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(54) ANTENNA MODULE AND COMMUNICATION DEVICE EQUIPPED WITH THE SAME

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(57) ABSTRACT

An antenna module includes a dielectric substrate, a ground electrode disposed in the dielectric substrate, flat-plate-shaped radiating elements, feed lines, and a via electrode connected to the ground electrode. The radiating element is disposed opposite the ground electrode in the dielectric substrate. The radiating element is disposed between the radiating element and the ground electrode. The feed line extends through the radiating element and transmits a radio-frequency signal to the radiating element. The feed line transmits a radio-frequency signal to the radiating element. The feed line is electrically coupled to the radiating element at a position offset from a center of the radiating element in a first direction. The feed line is electrically coupled to the radiating element at a position offset from a center of the radiating element in a second direction different from the first direction.

