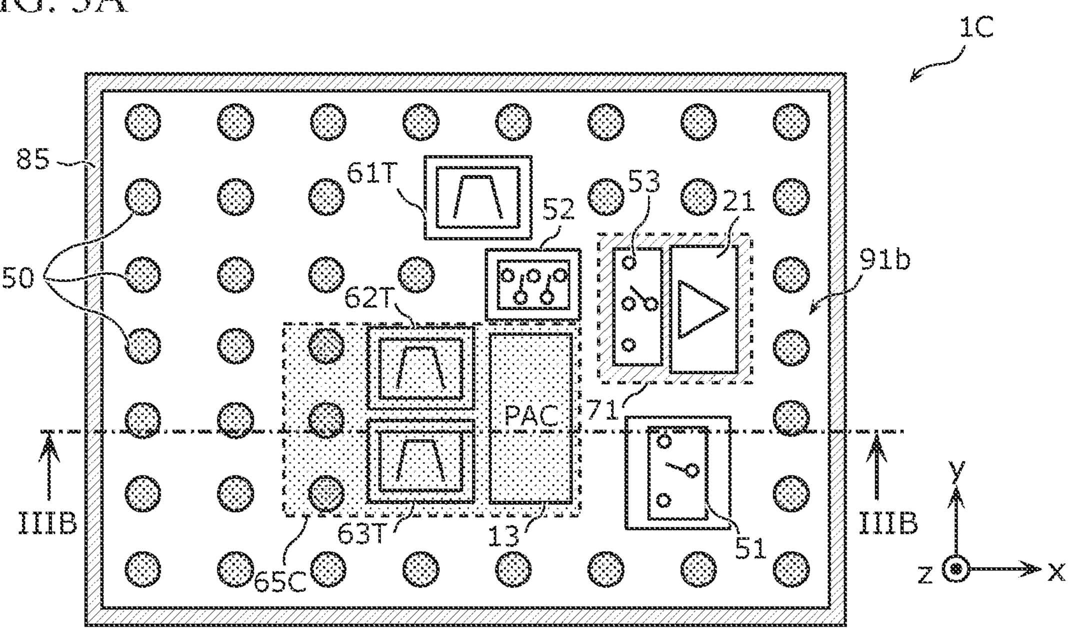
z
x

FIG. 3A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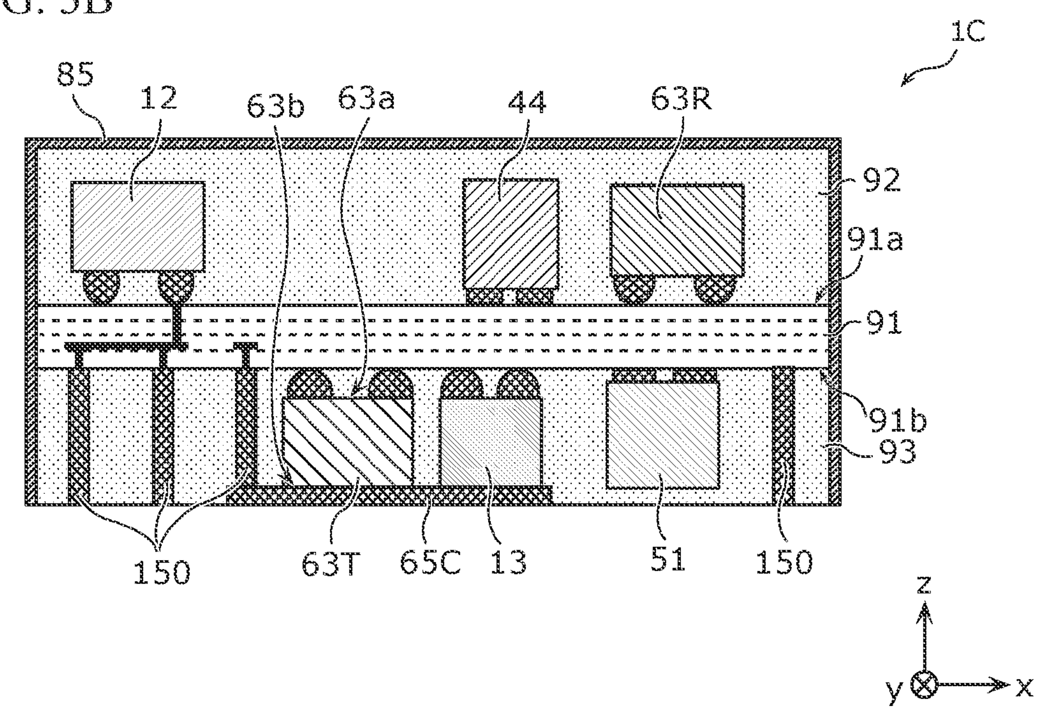
62T
PAC
71
IIIB
IIIB
63T
13
51
65C
y
z
x

FIG. 3B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63b
63a
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91a
91
91b
93
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63T
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13
51
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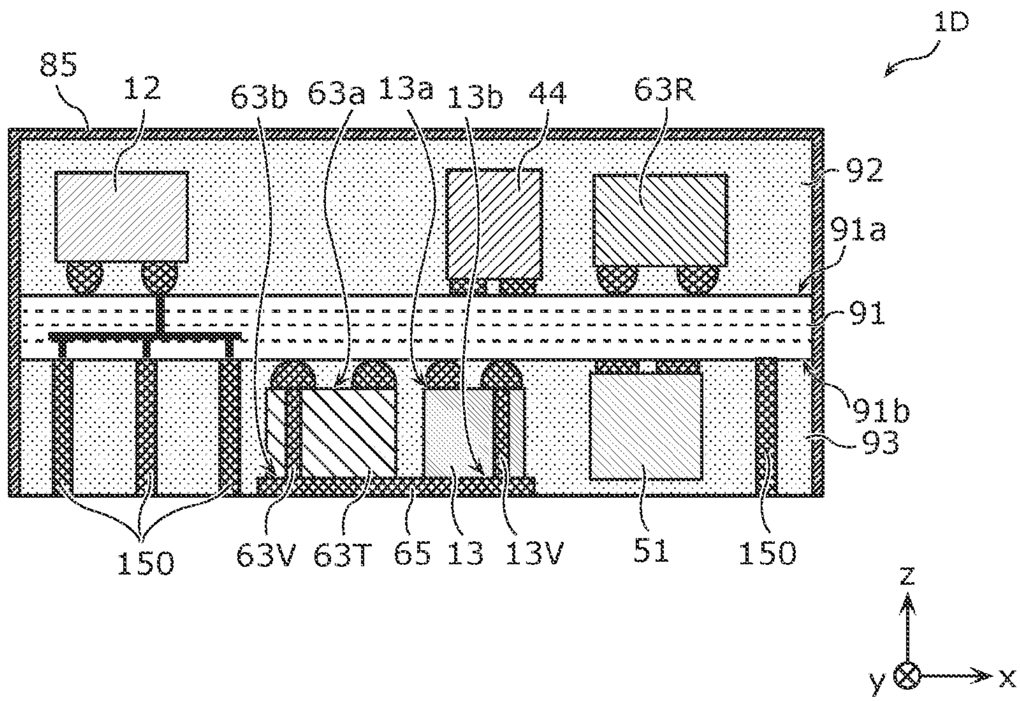
z
y
x

FIG. 3C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13b
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91b
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63V
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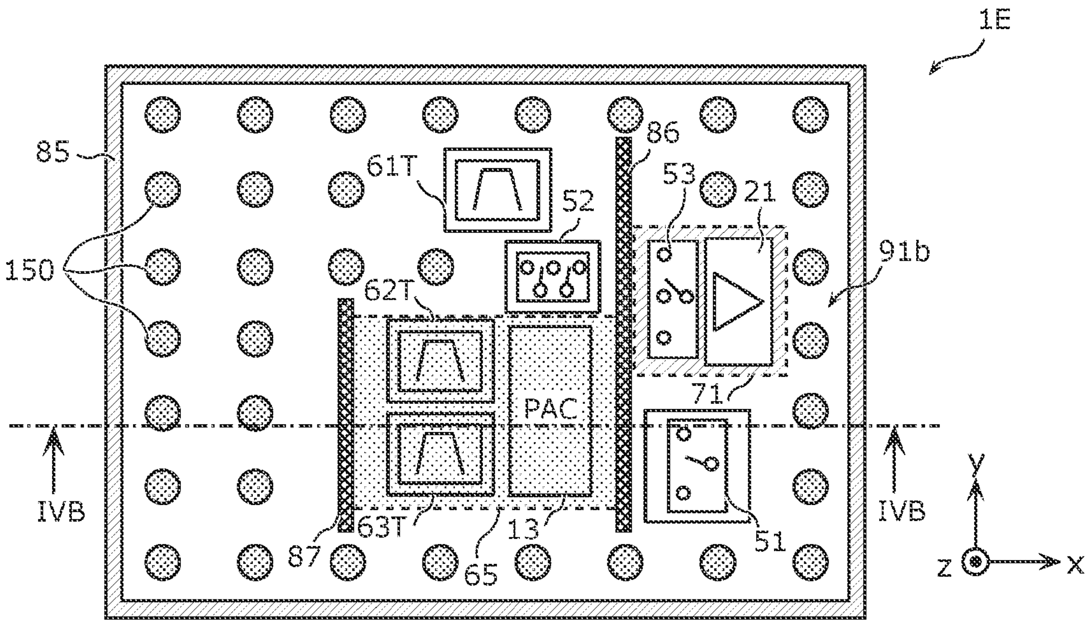
13
13V
51
150
z
y
x

FIG. 4A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61T
53
21
52
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91b
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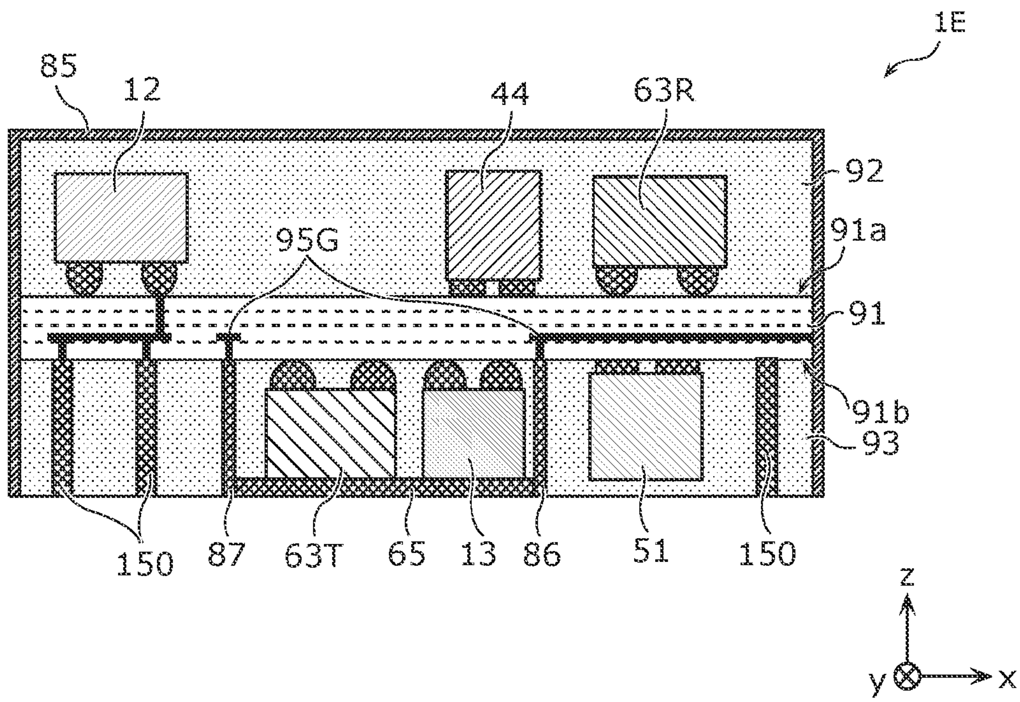
PAC
71
IVB
IVB
y
63T
13
51
87
65
z
x

FIG. 4B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44
63R
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91a
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91b
93
150
87
63T
65
13
86
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150
z
y
x

FIG. 5A

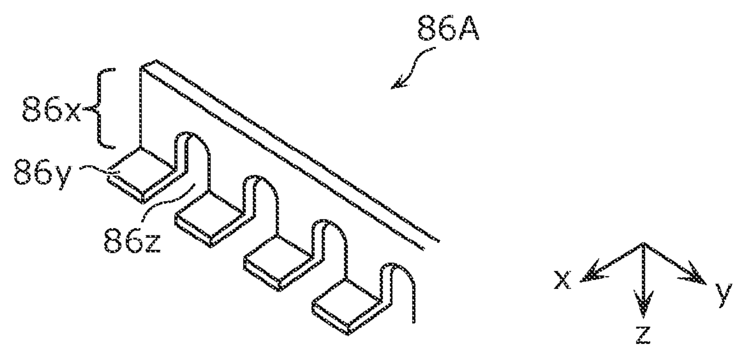


FIG. 5B

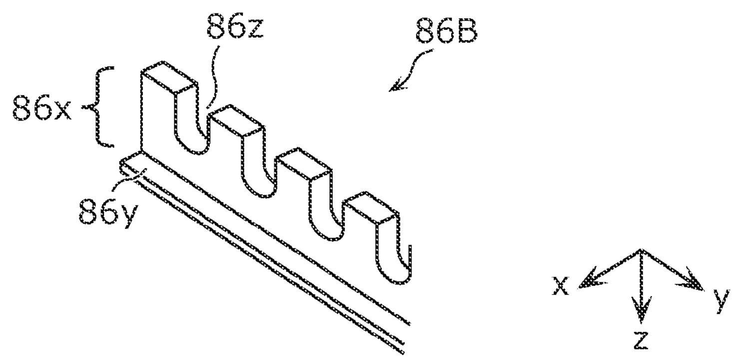


FIG. 5C

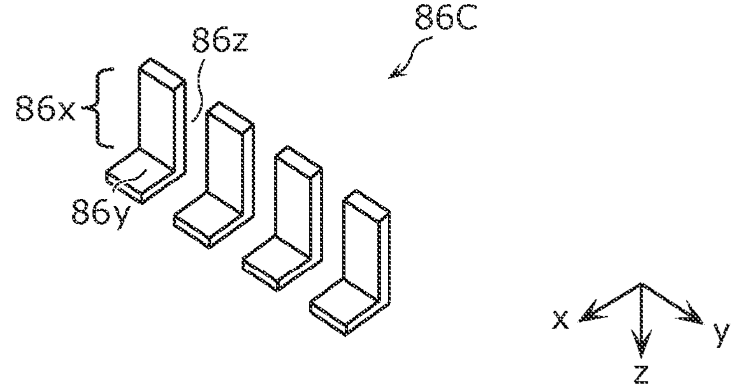


FIG. 6

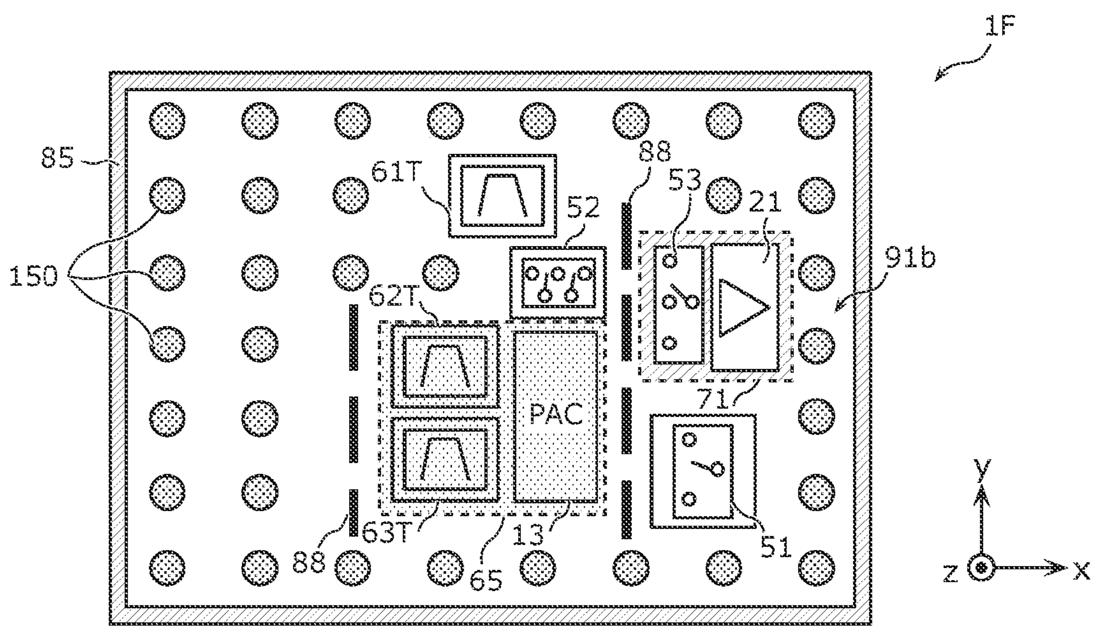
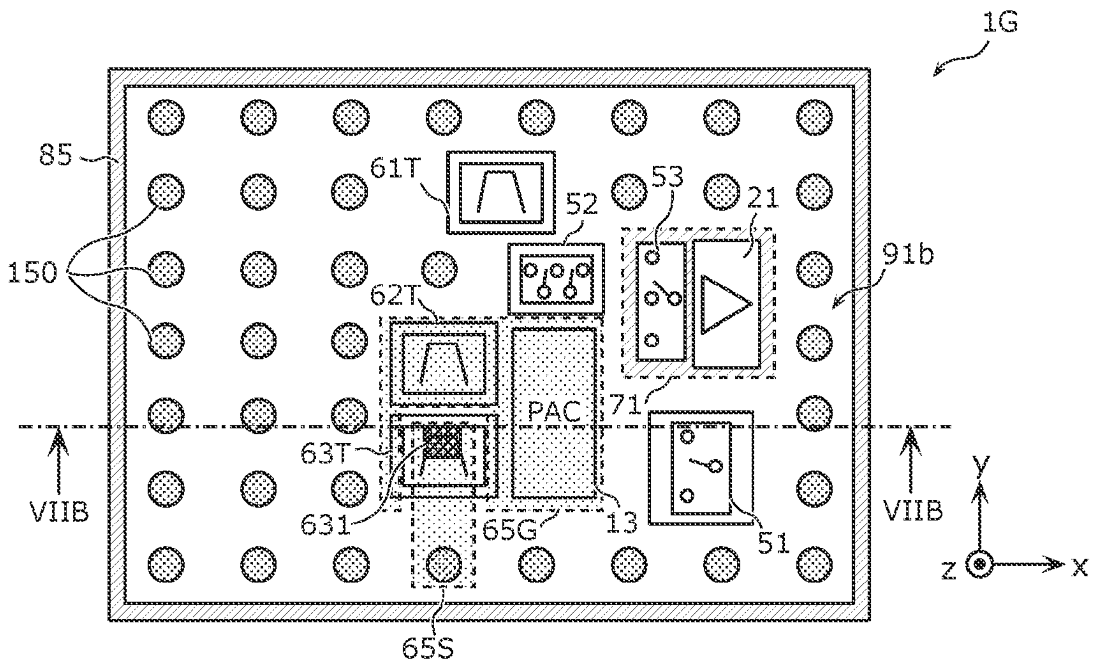


FIG. 7A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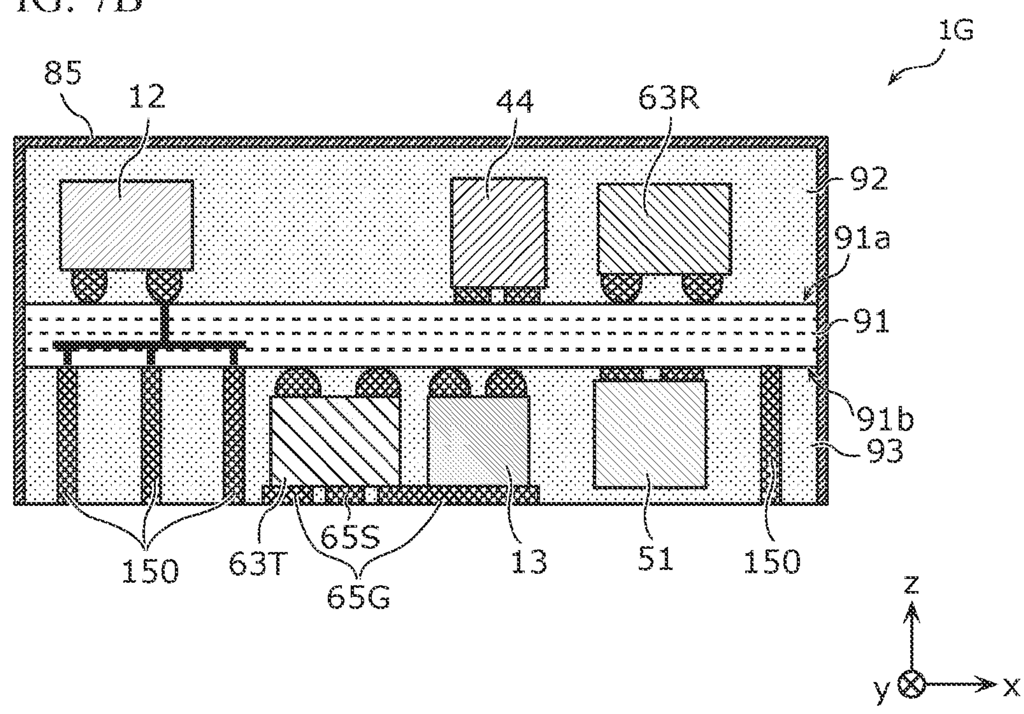
61T
52
53
21
91b
62T
PAC
71
63T
631
65G
13
51
VIIB
VIIB
65S
y
z
x

FIG. 7B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12
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63R
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91
91b
93
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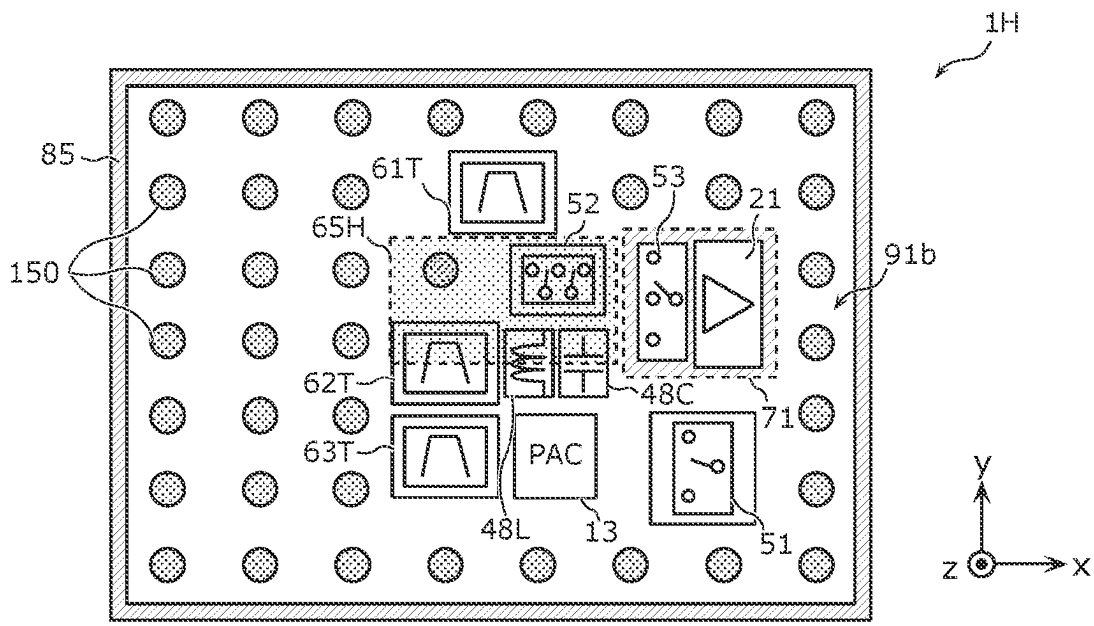
63T
65S
65G
13
51
150
z
y
x

FIG. 8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61T
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21
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62T
63T
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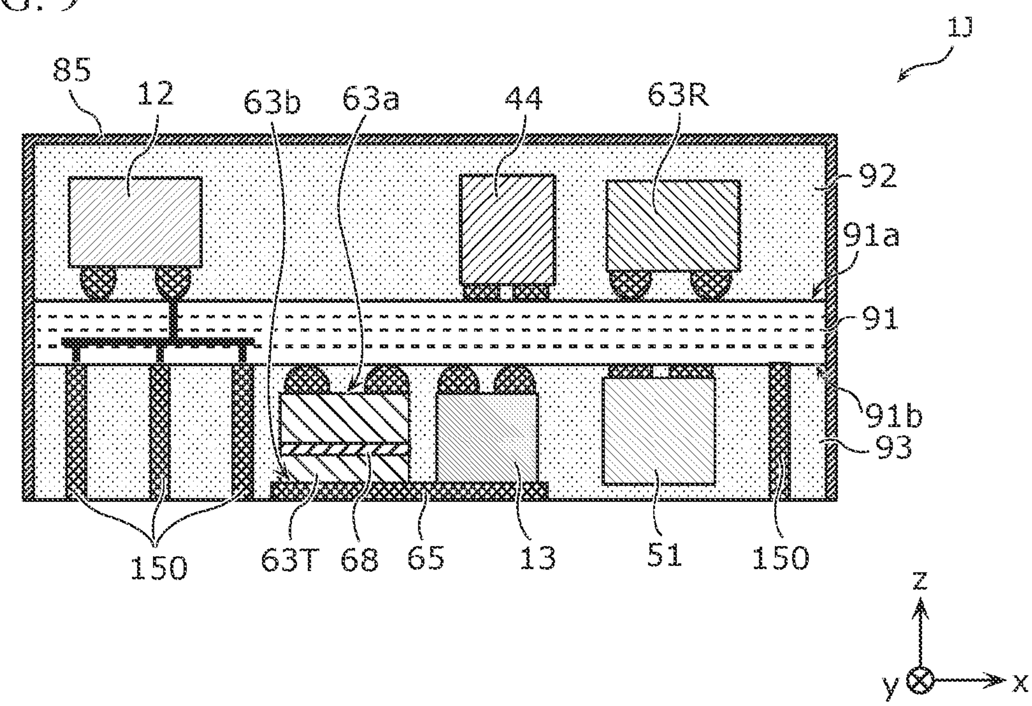
71
48L
13
51
y
z
x

FIG. 9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63b
63a
44
63R
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91a
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91b
93
150
63T
68
65
13
51
150
z
y
x

FIG. 10A

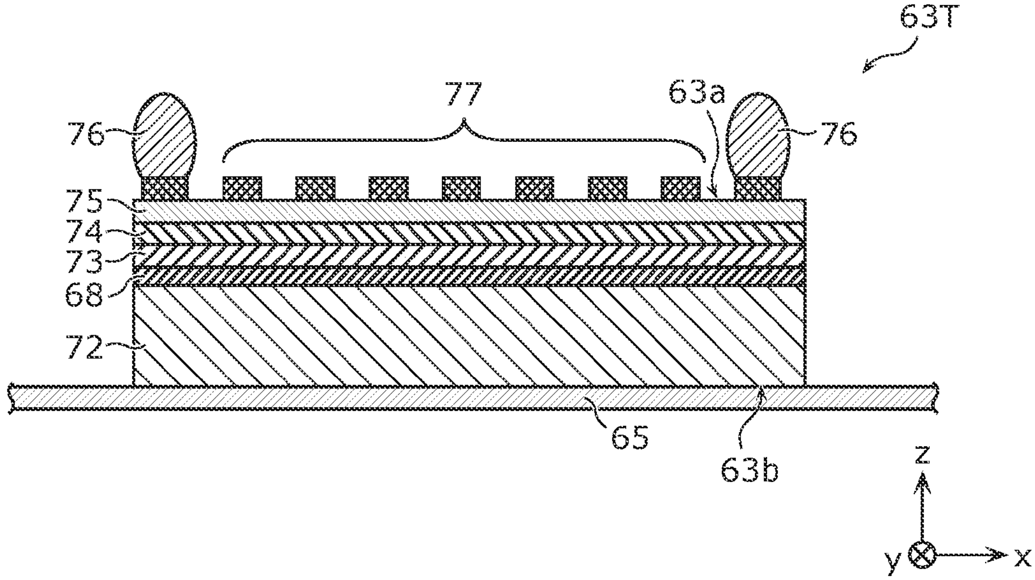


FIG. 10B

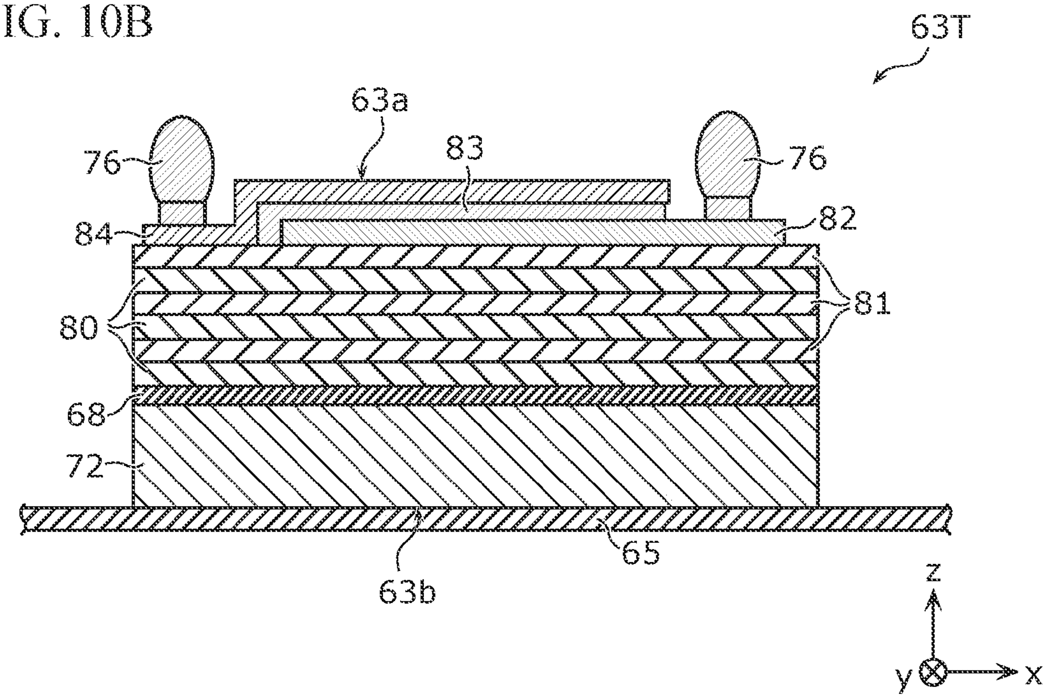
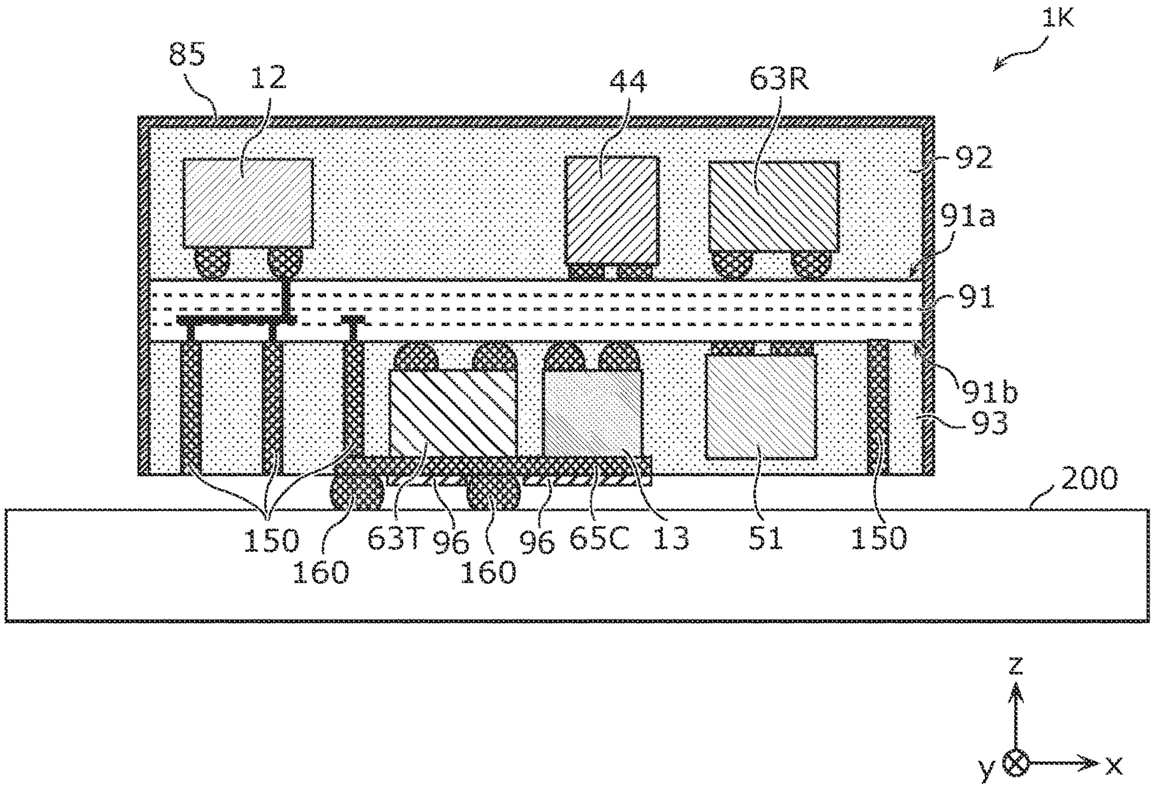


FIG. 11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12
44
63R
92
91a
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91b
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160
63T
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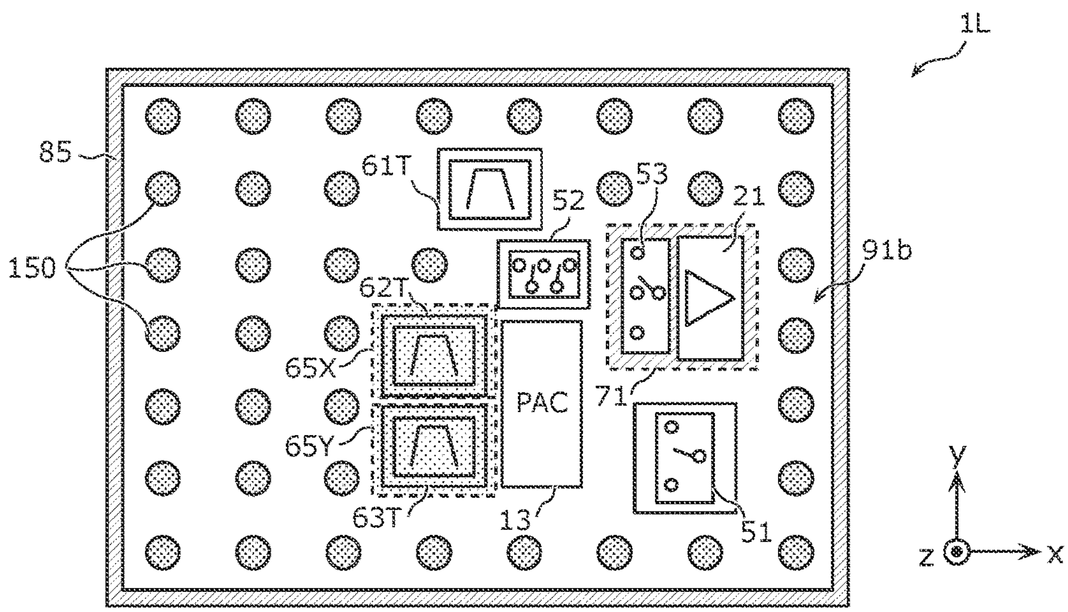
160
96
65C
13
51
150
z
y
x

FIG. 12


1L
85
61T
52
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21
150
62T
91b
65X
PAC
71
65Y
63T
13
51
y
z
x

RADIO-FREQUENCY MODULE AND COMMUNICATION DEVICE

CROSS REFERENCE TO RELATED APPLICATION

This is a continuation of International Application No. PCT/JP2021/042038 filed on Nov. 16, 2021 which claims priority from Japanese Patent Application No. 2020-215246 filed on Dec. 24, 2020. The contents of these applications are incorporated herein by reference in their entireties.

BACKGROUND ART

Technical Field

The present disclosure relates to a radio-frequency module and a communication device.

In mobile communication devices, such as mobile phones, in particular, the layout and configuration of circuit elements constituting a radio-frequency front-end circuit becomes complicated as multiband support progresses.

Patent Document 1 discloses a radio-frequency module including a mounting substrate with both surfaces where circuit components can be mounted, and, of main surfaces facing each other of the mounting substrate, an acoustic wave filter disposed on or above a main surface where an external connection terminal is disposed.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 2020-102693

BRIEF SUMMARY

In the radio-frequency module disclosed in Patent Document 1, however, heat of the acoustic wave filter disposed on or above the main surface where the external connection terminal is disposed is dissipated, mainly, through a terminal connected to the mounting substrate, and heat dissipation is therefore insufficient. As a result, in some cases, filter characteristics deteriorate due to a frequency shift due to changes in temperature in the acoustic wave filter.

The present disclosure has been made to solve the above-described issue and aims to provide a radio-frequency module and a communication device in which heat dissipation of an acoustic wave filter is improved.

A radio-frequency module according to an aspect of the present disclosure includes a module substrate having a first main surface and a second main surface facing each other, a first acoustic wave filter that has a first bottom surface and a first top surface facing each other and passes a radio-frequency signal, and an external connection terminal disposed on the second main surface. The first bottom surface faces the second main surface and is disposed closer to the second main surface than the first top surface. The radio-frequency module further includes a first metal electrode joined to the first top surface.

The present disclosure can provide the radio-frequency module and a communication device in which heat dissipation of the acoustic wave filter is improved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a circuit configuration diagram of a radio-frequency module and a communication device according to an embodiment.

FIGS. **2**AA and **2**AB include plan views of a radio-frequency module according to Example 1.

FIG. **2**B is a cross-sectional view of the radio-frequency module according to Example 1.

FIG. **2**C is a plan view of a radio-frequency module according to Modification 1.

FIG. **3**A is a plan view of a radio-frequency module according to Example 2.

FIG. **3**B is a cross-sectional view of the radio-frequency module according to Example 2.

FIG. **3**C is a cross-sectional view of a radio-frequency module according to Modification 2.

FIG. **4**A is a plan view of a radio-frequency module according to Example 3.

FIG. **4**B is a cross-sectional view of the radio-frequency module according to Example 3.

FIG. **5**A is an external perspective view illustrating a first example of a metal shield plate.

FIG. **5**B is an external perspective view illustrating a second example of the metal shield plate.

FIG. **5**C is an external perspective view illustrating a third example of the metal shield plate.

FIG. **6** is a plan view of a radio-frequency module according to Modification 3.

FIG. **7**A is a plan view of a radio-frequency module according to Example 4.

FIG. **7**B is a cross-sectional view of the radio-frequency module according to Example 4.

FIG. **8** is a plan view of a radio-frequency module according to Example 5.

FIG. **9** is a cross-sectional view of a radio-frequency module according to Example 6.

FIG. **10**A is a cross-sectional view illustrating a configuration of a first example of a transmission filter according to Example 6.

FIG. **10**B is a cross-sectional view illustrating a configuration of a second example of the transmission filter according to Example 6.

FIG. **11** is a cross-sectional view of a radio-frequency module according to Example 7.

FIG. **12** is a plan view of a radio-frequency module according to Example 8.

DETAILED DESCRIPTION

Embodiments of the present disclosure will be described in detail below. Incidentally, all of the embodiments described below describe comprehensive or specific examples. Numerical values, shapes, materials, components, the arrangement and connection configuration of the components, and so forth that are described in the following embodiments are merely examples and are not intended to limit the present disclosure. Of components in the following examples and modifications, a component not described in an independent claim is described as an optional component. Furthermore, the sizes or size ratio of components illustrated in drawings are or is not necessarily exact. In figures, components that are substantially the same are denoted by the same reference signs, and a repeated description thereof is omitted or simplified in some cases.

Furthermore, in the following description, terms, such as parallel and perpendicular, representing a relationship between elements, a term, such as rectangular, representing the shape of an element, and a numerical range refer to not only their exact meanings but also the inclusion of a substantially equivalent range, for example, a difference of about a few percent.

Furthermore, in the following embodiments, “A is disposed on a first main surface of a substrate” refers to not only the fact that A is mounted directly on the first main surface but also the fact that, of a first main surface-side space and a second main surface-side space that are separated by the substrate, A is disposed in the first main surface-side space. That is, there is included the fact that A is mounted on the first main surface with another circuit element, an electrode, or the like interposed between A and the first main surface.

Furthermore, in the following embodiments, "A and B are connected to each other" does not only refer to the fact that A and B are in contact with each other but also defines the inclusion of the fact that A and B are electrically connected to each other via a conductor electrode, a conductor terminal, a line, another circuit component, or the like. Additionally, "something is connected between A and B" refers to the fact that something is connected to both A and B between A and B.

Furthermore, in the following embodiments, "A and B are joined to each other" refers to the fact that A and B are mechanically (physically) bonded together, and defines, in particular, the inclusion of the fact that one surface that A has and one surface that B has are bonded together.

In the following figures, an x axis and a y axis are axes orthogonal to each other on a plane parallel to a main surface of a module substrate. Furthermore, a z axis is an axis perpendicular to the main surface of the module substrate, a positive direction thereof represents an upward direction, and a negative direction thereof represents a downward direction.

Furthermore, in a module configuration in the present disclosure, "an object is viewed in plan" refers to the fact that the object is orthographically projected from a positive side of the z axis onto an x-y plane and is viewed. "A component is disposed on a main surface of a substrate" includes, in addition to the fact that the component is disposed on the main surface of the substrate with the component being in contact with the main surface, the fact that the component is disposed above the main surface without necessarily the component being in contact with the main surface, and the fact that part of the component is disposed so as to be embedded in the substrate from a main surface side.

Furthermore, in the following description, with respect to A, B, and C mounted in or on a substrate, "when the substrate (or a main surface of the substrate) is viewed in plan, C is disposed between A and B" refers to the fact that, when the substrate is viewed in plan, at least one of a plurality of line segments connecting points within a region of A with points within a region of B passes through a region of C. Furthermore, a description that the substrate is viewed in plan refers to the fact that the substrate and circuit elements mounted in or on the substrate are orthographically projected onto a plane parallel to the main surface of the substrate and are viewed.

Furthermore, in the following description, "transmission path" refers to a transmission line constituted by a line through which a radio-frequency transmission signal propagates, an electrode connected directly to the line, a terminal connected directly to the line or the electrode, and so forth. Additionally, "reception path" refers to a transmission line constituted by a line through which a radio-frequency reception signal propagates, an electrode connected directly to the line, a terminal connected directly to the line or the electrode, and so forth.

EMBODIMENT

1. Circuit Configuration of Radio-Frequency Module 1 and Communication Device 5

FIG. **1** is a circuit configuration diagram of a radio-frequency module **1** and a communication device **5** according to an embodiment. As illustrated in FIG. **1**, the communication device **5** includes the radio-frequency module **1**, an antenna **2**, an RF signal processing circuit (RFIC) **3**, and a baseband signal processing circuit (BBIC) **4**.

The RFIC **3** is an RF signal processing circuit that processes radio-frequency signals transmitted and received by the antenna **2**. Specifically, the RFIC **3** performs, for example, through down-conversion, signal processing on a radio-frequency reception signal input through a reception signal path of the radio-frequency module **1** and outputs a reception signal generated through this signal processing to the BBIC **4**. Furthermore, the RFIC **3** performs, for example, through up-conversion, signal processing on a transmission signal input from the BBIC **4** and outputs a radio-frequency transmission signal generated through this signal processing to a transmission signal path of the radio-frequency module **1**.

The BBIC **4** is a circuit that performs signal processing by using an intermediate frequency band lower in frequency than a radio-frequency signal that propagates through the radio-frequency module **1**. A signal processed by the BBIC **4** is used, for example, as an image signal for displaying an image, or is used as a voice signal for a phone call through a speaker.

Furthermore, the RFIC **3** also has a function of a control unit that controls, in accordance with a communication band (frequency band) that is used, connections of switches **51**, **52**, and **53** included in the radio-frequency module **1**. Specifically, the RFIC **3** switches between connections of the switches **51** to **53** included in the radio-frequency module **1** in accordance with a control signal (not illustrated). Specifically, the RFIC **3** outputs, to a PA control circuit **13**, a digital control signal for controlling the switches **51** to **53**. The PA control circuit **13** of the radio-frequency module **1** outputs, in accordance with the digital control signal input from the RFIC **3**, a digital control signal to the switches **51** to **53** to thereby control connection and disconnection of each of the switches **51** to **53**.

Furthermore, the RFIC **3** also has a function of the control unit that controls gains of power amplifiers **11** and **12** included in the radio-frequency module **1**, and a power-supply voltage Vcc and a bias voltage Vbias that are to be supplied to the power amplifiers **11** and **12**. Specifically, the RFIC **3** outputs a digital control signal to a control signal terminal **130** of the radio-frequency module **1**. The PA control circuit **13** outputs, in accordance with the digital control signal input through the control signal terminal **130**, a control signal, a power-supply voltage Vcc, or a bias voltage Vbias to the power amplifiers **11** and **12** to adjust the gains of the power amplifiers **11** and **12**. Incidentally, the control unit may be provided outside the RFIC **3**. The control unit may be provided, for example, in the BBIC **4**.

The antenna **2** is connected to an antenna connection terminal **100** of the radio-frequency module **1** and radiates a radio-frequency signal output from the radio-frequency module **1**. Furthermore, the antenna **2** receives a radio-frequency signal from the outside and outputs the radio-frequency signal to the radio-frequency module **1**.

Incidentally, in the communication device **5** according to the present embodiment, the antenna **2** and the BBIC **4** are not indispensable components.

Next, a detailed configuration of the radio-frequency module **1** will be described.

As illustrated in FIG. **1**, the radio-frequency module **1** includes the power amplifiers **11** and **12**, a low noise amplifier **21**, the PA control circuit **13**, transmission filters **61**T, **62**T, and **63**T, reception filters **61**R, **62**R, and **63**R, matching networks **41**, **42**, **43**, **44**, **45**, **46**, and **47**, the switches **51**, **52**, and **53**, the antenna connection terminal **100**, transmission input terminals **111** and **112**, a reception output terminal **120**, and the control signal terminal **130**.

The antenna connection terminal **100** is connected to the antenna **2**. The transmission input terminals **111** and **112** are terminals for receiving a transmission signal from the outside of the radio-frequency module **1** (from the RFIC **3**). The reception output terminal **120** is a terminal for supplying a reception signal to the outside of the radio-frequency module **1** (to the RFIC **3**).

The power amplifier **11** is a transmission amplifier that can amplify at least one of transmission signals in a first band, a second band, and a third band. An input terminal of the power amplifier **11** is connected to the transmission input terminal **111**, and an output terminal of the power amplifier **11** is connected to the switch **52** via the matching network **45**.

The power amplifier **12** is a transmission amplifier that can amplify at least one of transmission signals in the first band, the second band, and the third band. An input terminal of the power amplifier **12** is connected to the transmission input terminal **112**, and an output terminal of the power amplifier **12** is connected to the switch **52** via the matching network **46**.

The low noise amplifier **21** is a reception amplifier that can amplify reception signals in the first band, the second band, and the third band with low noise. An input terminal of the low noise amplifier **21** is connected to the switch **53** via the matching network **47**, and an output terminal of the low noise amplifier **21** is connected to the reception output terminal **120**.

The PA control circuit **13** adjusts the gains of the power amplifiers **11** and **12**, for example, in accordance with a digital control signal input through the control signal terminal **130**. Incidentally, the PA control circuit **13** may be formed by a semiconductor IC (Integrated Circuit). The semiconductor IC is constructed, for example, by CMOS (Complementary Metal Oxide Semiconductor). Specifically, the semiconductor IC is formed by a SOI (Silicon On Insulator) process. Thus, semiconductor ICs can be fabricated inexpensively. Incidentally, the semiconductor IC may be made of at least any of GaAs, SiGe, and GaN. Thus, a radio-frequency signal having high-quality amplification performance and noise performance can be output.

The transmission filter **61**T is disposed in a transmission path connecting the power amplifiers **11** and **12** and the switch **51** and passes, of transmission signals amplified by the power amplifier **11** or **12**, a transmission signal in a transmission band of the third band.

Furthermore, the transmission filter **62**T is an example of a first acoustic wave filter and a second acoustic wave filter. The transmission filter **62**T is disposed in a transmission path connecting the power amplifiers **11** and **12** and the switch **51** and passes, of transmission signals amplified by the power amplifier **11** or **12**, a transmission signal in a transmission band of the second band.

Additionally, the transmission filter **63**T is an example of the first acoustic wave filter and the second acoustic wave filter. The transmission filter **63**T is disposed in a transmission path connecting the power amplifiers **11** and **12** and the switch **51** and passes, of transmission signals amplified by the power amplifier **11** or **12**, a transmission signal in a transmission band of the first band.

The reception filter **61**R is disposed in a reception path connecting the low noise amplifier **21** and the switch **51** and passes, of reception signals input from the antenna connection terminal **100**, a reception signal in a reception band of the third band. Furthermore, the reception filter **62**R is disposed in a reception path connecting the low noise amplifier **21** and the switch **51** and passes, of reception signals input from the antenna connection terminal **100**, a reception signal in a reception band of the second band. Additionally, the reception filter **63**R is disposed in a reception path connecting the low noise amplifier **21** and the switch **51** and passes, of reception signals input from the antenna connection terminal **100**, a reception signal in a reception band of the first band.

Incidentally, the above-described transmission filters **62**T and **63**T are, for example, acoustic wave filters using Surface Acoustic Waves (SAWs) or Bulk Acoustic Waves (BAWs). Furthermore, each of the transmission filter **61**T, the reception filters **61**R, **62**R, and **63**R may be, for example, any of a SAW filter, a BAW filter, an LC resonant filter, and a dielectric filter and is further not limited to these.

The transmission filter **61**T and the reception filter **61**R constitute a duplexer **61** whose pass band is the third band. Furthermore, the transmission filter **62**T and the reception filter **62**R constitute a duplexer **62** whose pass band is the second band different from the first band. Additionally, the transmission filter **63**T and the reception filter **63**R constitute a duplexer **63** whose pass band is the first band.

Incidentally, each of the duplexers **61** to **63** may be one filter that performs transmission by using a Time Division Duplex (TDD) system. In this case, a switch for switching between transmission and reception is disposed in at least one of stages preceding and subsequent to the above-described one filter.

The matching network **41** is disposed in a transmission-reception path connecting the antenna connection terminal **100** and the switch **51** and provides impedance matching between the antenna **2** and the switch **51**. Incidentally, the matching network **41** may include at least one inductor. Furthermore, the matching network **41** may be disposed in series with the above-described transmission-reception path or may be connected between the transmission-reception path and a ground.

The matching network **42** is disposed in a transmission-reception path connecting the switch **51** and the duplexer **61** and provides impedance matching between the switch **51** and the duplexer **61**. Incidentally, the matching network **42** may include at least one inductor. Furthermore, the matching network **42** may be disposed in series with the above-described transmission-reception path or may be connected between the transmission-reception path and a ground. The matching network **43** is disposed in a transmission-reception path connecting the switch **51** and the duplexer **62** and provides impedance matching between the switch **51** and the duplexer **62**. Incidentally, the matching network **43** may include at least one inductor. Furthermore, the matching network **43** may be disposed in series with the above-described transmission-reception path or may be connected between the transmission-reception path and a ground. The matching network **44** is disposed in a transmission-reception path connecting the switch **51** and the duplexer **63** and provides impedance matching between the switch **51** and the duplexer **63**. Incidentally, the matching network **44** may include at least one inductor. Furthermore, the matching network **44** may be disposed in series with the above-described transmission-reception path or may be connected between the transmission-reception path and a ground.

The matching network **45** is disposed in a transmission path connecting the power amplifier **11** and the switch **52** and provides impedance matching between the power amplifier **11** and the switch **52**. Incidentally, the matching network **45** includes at least one inductor. Furthermore, the matching network **45** may be disposed in series with the above-described transmission path or may be connected between the transmission path and a ground. The matching network **46** is disposed in a transmission path connecting the power amplifier **12** and the switch **52** and provides impedance matching between the power amplifier **12** and the switch **52**. Incidentally, the matching network **46** includes at least one inductor. Furthermore, the matching network **46** may be disposed in series with the above-described transmission path or may be connected between the transmission path and a ground. The matching network **47** is disposed in a reception path connecting the low noise amplifier **21** and the switch **53** and provides impedance matching between the low noise amplifier **21** and the switch **53**. Incidentally, the matching network **47** includes at least one inductor. Furthermore, the matching network **47** may be disposed in series with the above-described reception path or may be connected between the reception path and a ground.

Incidentally, the matching networks **41** to **47** do not have to be included. Furthermore, a matching network may be disposed at least at any of locations between the transmission filter **61**T and the switch **52**, between the transmission filter **62**T and the switch **52**, between the transmission filter **63**T and the switch **52**, between the reception filter **61**R and the switch **53**, between the reception filter **62**R and the switch **53**, and between the reception filter **63**R and the switch **53**.

The switch **51** includes a common terminal, a first selection terminal, and a second selection terminal. The common terminal is connected to the antenna connection terminal **100** via the matching network **41**. The first selection terminal is connected to the duplexer **61** via the matching network **42** and is connected to the duplexer **62** via the matching network **43**. The second selection terminal is connected to the duplexer **63** via the matching network **44**. That is, the switch **51** is an antenna switch disposed between the antenna connection terminal **100** and the duplexers **61** to **63**. The switch **51** switches between connection and disconnection of (1) the antenna connection terminal **100** with the duplexers **61** and **62**, and switches between connection and disconnection of (2) the antenna connection terminal **100** with the duplexer **63**. Incidentally, the switch **51** is constituted by a multi-connection switch circuit that can establish simultaneous connections of both the above-described (1) and (2).

The switch **52** is an example of a first switch and includes a first common terminal, a second common terminal, a first selection terminal, a second selection terminal, and a third selection terminal. The switch **52** is disposed between the power amplifiers **11** and **12** and the transmission filters **61**T, **62**T, and **63**T. The first common terminal is connected to the output terminal of the power amplifier **11** via the matching network **45**. The second common terminal is connected to the output terminal of the power amplifier **12** via the matching network **46**. The first selection terminal is connected to the transmission filter **61**T, the second selection terminal is connected to the transmission filter **62**T, and the third selection terminal is connected to the transmission filter **63**T. In the above-described connection configuration, the switch **52** switches the connection of the power amplifier **11** between the transmission filters **61**T, **62**T, and **63**T and also switches the connection of the power amplifier **12** between the transmission filters **61**T, **62**T, and **63**T. The switch **52** is constituted, for example, by a DP3T (Double Pole 3 Throw) switch circuit. Incidentally, the switch **52** may be constituted, for example, by a plurality of switch circuits including at least one of an SPDT (Single Pole Double Throw) switch and an SP3T (Single Pole 3 Throw) switch.

The switch **53** includes a common terminal, a first selection terminal, a second selection terminal, and a third selection terminal and is disposed between the low noise amplifier **21** and the reception filters **61**R, **62**R, and **63**R. The common terminal is connected to the input terminal of the low noise amplifier **21** via the matching network **47**. The first selection terminal is connected to the reception filter **61**R, the second selection terminal is connected to the reception filter **62**R, and the third selection terminal is connected to the reception filter **63**R. In the above-described connection configuration, the switch **53** switches the connection of the low noise amplifier **21** between the reception filters **61**R, **62**R, and **63**R. The switch **53** is constituted, for example, by an SP3T switch circuit. Incidentally, the switch **53** may be constituted, for example, by a plurality of switch circuits including an SPDT switch.

Note that, in a radio-frequency module according to the present disclosure, of circuit components illustrated in FIG. **1**, at least the transmission filter **63**T only has to be included.

Here, in the radio-frequency module **1** having the above-described circuit configuration, the transmission filter **63**T passes a high-power transmission signal and is therefore likely to generate heat to result in insufficient heat dissipation. Thus, in some cases, filter characteristics deteriorate. A configuration will be described below in which heat dissipation of the radio-frequency module **1** according to the present embodiment is improved.

2. Layout and Configuration of Circuit Components of Radio-Frequency Module 1A According to Example 1

FIGS. **2**AA and **2**AB include plan views of a radio-frequency module **1**A according to Example 1. Furthermore, FIG. **2**B is a cross-sectional view of the radio-frequency module **1**A according to Example 1, specifically, a cross-sectional view taken along line IIB-IIB in FIGS. **2**AA and **2**AB. Besides, FIG. **2**AA illustrates the layout of circuit components when, of main surfaces **91***a* and **91***b* facing each other of a module substrate **91**, the main surface **91***a* is viewed from a positive side of a z axis. On the other hand, FIG. **2**AB illustrates the layout of circuit components as seen through the main surface **91***b* when the main surface **91***b* is viewed from the positive side of the z axis.

Furthermore, in FIGS. **2**AA and **2**AB, although the circuit components have marks representing their functions to facilitate understanding of a layout relationship between the circuit components, these marks are not put in the actual radio-frequency module **1**A.

The radio-frequency module **1**A according to Example 1 specifically represents the layout and configuration of circuit elements constituting the radio-frequency module **1** according to the embodiment.

As illustrated in FIGS. **2**AA, **2**AB, and **2**B, the radio-frequency module **1**A according to this example further includes the module substrate **91**, resin members **92** and **93**, external connection terminals **150**, a metal shield layer **85**, and a metal electrode **65** in addition to the circuit configuration illustrated in FIG. **1**.

The module substrate **91** has the main surfaces **91***a* and **91***b* facing each other and is a substrate where circuit components constituting the radio-frequency module **1**A are mounted. As the module substrate **91**, for example, a Low Temperature Co-fired Ceramics (LTCC) substrate having a multilayer structure including a plurality of dielectric layers, a High Temperature Co-fired Ceramics (HTCC) substrate, a substrate with a built-in component, a substrate with a Redistribution Layer (RDL), or a printed substrate is used.

Furthermore, in this example, the main surface **91***a* corresponds to a first main surface, and the main surface **91***b* corresponds to a second main surface.

Incidentally, although not illustrated, the antenna connection terminal **100**, the transmission input terminals **111** and **112**, the reception output terminal **120**, and the control signal terminal **130** may be formed on the main surface **91***b*.

The resin member **92** is disposed on the main surface **91***a* and covers some of the circuit components constituting the radio-frequency module **1**A and the main surface **91***a*. The resin member **93** is disposed on the main surface **91***b* and covers some of the circuit components constituting the radio-frequency module **1**A and the main surface **91***b*. The resin members **92** and **93** have a function of ensuring the reliability, for example, of mechanical strength and resistance to moisture of the circuit components constituting the radio-frequency module **1**A. Incidentally, the resin members **92** and **93** are not components indispensable to the radio-frequency module **1** according to the present embodiment.

The metal shield layer **85** is formed on a surface of the resin member **92** and is set at ground potential. The metal shield layer **85** is a metal thin film formed, for example, by using a sputtering method and is copper, an alloy containing copper, or a multilayer body containing copper. Incidentally, the metal shield layer **85** is not a component indispensable to the radio-frequency module **1** according to the present embodiment.

As illustrated in FIGS. **2**AA, **2**AB, and **2**B, in the radio-frequency module **1**A according to this example, the power amplifiers **11** and **12**, the reception filters **61**R, **62**R, and **63**R, and the matching networks **41**, **42**, **43**, **44**, **45**, **46**, and **47** are disposed on the main surface **91***a*. On the other hand, the low noise amplifier **21**, the transmission filters **61**T, **62**T, and **63**T, the PA control circuit **13**, the switches **51**, **52**, and **53** are disposed on the main surface **91***b*.

Incidentally, although not illustrated in FIGS. **2**AA and **2**AB, lines connecting the circuit components illustrated in FIG. **1** are formed within the module substrate **91** and on the main surfaces **91***a* and **91***b*. Furthermore, each of the above-described lines may be a bonding wire with each end bonded to any of the main surfaces **91***a* and **91***b* and the circuit components constituting the radio-frequency module **1**A, or alternatively may be a terminal, an electrode, or a line formed on a surface of a circuit component constituting the radio-frequency module **1**A.

Furthermore, in the radio-frequency module **1**A according to this example, a plurality of external connection terminals **150** are disposed on the main surface **91***b*. The radio-frequency module **1**A exchanges electrical signals with an external substrate disposed on a negative side of the z axis of the radio-frequency module **1**A through the plurality of external connection terminals **150**. Furthermore, some of the plurality of external connection terminals **150** are set at ground potential of the external substrate. Of the main surfaces **91***a* and **91***b*, on the main surface **91***b* facing the external substrate, a circuit component that is difficult to reduce in height is not disposed, but the low noise amplifier **21**, the switches **51** to **53**, the PA control circuit **13**, and the transmission filters **61**T to **63**T that are easy to reduce in height are disposed.

Incidentally, the external connection terminals **150** may be columnar electrodes extending through the resin member **93** in a z-axis direction as illustrated in FIGS. **2**AA, **2**AB, and **2**B. Alternatively, the external connection terminals **150** may be bump electrodes formed on the main surface **91***b*. In this case, the resin member **93** on the main surface **91***b* does not have to be provided.

Furthermore, in the radio-frequency module **1**A according to this example, the transmission filter **63**T has to be disposed on the main surface **91***b*, and the other circuit components may be disposed on either the main surface **91***a* or **91***b*.

The transmission filter **63**T is an example of the first acoustic wave filter and has a bottom surface **63***a* (first bottom surface) and a top surface **63***b* (first top surface) facing each other. As illustrated in FIG. **2**B, the bottom surface **63***a* faces the main surface **91***b* and is disposed closer to the main surface **91***b* than the top surface **63***b*.

The metal electrode **65** is an example of a first metal electrode and is joined to the top surface **63***b*.

The transmission filter **63**T is a circuit component that passes a transmission signal amplified by the power amplifier **11** or **12** and is thus, of the circuit components included in the radio-frequency module **1**A, a component that generates a large amount of heat. To improve the heat dissipation of the radio-frequency module **1**A, it is suitable to dissipate heat generated by the transmission filter **63**T to the external substrate by using a heat dissipation path with a small thermal resistance. If no metal electrode **65** is provided, as a heat dissipation path of the transmission filter **63**T, a heat dissipation path running only through a planar wiring pattern (along an x-y planar direction) on the main surface **91***b* is included. The above-described planar wiring pattern is formed from a metal thin film and thus has a large thermal resistance. As a result, if the transmission filter **63**T is disposed on the main surface **91***b*, heat dissipation is reduced.

On the other hand, in the radio-frequency module **1**A according to this example, the metal electrode **65** is joined to the top surface **63***b* of the transmission filter **63**T as illustrated in FIG. **2**B, and thus heat generated by the transmission filter **63**T can be dissipated to an external substrate side through the metal electrode **65**. That is, heat can be dissipated not only through, as a heat dissipation path of the transmission filter **63**T, a heat dissipation path running through the module substrate **91**, but also from the top surface **63***b* of the transmission filter **63**T without necessarily passing through the module substrate **91**. Hence, the radio-frequency module **1**A can be provided in which heat dissipation of the transmission filter **63**T, which is an acoustic wave filter, is improved.

Furthermore, as illustrated in FIGS. **2**AA and **2**AB, the metal electrode **65** may be further joined to the transmission filter **63**T and to the PA control circuit **13**.

This further improves the heat dissipation of the radio-frequency module **1**A.

Furthermore, the radio-frequency module **1**A further includes a via conductor **91**V (first via conductor) formed within the module substrate **91** and connecting the main surfaces **91***a* and **91***b*. One end of the via conductor **91**V is connected to a ground electrode of the power amplifier **11** or **12** at the main surface **91***a*, and other ends of the via conductor **91**V are connected to a plurality of external connection terminals **150** at the main surface **91***b*.

Each of the power amplifiers **11** and **12** is, of the circuit components included in the radio-frequency module **1**A, a component that generates a large amount of heat. To improve the heat dissipation of the radio-frequency module **1**A, it is suitable to dissipate heat generated by the power amplifiers **11** and **12** to the external substrate by using a heat dissipation path with a small thermal resistance. If the power amplifiers **11** and **12** are mounted in or on the main surface **91***b*, an electrode line to be connected to the power amplifiers **11** and **12** is disposed on the main surface **91***b*. For this reason, as a heat dissipation path, a heat dissipation path running only through a planar wiring pattern (along the x-y planar direction) on the main surface **91***b* is included. The above-described planar wiring pattern is formed from a metal thin film and thus has a large thermal resistance. As a result, if the power amplifiers **11** and **12** are disposed on the main surface **91***b*, heat dissipation is reduced.

On the other hand, as illustrated in FIG. **2**B, the radio-frequency module **1**A according to this example further includes the via conductor **91**V for heat dissipation connected to the ground electrode of the power amplifier **11** or **12** at the main surface **91***a* and extending from the main surface **91***a* to the main surface **91***b*. Furthermore, the via conductor **91**V is connected to the external connection terminals **150** set at the ground potential at the main surface **91***b*.

Thus, the power amplifier **11** or **12** can be connected to the external connection terminals **150** via the via conductor **91**V for heat dissipation. Hence, as a heat dissipation path of the power amplifier **11** or **12**, of lines in the module substrate **91**, a heat dissipation path running only through the planar wiring pattern that has a large thermal resistance and is provided along the x-y planar direction can be excluded. Thus, the small-sized radio-frequency module **1**A can be provided in which heat dissipation from the power amplifier **11** or **12** to the external substrate is improved.

Furthermore, in the radio-frequency module **1**A according to this example, the low noise amplifier **21** and the switch **53** are included in a semiconductor IC **71**. Thus, the radio-frequency module **1**A can be reduced in size.

Furthermore, the power amplifiers **11** and **12**, and the low noise amplifier **21** are provided on both the surfaces of the module substrate **91** such that the power amplifiers **11** and **12** are separated from the low noise amplifier **21** with the module substrate **91** interposed between the power amplifiers **11** and **12** and the low noise amplifier **21**, thus enabling an improvement in isolation between transmission and reception.

FIG. **2**C is a plan view of a radio-frequency module **1**B according to Modification 1. When compared with the radio-frequency module **1**A according to Example 1, the radio-frequency module **1**B illustrated in FIG. **2**C differs from the radio-frequency module **1**A only in the placement and configuration of a metal electrode **65**B. In the radio-frequency module **1**B according to this modification, a description of a configuration that is the same as a configuration in the radio-frequency module **1**A according to Example 1 is omitted, and a description will be given below with emphasis on a configuration different from the configuration in the radio-frequency module **1**A.

In this modification, the transmission filter **62**T is an example of the first acoustic wave filter and has a bottom surface **62***a* and a top surface **62***b* facing each other. The bottom surface **62***a* faces the main surface **91***b* and is disposed closer to the main surface **91***b* than the top surface **62***b*. The transmission filter **63**T is an example of a second filter. In the transmission filter **62**T, an input-output terminal **621** is formed on the bottom surface **62***a*. The input-output terminal **621** is an example of a first input-output terminal and is connected to the second selection terminal of the switch **52**.

The metal electrode **65**B is an example of the first metal electrode and is joined to the top surface **62***b*.

Here, when the top surface **62***b* is viewed in plan, the input-output terminal **621** and the metal electrode **65**B overlap each other.

Thus, since the input-output terminal **621** that generates the largest amount of heat in the transmission filter **62**T and whose temperature is likely to reach a high temperature and the metal electrode **65**B overlap each other when the top surface **62***b* is viewed in plan, heat dissipation of the transmission filter **62**T, which is an acoustic wave filter, can be improved more effectively.

3. Layout and Configuration of Circuit Components of Radio-Frequency Module 1C According to Example 2

FIG. **3**A is a plan view of a radio-frequency module **1**C according to Example 2. Furthermore, FIG. **3**B is a cross-sectional view of the radio-frequency module **1**C according to Example 2, specifically, a cross-sectional view taken along line IIIB-IIIB in FIG. **3**A. Incidentally, FIG. **3**A illustrates, when, of the main surfaces **91***a* and **91***b* facing each other of the module substrate **91**, the main surface **91***b* is viewed from the positive side of the z axis, the layout of circuit components as seen through the main surface **91***b*. Furthermore, in FIG. **3**A, although the circuit components have marks representing their functions to facilitate understanding of a layout relationship between the circuit components, these marks are not put in the actual radio-frequency module **1**C.

The radio-frequency module **1**C according to Example 2 specifically represents the layout and configuration of circuit elements constituting the radio-frequency module **1** according to the embodiment.

When compared with the radio-frequency module **1**A according to Example 1, the radio-frequency module **1**C illustrated in FIGS. **3**A and **3**B differs from the radio-frequency module **1**A only in the placement and configuration of a metal electrode **65**C. In the radio-frequency module **1**C according to this example, a description of a configuration that is the same as a configuration in the radio-frequency module **1**A according to Example 1 is omitted, and a description will be given below with emphasis on a configuration different from the configuration in the radio-frequency module **1**A.

The metal electrode **65**C is an example of the first metal electrode and is joined to the top surface **63***b* as illustrated in FIG. **3**B. Furthermore, on a plane containing the top surface **63***b*, the metal electrode **65**C is joined to external connection terminals **150** set at the ground potential.

In the above-described configuration, the metal electrode **65**C serves as a ground electrode, a transmission signal and a harmonic that are radiated from the transmission filter **63**T can thus be suppressed, and noise can also be kept from entering the transmission filter **63**T from the outside. Hence, isolation between signals can be improved while the heat dissipation of the radio-frequency module **1**C is improved.

Incidentally, in the radio-frequency module **1**C according to this example, although the metal electrode **65**C and the main surface **91***b* are connected to each other via the external connection terminals **150**, the metal electrode **65**C and a ground electrode formed on the main surface **91***b* may be connected to each other via a bonding wire.

FIG. **3**C is a cross-sectional view of a radio-frequency module **1**D according to Modification 2. When compared with the radio-frequency module **1**A according to Example 1, the radio-frequency module **1**D illustrated in FIG. **3**C differs from the radio-frequency module **1**A only in that the radio-frequency module **1**D further includes via conductors **63**V and **13**V. In the radio-frequency module **1**D according to this modification, a description of a configuration that is the same as a configuration in the radio-frequency module **1**A according to Example 1 is omitted, and a description will be given below with emphasis on a configuration different from the configuration in the radio-frequency module **1**A.

In the transmission filter **63**T, the via conductor **63**V (second via conductor) connecting the bottom surface **63***a* and the top surface **63***b* is formed. One end of the via conductor **63**V is connected to the ground electrode formed on the main surface **91***b*, and the other end of the via conductor **63**V is connected to the metal electrode **65**.

In the above-described configuration, the metal electrode **65** serves as a ground electrode, a transmission signal and a harmonic that are radiated from the transmission filter **63**T can thus be suppressed, and noise can also be kept from entering the transmission filter **63**T from the outside. Hence, isolation between signals can be improved while the heat dissipation of the radio-frequency module **1**D is improved.

Furthermore, the PA control circuit **13** has main surfaces **13***a* and **13***b* facing each other. As illustrated in FIG. **3**C, the main surface **13***a* faces the main surface **91***b* and is disposed closer to the main surface **91***b* than the main surface **13***b*.

In the PA control circuit **13**, the via conductor **13**V connecting the main surface **13***a* and main surface **13***b* is formed. One end of the via conductor **13**V is connected to the ground electrode formed on the main surface **91***b*, and the other end of the via conductor **13**V is connected to the metal electrode **65**.

In the above-described configuration, the metal electrode **65** serves as a ground electrode, digital noise radiated from the PA control circuit **13** can thus be suppressed, and noise can also be kept from entering the PA control circuit **13** from the outside.

4. Layout and Configuration of Circuit Components of Radio-Frequency Module 1E According to Example 3

FIG. **4**A is a plan view of a radio-frequency module **1**E according to Example 3. Furthermore, FIG. **4**B is a cross-sectional view of the radio-frequency module **1**E according to Example 3, specifically, a cross-sectional view taken along line IVB-IVB in FIG. **4**A. Incidentally, FIG. **4**A illustrates, when, of the main surfaces **91***a* and **91***b* facing each other of the module substrate **91**, the main surface **91***b* is viewed from the positive side of the z axis, the layout of circuit components as seen through the main surface **91***b*.

Furthermore, in FIG. **4**A, although the circuit components have marks representing their functions to facilitate understanding of a layout relationship between the circuit components, these marks are not put in the actual radio-frequency module **1**E.

The radio-frequency module **1**E according to Example 3 specifically represents the layout and configuration of circuit elements constituting the radio-frequency module **1** according to the embodiment.

When compared with the radio-frequency module **1**A according to Example 1, the radio-frequency module **1**E illustrated in FIGS. **4**A and **4**B differs from the radio-frequency module **1**A in that metal shield plates **86** and **87** are disposed. In the radio-frequency module **1**E according to this example, a description of a configuration that is the same as a configuration in the radio-frequency module **1**A according to Example 1 is omitted, and a description will be given below with emphasis on a configuration different from the configuration in the radio-frequency module **1**A.

When compared with the radio-frequency module **1**A according to Example 1, the radio-frequency module **1**E further includes the metal shield plates **86** and **87**.

The metal shield plate **86** is erected on the main surface **91***b* and is disposed between the transmission filter **63**T and the low noise amplifier **21** when the module substrate **91** is viewed in plan. The metal shield plate **86** is joined to the ground electrode formed on the main surface **91***b* and to the metal electrode **65**. Incidentally, the metal shield plate **86** may be connected to a ground electrode layer **95**G formed in the module substrate **91**. The metal shield plate **86** is joined to the ground electrode and to the metal electrode **65** at its upper and lower ends and is disposed between the transmission filter **63**T and the low noise amplifier **21**, and thus a function of shielding against an electromagnetic field between the transmission filter **63**T and the low noise amplifier **21** can be strengthened. Hence, isolation between transmission and reception in the radio-frequency module **1**E can be further improved.

Furthermore, the metal shield plate **87** is erected on the main surface **91***b* and is joined to the ground electrode formed on the main surface **91***b* and to the metal electrode **65**.

Thus, the metal electrode **65** serves as a ground electrode, a transmission signal and a harmonic that are radiated from the transmission filter **63**T can therefore be suppressed, and noise can also be kept from entering the transmission filter **63**T from the outside. Hence, isolation between signals can be improved while the heat dissipation of the radio-frequency module **1**E is improved.

A detailed structure of each of the metal shield plates **86** and **87** will be described with reference to FIGS. **5**A to **5**C.

FIG. **5**A is an external perspective view of a metal shield plate **86**A. The metal shield plate **86**A illustrated in FIG. **5**A is an example of the metal shield plates **86** and **87** according to Example 3. The metal shield plate **86**A is erected from the main surface **91***b* (not illustrated) toward the negative side of the z axis. Between the metal shield plate **86**A and the main surface **91***b*, holes **86***z* extending in a direction (x-axis direction) of a normal to the metal shield plate **86**A are formed.

Furthermore, the metal shield plate **86**A includes a body portion **86***x* erected from the main surface **91***b* toward the negative side of the z axis, and junction portions **86***y* provided on a main surface **91***b* side so as to extend in parallel to the main surface **91***b* and joined to the ground electrode (not illustrated) on the main surface **91***b*.

In the structure of the metal shield plate **86**A, since the holes **86***z* are formed between the body portion **86***x* and the main surface **91***b*, in a process of forming the resin member **93** on the main surface **91***b*, good fluidity of a liquid resin near the metal shield plate **86**A can be provided. Hence, occurrence of, for example, a void where no resin member **93** is formed near the metal shield plate **86**A can be suppressed.

FIG. **5**B is an external perspective view of a metal shield plate **86**B. The metal shield plate **86**B illustrated in FIG. **5**B is an example of the metal shield plates **86** and **87** according to Example 3. The metal shield plate **86**B is erected from the main surface **91***b* (not illustrated) toward the negative side of the z axis. Between the metal shield plate **86**B and the plane containing the top surface **63***b*, holes **86***z* extending in a direction (x-axis direction) of a normal to the metal shield plate **86**B are formed.

Furthermore, the metal shield plate **86**B includes a body portion **86***x* erected from the main surface **91***b* toward the negative side of the z axis, and a junction portion **86***y* provided on the main surface **91***b* side so as to extend in parallel to the main surface **91***b* and joined to the ground electrode (not illustrated) on the main surface **91***b*.

In the structure of the metal shield plate **86**B, since the holes **86***z* are formed between the body portion **86***x* and the plane containing the top surface **63***b*, in a process of forming the resin member **93** on the main surface **91***b*, good fluidity of a liquid resin near the metal shield plate **86**B can be provided. Hence, occurrence of, for example, a void where no resin member **93** is formed near the metal shield plate **86**B can be suppressed. Furthermore, since no holes **86***z* are formed in a region (a lower region of the body portion **86***x*) in contact with the main surface **91***b*, isolation between circuit components disposed on the main surface **91***b* with the metal shield plate **86**B interposed between the circuit components is improved.

FIG. **5**C is an external perspective view of a metal shield plate **86**C. The metal shield plate **86**C illustrated in FIG. **5**C is an example of the metal shield plates **86** and **87** according to Example 3. The metal shield plate **86**C is erected from the main surface **91***b* (not illustrated) toward the negative side of the z axis. Between the main surface **91***b* and the plane containing the top surface **63***b*, holes **86***z* extending in a direction (x-axis direction) of a normal to the metal shield plate **86**C are formed.

Furthermore, the metal shield plate **86**C includes body portions **86***x* erected from the main surface **91***b* toward the negative side of the z axis, and junction portions **86***y* provided on the main surface **91***b* side so as to extend in parallel to the main surface **91***b* and joined to the ground electrode (not illustrated) on the main surface **91***b*. In the metal shield plate **86**C, a plurality of body portions **86***x* are discretely disposed with the holes **86***z* interposed therebetween, and a plurality of junction portions **86***y* are also discretely disposed with the holes **86***z* interposed therebetween.

In the structure of the metal shield plate **86**C, since the holes **86***z* are formed between the main surface **91***b* and the plane containing the top surface **63***b*, in a process of forming the resin member **93** on the main surface **91***b*, good fluidity of a liquid resin near the metal shield plate **86**C can be provided. Hence, occurrence of, for example, a void where no resin member **93** is formed near the metal shield plate **86**C can be suppressed.

Incidentally, an example of the structure of each of the metal shield plates **86** and **87** is not limited to the above-described metal shield plates **86**A to **86**C. For example, a plurality of holes **86***z* may be disposed from the main surface **91***b* to the plane containing the top surface **63***b*. Furthermore, a direction in which a junction portion **86***y* provided so as to extend is not limited to a positive direction of an x axis as illustrated in FIGS. **5**A to **5**C, and may be a negative direction of the x axis. Additionally, each of the metal shield plates **86** and **87** may include both a junction portion **86***y* provided so as to extend in the positive direction of the x axis and a junction portion **86***y* provided so as to extend in the negative direction of the x axis.

FIG. **6** is a plan view of a radio-frequency module **1**F according to Modification 3. When compared with the radio-frequency module **1**E according to Example 3, the radio-frequency module **1**F illustrated in FIG. **6** differs from the radio-frequency module **1**E only in that bonding wires **88** are disposed in place of the metal shield plates **86** and **87**. In the radio-frequency module **1**F according to this modification, a description of a configuration that is the same as a configuration in the radio-frequency module **1**E according to Example 3 is omitted, and a description will be given below with emphasis on a configuration different from the configuration in the radio-frequency module **1**E.

In the radio-frequency module **1**E according to this example, a plurality of bonding wires **88** are disposed, in place of the metal shield plate **86**, between the transmission filter **63**T and the low noise amplifier **21**. One end of each bonding wire **88** is joined to the ground electrode formed on the main surface **91***b*, and the other end is joined to the metal electrode **65**.

Thus, a function of shielding against an electromagnetic field between the transmission filter **63**T and the low noise amplifier **21** can be strengthened, and isolation between transmission and reception in the radio-frequency module **1**F can therefore be further improved.

Furthermore, although not illustrated, in the radio-frequency module **1**E according to this example, a plurality of external connection terminals **150** set at a ground may be disposed, in place of the metal shield plate **86**, between the transmission filter **63**T and the low noise amplifier **21**. In this case, one end of each external connection terminal **150** is joined to the ground electrode formed on the main surface **91***b*, and the other end is joined to the metal electrode **65**.

Thus, a function of shielding against an electromagnetic field between the transmission filter **63**T and the low noise amplifier **21** can also be strengthened, and isolation between transmission and reception in the radio-frequency module **1**E can therefore be further improved.

5. Layout and Configuration of Circuit Components of Radio-Frequency Module 1G According to Example 4

FIG. **7**A is a plan view of a radio-frequency module **1**G according to Example 4. Furthermore, FIG. **7**B is a cross-sectional view of the radio-frequency module **1**G according to Example 4, specifically, a cross-sectional view taken along line VIIB-VIIB in FIG. **7**A. Incidentally, FIG. **7**A illustrates, when, of the main surfaces **91***a* and **91***b* facing each other of the module substrate **91**, the main surface **91***b* is viewed from the positive side of the z axis, the layout of circuit components as seen through the main surface **91***b*. Furthermore, in FIG. **7**A, although the circuit components have marks representing their functions to facilitate understanding of a layout relationship between the circuit components, these marks are not put in the actual radio-frequency module **1**G.

The radio-frequency module **1**G according to Example 4 specifically represents the layout and configuration of circuit elements constituting the radio-frequency module **1** according to the embodiment.

When compared with the radio-frequency module **1**A according to Example 1, the radio-frequency module **1**G illustrated in FIGS. **7**A and **7**B differs from the radio-frequency module **1**A only in the layout and configuration of metal electrodes **65**S and **65**G. In the radio-frequency module **1**G according to this example, a description of a configuration that is the same as a configuration in the radio-frequency module **1**A according to Example 1 is omitted, and a description will be given below with emphasis on a configuration different from the configuration in the radio-frequency module **1**A.

The metal electrode **65**S is an example of the first metal electrode and is joined to the top surface **63***b*. The metal electrode **65**S is a signal electrode (HOT electrode) that inputs a radio-frequency signal to the transmission filter **63**T or outputs a radio-frequency signal from the transmission filter **63**T. The metal electrode **65**S may be connected, for example, to an input-output terminal **631** disposed in or on the bottom surface **63***a* of the transmission filter **63**T via a via conductor.

Thus, since the metal electrode **65**S is joined to the top surface **63***b* of the transmission filter **63**T, heat generated by the transmission filter **63**T can be dissipated to the external substrate side through the metal electrode **65**S. Hence, the radio-frequency module **1**G can be provided in which the heat dissipation of the transmission filter **63**T, which is an acoustic wave filter, is improved.

Furthermore, in the radio-frequency module **1**G according to this example, the metal electrode **65**G is joined to the top surface **63***b* and is set at the ground. Thus, isolation between signals can be improved while the heat dissipation of the radio-frequency module **1**G is improved.

Incidentally, in the radio-frequency module **1**G according to this example, the metal electrode **65**G does not have to be disposed.

6. Layout and Configuration of Circuit Components of Radio-Frequency Module 1H According to Example 5

FIG. **8** is a plan view of a radio-frequency module **1**H according to Example 5. Incidentally, FIG. **8** illustrates, when, of the main surfaces **91***a* and **91***b* facing each other of the module substrate **91**, the main surface **91***b* is viewed from the positive side of the z axis, the layout of circuit components as seen through the main surface **91***b*.

Furthermore, in FIG. **8**, although the circuit components have marks representing their functions to facilitate understanding of a layout relationship between the circuit components, these marks are not put in the actual radio-frequency module **1**H.

The radio-frequency module **1**H according to Example 5 specifically represents the layout and configuration of circuit elements constituting the radio-frequency module **1** according to the embodiment.

When compared with the radio-frequency module **1**A according to Example 1, the radio-frequency module **1**H illustrated in FIG. **8** differs from the radio-frequency module **1**A in the addition of a metal electrode **65**H, an inductor **48**L, and a capacitor **48**C and in the placement and configuration of the metal electrode **65**H. In the radio-frequency module **1**H according to this example, a description of a configuration that is the same as a configuration in the radio-frequency module **1**A according to Example 1 is omitted, and a description will be given below with emphasis on a configuration different from the configuration in the radio-frequency module **1**A.

The inductor **48**L is a surface mount device disposed on the main surface **91***b*. Furthermore, the capacitor **48**C is a surface mount device disposed on the main surface **91***b*. The inductor **48**L and the capacitor **48**C are circuit components constituting, for example, a matching network included in the radio-frequency module **1**H and are also circuit components constituting an LC filter included in the radio-frequency module **1**H.

The metal electrode **65**H is an example of the first metal electrode and is joined to the top surface **62***b* of the transmission filter **62**T and to part of the inductor **48**L and capacitor **48**C at a plane containing the top surface **62***b*.

Thus, not only the heat dissipation of the transmission filter **62**T but also heat dissipation of the surface mount devices constituting the radio-frequency module **1**H can be improved. Hence, the heat dissipation of the radio-frequency module **1**H can be further improved.

7. Layout and Configuration of Circuit Components of Radio-Frequency Module 1J According to Example 6

FIG. **9** is a cross-sectional view of a radio-frequency module **1**J according to Example 6. The radio-frequency module **1**J according to Example 6 specifically represents the layout and configuration of circuit elements constituting the radio-frequency module **1** according to the embodiment.

When compared with the radio-frequency module **1**A according to Example 1, the radio-frequency module **1**J illustrated in FIG. **9** differs from the radio-frequency module **1**A only in the structure of the transmission filter **63**T. In the radio-frequency module **1**J according to this example, a description of a configuration that is the same as a configuration in the radio-frequency module **1**A according to Example 1 is omitted, and a description will be given below with emphasis on a configuration different from the configuration in the radio-frequency module **1**A.

The top surface **63***b* of the transmission filter **63**T is joined to the metal electrode **65**. The transmission filter **63**T includes a circuit unit (not illustrated) formed at a location closer to the bottom surface **63***a* than the top surface **63***b*, and a barrier metal layer **68** formed between the metal electrode **65** and the above-described circuit unit. Incidentally, the circuit unit corresponds to a medium that propagates an acoustic wave.

The metal electrode **65** is a metal thin film formed, for example, by using the sputtering method and is copper, an alloy containing copper, or a multilayer body containing copper.

The barrier metal layer **68** is an example of a metal layer, and is, for example, titanium, tantalum, cobalt, tungsten, or an alloy containing at least one of titanium, tantalum, cobalt, and tungsten.

In the radio-frequency module **1**J, since the metal electrode **65** is in contact with the transmission filter **63**T, in some cases, metal (such as a Cu atom) diffuses from the metal electrode **65** toward the circuit unit of the transmission filter **63**T. When the circuit unit is contaminated with, as an impurity, this metal that has diffused, the structure of the circuit unit is changed, sometimes resulting in a deterioration in filter bandpass characteristics.

On the other hand, in the above-described configuration of the radio-frequency module **1**J, the barrier metal layer **68** is disposed between the metal electrode **65** and the circuit unit. This can make the degree of metal diffusion from the barrier metal layer **68** to the circuit unit lower than the degree of metal diffusion from the metal electrode **65** to the circuit unit. That is, when compared with a transmission filter in which no barrier metal layer **68** is disposed, metal can be kept from diffusing from the metal electrode **65** to the circuit unit. Hence, the deterioration in the filter bandpass characteristics of the transmission filter **63**T can be suppressed while the heat dissipation of the radio-frequency module **1**J is improved.

Incidentally, a description that the degree of metal diffusion from A to B is low refers to, for example, the fact that the weight of a metallic material constituting A that diffuses to B is small, or the fact that the speed at which a metallic material constituting A diffuses to B is low. Specifically, it is defined that the coefficient of diffusion of a metallic material constituting A to B is small.

That is, the barrier metal layer **68** is defined as a metal layer that has a smaller coefficient of diffusion of a metallic material constituting the barrier metal layer **68** to the circuit unit than the coefficient of diffusion of a metallic material constituting the metal electrode **65** to the circuit unit.

FIG. **10**A is a cross-sectional view illustrating a configuration of a first example of the transmission filter **63**T according to Example 6.

The transmission filter **63**T is a surface acoustic wave filter. As illustrated in FIG. **10**A, the top surface **63***b* of the transmission filter **63**T is joined to the metal electrode **65**. Furthermore, the bottom surface **63***a* faces the main surface **91***b* and is connected to the main surface **91***b* via bump electrodes **76** formed on or above a surface of a piezoelectric layer **75**.

The transmission filter **63**T includes the piezoelectric layer **75**, a supporting substrate **72**, the barrier metal layer **68**, a high acoustic velocity layer **73**, a low acoustic velocity layer **74**, and an IDT electrode **77**. The supporting substrate **72**, the barrier metal layer **68**, the high acoustic velocity layer **73**, the low acoustic velocity layer **74**, the piezoelectric layer **75**, and the IDT electrode **77** are stacked in sequence.

The piezoelectric layer **75** is made, for example, of a $LiTaO_3$ piezoelectric single crystal or piezoelectric ceramics.

The supporting substrate **72** is a substrate that supports the high acoustic velocity layer **73**, the low acoustic velocity layer **74**, the piezoelectric layer **75**, and the IDT electrode **77** and is made, for example, of silicon.

The high acoustic velocity layer **73** is a layer in which a bulk wave that propagates through the layer is higher in acoustic velocity than acoustic waves, such as a surface acoustic wave and a boundary wave, that propagate along the piezoelectric layer **75**. The high acoustic velocity layer **73** functions so that a surface acoustic wave is confined in a portion where the piezoelectric layer **75** and the low acoustic velocity layer **74** are stacked on top of each other and does not leak downward with respect to the high acoustic velocity layer **73**.

The low acoustic velocity layer **74** is a layer in which a bulk wave that propagates through the layer is lower in acoustic velocity than a bulk wave that propagates through the piezoelectric layer **75** and is disposed between the piezoelectric layer **75** and the high acoustic velocity layer **73**. Because of this structure and the property of an acoustic wave whose energy essentially concentrates on a low acoustic velocity medium, leakage of surface acoustic wave energy outside the IDT electrode **77** is suppressed.

Incidentally, the supporting substrate **72** and the high acoustic velocity layer **73** may be made of the same material. In this case, a high acoustic velocity supporting substrate may be provided.

In the above-described configuration, when a radio-frequency signal is input between a pair of comb-shaped electrodes constituting the IDT electrode **77**, a potential difference occurs between the pair of comb-shaped electrodes, and thus the piezoelectric layer **75** is deformed to thereby generate a surface acoustic wave. Here, when a wavelength of the IDT electrode **77** (twice the distance between electrode fingers) is caused to substantially coincide with a wavelength in a pass band of the transmission filter **63**T, only a radio-frequency signal with a frequency component desired to be passed passes through the transmission filter **63**T.

Incidentally, when compared with an existing structure using a piezoelectric substrate of a single layer, the above-described stacked structure of the transmission filter **63**T makes it possible to significantly increase Q factors at a resonant frequency and an anti-resonant frequency. That is, an acoustic wave resonator with a high Q factor can be constructed, and thus a filter that provides low insertion loss can be constructed by using this acoustic wave resonator.

Incidentally, a surface acoustic wave refers to propagation of an acoustic wave along the surface of the piezoelectric layer **75** or a boundary between a plurality of materials and refers to various types of acoustic waves generated by using the IDT electrode **77**. Examples of a surface acoustic wave include a surface wave, a Love wave, a leaky wave, a Rayleigh wave, a boundary wave, a leaky SAW, a pseudo SAW, and a plate wave.

The IDT electrode **77**, the piezoelectric layer **75**, and the low acoustic velocity layer **74** are formed, of the bottom surface **63***a* and the top surface **63***b* of the transmission filter **63**T, on a bottom surface **63***a* side and correspond to the circuit unit that propagates a surface acoustic wave.

Thus, the deterioration in the filter bandpass characteristics of the transmission filter **63**T can be suppressed while the heat dissipation of the radio-frequency module **1**J is improved.

Incidentally, the barrier metal layer **68** only has to be formed between the metal electrode **65** and the circuit unit.

Furthermore, the transmission filter **63**T may be a bulk acoustic wave filter in addition to a surface acoustic wave filter.

FIG. **10**B is a cross-sectional view illustrating a configuration of a second example of the transmission filter **63**T according to Example 6.

The transmission filter **63**T is an SMR (Solidly Mounted Resonator)-type bulk acoustic wave filter. As illustrated in FIG. **10**B, the top surface **63***b* of the transmission filter **63**T is in contact with the metal electrode **65**. Furthermore, the bottom surface **63***a* (an upper electrode **84** and a lower electrode **82**) of the transmission filter **63**T faces the main surface **91***b* and is connected to the main surface **91***b* via the bump electrodes **76** formed on surfaces of the upper electrode **84** and the lower electrode **82**.

The transmission filter **63**T according to this example includes the supporting substrate **72**, the barrier metal layer **68**, low acoustic impedance films **81**, high acoustic impedance films **80**, the upper electrode **84** (second electrode), the lower electrode **82** (first electrode), and a piezoelectric layer **83**. The low acoustic impedance films **81** are stacked alternately with the high acoustic impedance films **80** to thereby form an acoustic multilayer film. In the transmission filter **63**T, the supporting substrate **72**, the barrier metal layer **68**, the acoustic multilayer film, the lower electrode **82**, the piezoelectric layer **83**, and the upper electrode **84** are stacked in sequence.

The supporting substrate **72** is a substrate that supports the acoustic multilayer film, the upper electrode **84**, the piezoelectric layer **83**, and the lower electrode **82** and is made, for example, of silicon.

In the above-described structure, the SMR-type bulk acoustic wave resonator confines a bulk acoustic wave in a portion (the upper electrode **84**, the piezoelectric layer **83**, and the lower electrode **82**) below the acoustic multilayer film by using Bragg reflection caused by the acoustic multilayer film disposed between the supporting substrate **72** and the upper electrode **84**.

In the above-described configuration, when a radio-frequency signal is input between the upper electrode **84** and the lower electrode **82**, a potential difference occurs between both the electrodes, and thus the piezoelectric layer **83** is deformed to thereby generate a bulk acoustic wave in a direction in which the upper electrode **84**, the piezoelectric layer **83**, and the lower electrode **82** are stacked. Here, when a film thickness of the piezoelectric layer **83** is caused to correspond to a wavelength in the pass band of the transmission filter **63**T, only a radio-frequency signal with a frequency component desired to be passed passes through the transmission filter **63**T.

The upper electrode **84**, the piezoelectric layer **83**, and the lower electrode **82** are formed, of the bottom surface **63***a* and the top surface **63***b* of the transmission filter **63**T, on the bottom surface **63***a* side and correspond to the circuit unit that propagates a bulk acoustic wave.

Thus, the deterioration in the filter bandpass characteristics of the transmission filter **63**T can be suppressed while the heat dissipation of the radio-frequency module **1**J is improved.

Incidentally, the barrier metal layer **68** only has to be formed between the metal electrode **65** and the circuit unit.

8. Layout and Configuration of Circuit Components of Radio-Frequency Module 1K According to Example 7

FIG. **11** is a cross-sectional view of a radio-frequency module **1**K according to Example 7. The radio-frequency module **1**K according to Example 7 specifically represents the layout and configuration of circuit elements constituting the radio-frequency module **1** according to the embodiment.

When compared with the radio-frequency module **1**C according to Example 2, the radio-frequency module **1**K illustrated in FIG. **11** differs from the radio-frequency module **1**C in that a resist layer **96** joined to the metal electrode **65**C is added. In the radio-frequency module **1**K according to this example, a description of a configuration that is the same as a configuration in the radio-frequency module **1**C according to Example 2 is omitted, and a description will be given below with emphasis on a configuration different from the configuration in the radio-frequency module **1**C.

The radio-frequency module **1**K is connected to an external substrate **200** via bump electrodes **160** joined to a surface of the metal electrode **65**C.

Here, at the surface of the metal electrode **65**C, the resist layer **96** is formed to cover a region other than junction regions with the bump electrodes **160**. The resist layer **96** is an insulating layer.

Thus, the resist layer **96** can keep an unnecessary short circuit from occurring between the metal electrode **65**C and the external substrate **200**.

9. Layout and Configuration of Circuit Components of Radio-Frequency Module 1L According to Example 8

FIG. **12** is a plan view of a radio-frequency module **1**L according to Example 8. Incidentally, FIG. **12** illustrates, when, of the main surfaces **91***a* and **91***b* facing each other of the module substrate **91**, the main surface **91***b* is viewed from the positive side of the z axis, the layout of circuit components as seen through the main surface **91***b*. Furthermore, in FIG. **12**, although the circuit components have marks representing their functions to facilitate understanding of a layout relationship between the circuit components, these marks are not put in the actual radio-frequency module **1**L.

The radio-frequency module **1**L according to Example 8 specifically represents the layout and configuration of circuit elements constituting the radio-frequency module **1** according to the embodiment.

When compared with the radio-frequency module **1**A according to Example 1, the radio-frequency module **1**L illustrated in FIG. **12** differs from the radio-frequency module **1**A in the layout and configuration of metal electrodes **65**X and **65**Y. In the radio-frequency module **1**L according to this example, a description of a configuration that is the same as a configuration in the radio-frequency module **1**A according to Example 1 is omitted, and a description will be given below with emphasis on a configuration different from the configuration in the radio-frequency module **1**A.

The transmission filter **63**T is an example of the first acoustic wave filter and passes a transmission signal in a transmission band of the first band. The transmission filter **63**T has the bottom surface **63***a* (first bottom surface) and the top surface **63***b* (first top surface) facing each other. The bottom surface **63***a* faces the main surface **91***b* and is disposed closer to the main surface **91***b* than the top surface **63***b*.

The transmission filter **62**T is an example of the second acoustic wave filter and passes a transmission signal in a transmission band of the second band. The transmission filter **62**T has the bottom surface **62***a* (second bottom surface) and the top surface **62***b* (second top surface) facing each other. The bottom surface **62***a* faces the main surface **91***b* and is disposed closer to the main surface **91***b* than the top surface **62***b*.

The metal electrode **65**Y is an example of the first metal electrode and is joined to the top surface **63***b*.

The metal electrode **65**X is an example of a second metal electrode and is joined to the top surface **62***b*.

The metal electrode **65**Y and the metal electrode **65**X are isolated from each other and formed on the plane containing the top surface **63***b* and on the plane containing the top surface **62***b*.

In the above-described configuration, heat generated by the transmission filter **63**T can be dissipated from the top surface **63***b* without necessarily passing through the module substrate **91**, and heat generated by the transmission filter **62**T can be dissipated from the top surface **62***b* without necessarily passing through the module substrate **91**. Furthermore, since the metal electrode **65**Y and the metal electrode **65**X are isolated from each other and formed, transmission signals in different bands (frequencies) can be kept from interfering with each other through the metal electrodes **65**X and **65**Y. Hence, isolation between different bands can be improved while the heat dissipation of the transmission filters **62**T and **63**T is improved.

10. Effects

As described above, the radio-frequency module **1**A according to the present embodiment includes the module substrate **91** having the main surfaces **91***a* and **91***b* facing each other, the transmission filter **63**T that has the bottom surface **63***a* and the top surface **63***b* facing each other and passes a radio-frequency signal, and an external connection terminal **150** disposed on the main surface **91***b*. The bottom surface **63***a* faces the main surface **91***a* and is disposed closer to the main surface **91***b* than the top surface **63***b*. The radio-frequency module **1**A further includes the metal electrode **65** joined to the top surface **63***b*.

Thus, since the metal electrode **65** is joined to the top surface **63***b*, heat generated by the transmission filter **63**T can be dissipated to the external substrate side through the metal electrode **65**. That is, heat generated by the transmission filter **63**T can be dissipated from the top surface **63***b* without necessarily passing through the module substrate **91**. Hence, the heat dissipation of the radio-frequency module **1**A can be improved.

Furthermore, the radio-frequency module **1**B further includes the power amplifier **11**, the transmission filter **62**T, and the switch **52** that switches between a connection between the power amplifier **11** and the transmission filter **63**T and a connection between the power amplifier **11** and the transmission filter **62**T.

Furthermore, in the radio-frequency module **1**B, the transmission filter **62**T may include the input-output terminal **621** connected to the switch **52**, and, when the top surface **62***b* is viewed in plan, the input-output terminal **621** and the metal electrode **65**B may overlap each other.

Thus, since the input-output terminal **621** that generates the largest amount of heat in the transmission filter **62**T and whose temperature is likely to reach a high temperature and the metal electrode **65**B overlap each other when the top surface **62***b* is viewed in plan, the heat dissipation of the transmission filter **62**T can be improved more effectively.

Furthermore, in the radio-frequency module **1**L, the transmission filter **63**T passes a transmission signal in the first band, the transmission filter **62**T passes a transmission signal in the second band, the transmission filter **62**T has the bottom surface **62***a* and the top surface **62***b* facing each other, and the bottom surface **62***a* faces the main surface **91***b* and is disposed closer to the main surface **91***b* than the top surface **62***b*. The radio-frequency module **1**L may include the metal electrode **65**Y formed on the top surface **63***b* and the metal electrode **65**X formed on the top surface **62***b*, and the metal electrode **65**Y and the metal electrode **65**X may be isolated from each other and formed on the plane containing the top surface **63***b* and on the plane containing the top surface **62***b*.

Thus, heat generated by the transmission filter **63**T can be dissipated from the top surface **63***b* without necessarily passing through the module substrate **91**, and heat generated by the transmission filter **62**T can be dissipated from the top surface **62***b* without necessarily passing through the module substrate **91**. Furthermore, since the metal electrode **65**Y and the metal electrode **65**X are isolated from each other and formed, transmission signals in different bands (frequencies) can be kept from interfering with each other through the metal electrodes **65**X and **65**Y. Hence, isolation between different bands can be improved while the heat dissipation of the transmission filters **62**T and **63**T is improved.

Furthermore, in the radio-frequency module **1**A, the power amplifier **12** may be disposed on the main surface **91***a*, the radio-frequency module **1**A may further include the via conductor **91**V formed within the module substrate **91** and connecting the main surfaces **91***a* and **91***b*, one end of the via conductor **91**V may be connected to the ground electrode of the power amplifier **12** at the main surface **91***a*, and another end of the via conductor **91**V may be connected to the external connection terminal **150** set at the ground potential at the main surface **91***b*.

Thus, as a heat dissipation path of the power amplifier **12**, of lines in the module substrate **91**, a heat dissipation path running only through the planar wiring pattern having a large thermal resistance can be excluded. Hence, heat dissipation from the power amplifier **12** to the external substrate can be improved.

Furthermore, the radio-frequency module **1**H may further include the surface-mount type inductor **48**L and the surface-mount type capacitor **48**C that are disposed on the main surface **91***b*, and the metal electrode **65**H may be joined to the top surface **62***b* of the transmission filter **62**T and may be joined to main surfaces of the inductor **48**L and the capacitor **48**C.

Thus, not only the heat dissipation of the transmission filter **62**T but also the heat dissipation of the surface mount devices constituting the radio-frequency module **1**H can be improved. Hence, the heat dissipation of the radio-frequency module **1**H can be further improved.

Furthermore, in the radio-frequency module **1**C, the metal electrode **65**C may be set at the ground.

Thus, a transmission signal and a harmonic that are radiated from the transmission filter **63**T can be suppressed, and noise can also be kept from entering the transmission filter **63**T from the outside. Hence, isolation between signals can be improved while the heat dissipation of the radio-frequency module **1**C is improved.

Furthermore, in the radio-frequency module **1**C, the metal electrode **65**C may be joined to the external connection terminal **150** on the plane containing the top surface **63***b*.

Furthermore, in the radio-frequency module **1**C, the metal electrode **65**C may be connected to the ground electrode formed on the main surface **91***b* via a bonding wire.

Furthermore, in the radio-frequency module **1**D, the metal electrode **65** may be connected to the ground electrode formed on the main surface **91***b* via the via conductor **63**V connecting the top surface **63***b* and the top surface **63***a*.

Furthermore, in the radio-frequency module **1**G, the metal electrode **65**S may be a signal electrode that inputs a radio-frequency signal to the transmission filter **63**T or outputs a radio-frequency signal from the transmission filter **63**T.

Thus, heat generated by the transmission filter **63**T can be dissipated to the external substrate side through the metal electrode **65**S. Hence, the heat dissipation of the radio-frequency module **1**G is improved.

Furthermore, the radio-frequency module **1**A may further include the low noise amplifier **21** disposed on the main surface **91***b*.

Thus, the power amplifiers **11** and **12**, and the low noise amplifier **21** are provided on both the surfaces of the module substrate **91** such that the power amplifiers **11** and **12** are separated from the low noise amplifier **21** with the module substrate **91** interposed between the power amplifiers **11** and **12** and the low noise amplifier **21**, therefore enabling an improvement in isolation between transmission and reception.

Furthermore, the radio-frequency module **1**E may further include, on the main surface **91***b*, the metal shield plate **86** disposed between the transmission filter **63**T and the low noise amplifier **21** when the module substrate **91** is viewed in plan, and the metal shield plate **86** may be joined to the ground electrode formed on the main surface **91***b* and to the metal electrode **65**.

Thus, the metal electrode **65** serves as a ground electrode, a transmission signal and a harmonic that are radiated from the transmission filter **63**T can therefore be suppressed, and noise can also be kept from entering the transmission filter **63**T from the outside. Hence, isolation between signals can be improved while the heat dissipation of the radio-frequency module **1**E is improved.

Furthermore, in the radio-frequency module **1**E, the external connection terminal **150** may be disposed between the transmission filter **63**T and the low noise amplifier **21** when the module substrate **91** is viewed in plan and may be set at the ground.

Furthermore, in the radio-frequency module **1**J, the transmission filter **63**T may include the circuit unit formed at a location closer to the bottom surface **63**a than the top surface **63**b, and the barrier metal layer **68** formed between the metal electrode **65** and the circuit unit.

Furthermore, in the radio-frequency module **1**J, the metal electrode **65** may be copper, an alloy containing copper, or a multilayer body containing copper, and the barrier metal layer **68** may be titanium, tantalum, cobalt, tungsten, or an alloy containing at least one of titanium, tantalum, cobalt, and tungsten.

This can make the degree of metal diffusion from the barrier metal layer **68** to the circuit unit lower than the degree of metal diffusion from the metal electrode **65** to the circuit unit. That is, when compared with a transmission filter in which no barrier metal layer **68** is disposed, metal can be kept from diffusing from the metal electrode **65** to the circuit unit. Hence, the deterioration in the filter bandpass characteristics of the transmission filter **63**T can be suppressed while the heat dissipation of the radio-frequency module **1**J is improved.

Furthermore, in the radio-frequency module **1**J, the transmission filter **63**T may be a surface acoustic wave filter and may include the piezoelectric layer **75**, the supporting substrate **72**, the barrier metal layer **68**, the high acoustic velocity layer **73**, the low acoustic velocity layer **74**, and the IDT electrode **77**. The supporting substrate **72**, the barrier metal layer **68**, the high acoustic velocity layer **73**, the low acoustic velocity layer **74**, the piezoelectric layer **75**, and the IDT electrode **77** may be stacked in sequence.

Furthermore, in the radio-frequency module **1**J, the transmission filter **63**T may be a bulk acoustic wave filter and may include the supporting substrate **72**, the barrier metal layer **68**, the acoustic multilayer film including the low acoustic impedance films **81** and the high acoustic impedance films **80** that are alternately stacked, the lower electrode **82** and the upper electrode **84**, and the piezoelectric layer **83**. The supporting substrate **72**, the barrier metal layer **68**, the acoustic multilayer film, the lower electrode **82**, the piezoelectric layer **83**, and the upper electrode **84** may be stacked in sequence.

Furthermore, the communication device **5** includes the RFIC **3** that processes radio-frequency signals transmitted and received by the antenna **2**, and the radio-frequency module **1** that transmits a radio-frequency signal between the antenna **2** and the RFIC **3**.

Thus, the communication device **5** can be provided in which heat dissipation of an acoustic wave filter is improved.

Other Embodiments

Although a radio-frequency module and a communication device according to the present disclosure have been described above with an embodiment, examples, and modifications, a radio-frequency module and a communication device according to the present disclosure are not limited to the above-described embodiment, examples, and modifications. The present disclosure also encompasses another embodiment achieved by combining any components in the above-described embodiment, examples, and modifications, modifications obtained by making various modifications conceived by a person skilled in the art to the above-described embodiment, examples, and modifications within the scope of the gist of the present disclosure, and various devices including the above-described radio-frequency modules and communication device.

For example, although, in Examples 1 to 3, a configuration is provided in which the transmission filter **63**T is disposed on the main surface **91**b and the metal electrode **65** is joined to the top surface **63**b, a radio-frequency module according to the present disclosure may have a configuration in which, in place of the transmission filter **63**T or in addition to the transmission filter **63**T, at least one reception filter of the reception filters **61**R to **63**R is disposed on the main surface **91**b and a top surface of this reception filter is joined to a metal electrode.

Thus, since the metal electrode is joined to the top surface of the reception filter, heat generated by the reception filter can be dissipated to the external substrate side through the metal electrode. That is, heat generated by the reception filter can be dissipated from the top surface of the reception filter without necessarily passing through the module substrate **91**. Hence, the heat dissipation of the radio-frequency module can be improved.

For example, in the radio-frequency modules according to the above-described embodiment, examples, and modifications, circuit components constituting each radio-frequency module are disposed on both the surfaces of the module substrate **91**, whereas each circuit component may be disposed on only the second main surface of the module substrate. That is, each circuit component constituting the above-described radio-frequency module may be mounted on one surface of the module substrate or may be mounted on both the surfaces.

For example, in the radio-frequency modules and the communication device according to the above-described embodiment, examples, and modifications, another circuit element, a line, and so forth may be inserted between paths connecting circuit elements and signal paths that are illustrated in the drawings.

INDUSTRIAL APPLICABILITY

The present disclosure can be widely used, as a radio-frequency module disposed in a multiband front-end section, in communication equipment, such as mobile phones.

REFERENCE SIGNS LIST

- **1**, **1**A, **1**B, **1**C, **1**D, **1**E, **1**F, **1**G, **1**H, **1**J, **1**K, **1**L radio-frequency module
- **2** antenna
- **3** RF signal processing circuit (RFIC)
- **4** baseband signal processing circuit (BBIC)
- **5** communication device
- **11**, **12** power amplifier
- **13** PA control circuit
- **13**a, **13**b, **91**a, **91**b main surface
- **13**V, **63**V, **91**V via conductor
- **21** low noise amplifier
- **41**, **42**, **43**, **44**, **45**, **46**, **47** matching network
- **48**C capacitor
- **48**L inductor
- **51**, **52**, **53** switch
- **61**, **62**, **63** duplexer
- **61**R, **62**R, **63**R reception filter
- **61**T, **62**T, **63**T transmission filter
- **62**a, **63**a bottom surface
- **62**b, **63**b top surface
- **65**, **65**B, **65**C, **65**G, **65**H, **65**S, **65**X, **65**Y metal electrode
- **68** barrier metal layer
- **71** semiconductor IC
- **72** supporting substrate
- **73** high acoustic velocity layer
- **74** low acoustic velocity layer

75, **83** piezoelectric layer
76, **160** bump electrode
77 IDT electrode
80 high acoustic impedance film
81 low acoustic impedance film
82 lower electrode
84 upper electrode
85 metal shield layer
86, **86**A, **86**B, **86**C, **87** metal shield plate
86*x* body portion
86*y* junction portion
86*z* hole
88 bonding wire
91 module substrate
92, **93** resin member
95G ground electrode layer
96 resist layer
100 antenna connection terminal
111, **112** transmission input terminal
120 reception output terminal
130 control signal terminal
150 external connection terminal
200 external substrate
621, **631** input-output terminal

The invention claimed is:

1. A radio-frequency module comprising:

a module substrate having a first main surface and a second main surface facing each other;

a first acoustic wave filter having a first bottom surface and a first top surface facing each other, and configured to pass a radio-frequency signal;

an external connection terminal on the second main surface; and

a first metal electrode,

wherein the first bottom surface faces the second main surface and is closer to the second main surface than the first top surface, and

wherein the first metal electrode is joined to the first top surface.

2. The radio-frequency module according to claim **1**, further comprising:

a power amplifier;

a second acoustic wave filter; and

a first switch configured to switch connection of the power amplifier between the first acoustic wave filter and the second acoustic wave filter.

3. The radio-frequency module according to claim **2**,

wherein the first acoustic wave filter comprises a first input-output terminal connected to the first switch, and

wherein the first input-output terminal and the first metal electrode overlap each other in a plan view of the radio-frequency module.

4. The radio-frequency module according to claim **2**,

wherein the first acoustic wave filter passes a transmission signal in a first band,

wherein the second acoustic wave filter passes a transmission signal in a second band different from the first band,

wherein the second acoustic wave filter has a second bottom surface and a second top surface facing each other,

wherein the second bottom surface faces the second main surface and is closer to the second main surface than the second top surface,

wherein the radio-frequency module further comprises a second metal electrode on the second top surface, and

wherein the first metal electrode and the second metal electrode are isolated from each other, and are on a plane comprising the first top surface and on a plane comprising the second top surface.

5. The radio-frequency module according to claim **2**,

wherein the power amplifier is on the first main surface,

wherein the radio-frequency module further comprises a first via conductor within the module substrate that connects the first main surface and the second main surface, and

wherein a first end of the first via conductor is connected to a ground electrode of the power amplifier at the first main surface, and a second end of the first via conductor is connected to the external connection terminal set at ground potential at the second main surface.

6. The radio-frequency module according to claim **1**, further comprising:

a surface mount device on the second main surface,

wherein the first metal electrode is joined to a main surface of the surface mount device.

7. The radio-frequency module according to claim **1**, wherein the first metal electrode is at a ground potential.

8. The radio-frequency module according to claim **7**, wherein the first metal electrode is joined to the external connection terminal on a plane comprising the first top surface.

9. The radio-frequency module according to claim **7**, wherein the first metal electrode is connected to a ground electrode on the second main surface via a bonding wire.

10. The radio-frequency module according to claim **7**, wherein the first metal electrode is connected to a ground electrode on the second main surface via a second via conductor that connects the first bottom surface and the first top surface.

11. The radio-frequency module according to claim **1**, wherein the first metal electrode is a signal electrode configured to input the radio-frequency signal to the first acoustic wave filter or configured to output the radio-frequency signal from the first acoustic wave filter.

12. The radio-frequency module according to claim **1**, further comprising:

a low noise amplifier on the second main surface.

13. The radio-frequency module according to claim **12**, further comprising:

a metal shield plate on the second main surface between the first acoustic wave filter and the low noise amplifier in a plan view of the module substrate,

wherein the metal shield plate is joined to a ground electrode on the second main surface and to the first metal electrode.

14. The radio-frequency module according to claim **12**, wherein the external connection terminal is between the first acoustic wave filter and the low noise amplifier in the plan view, and is at a ground potential.

15. The radio-frequency module according to claim **1**,

wherein the first acoustic wave filter comprises:

a circuit closer to the first bottom surface than the first top surface, and

a metal layer between the first metal electrode and the circuit, and

wherein the metal layer is a barrier metal.

16. The radio-frequency module according to claim **1**,

wherein the first acoustic wave filter comprises:

a circuit closer to the first bottom surface than the first top surface, and

a metal layer between the first metal electrode and the circuit, wherein the first metal electrode is copper, an alloy containing copper, or a multilayer body containing copper, and

wherein the metal layer is titanium, tantalum, cobalt, tungsten, or an alloy comprising titanium, tantalum, cobalt, or tungsten.

17. The radio-frequency module according to claim **15**,

wherein the first acoustic wave filter is a surface acoustic wave filter and comprises:

a piezoelectric layer;

a supporting substrate;

the metal layer;

a high acoustic velocity layer in which an acoustic velocity of a bulk wave that propagates through the high acoustic velocity is higher than an acoustic wave that propagates along the piezoelectric layer;

a low acoustic velocity layer in which an acoustic velocity of a bulk wave that propagates through the low acoustic velocity layer is lower than a bulk wave that propagates through the piezoelectric layer; and

an interdigital transducer (IDT) electrode on the piezoelectric layer, and

wherein the supporting substrate, the metal layer, the high acoustic velocity layer, the low acoustic velocity layer, the piezoelectric layer, and the IDT electrode are stacked in sequence, the metal layer being between the supporting substrate and the high acoustic velocity layer, the high acoustic velocity layer being between the metal layer and the low acoustic velocity layer, the low acoustic velocity layer being between the high acoustic velocity layer and the piezoelectric layer, and the piezoelectric layer being between the low acoustic velocity layer and the IDT electrode.

18. The radio-frequency module according to claim **15**,

wherein the first acoustic wave filter is a bulk acoustic wave filter and comprises:

a supporting substrate;

the metal layer;

an acoustic multilayer film comprising a low acoustic impedance film and a high acoustic impedance film that are alternately stacked;

a first electrode and a second electrode; and

a piezoelectric layer, and

wherein the supporting substrate, the metal layer, the acoustic multilayer film, the first electrode, the piezoelectric layer, and the second electrode are stacked in sequence, the metal layer being between the supporting substrate and the acoustic multifilm layer, the acoustic multilayer film being between the metal layer and the first electrode, the first electrode being between acoustic multilayer film and the piezoelectric layer, and the piezoelectric layer being between the first electrode and the second electrode.

19. A communication device comprising:

a radio-frequency (RF) signal processing circuit configured to process radio-frequency signals transmitted and received by an antenna; and

the radio-frequency module according to claim **1** configured to pass a radio-frequency signal between the antenna and the RF signal processing circuit.

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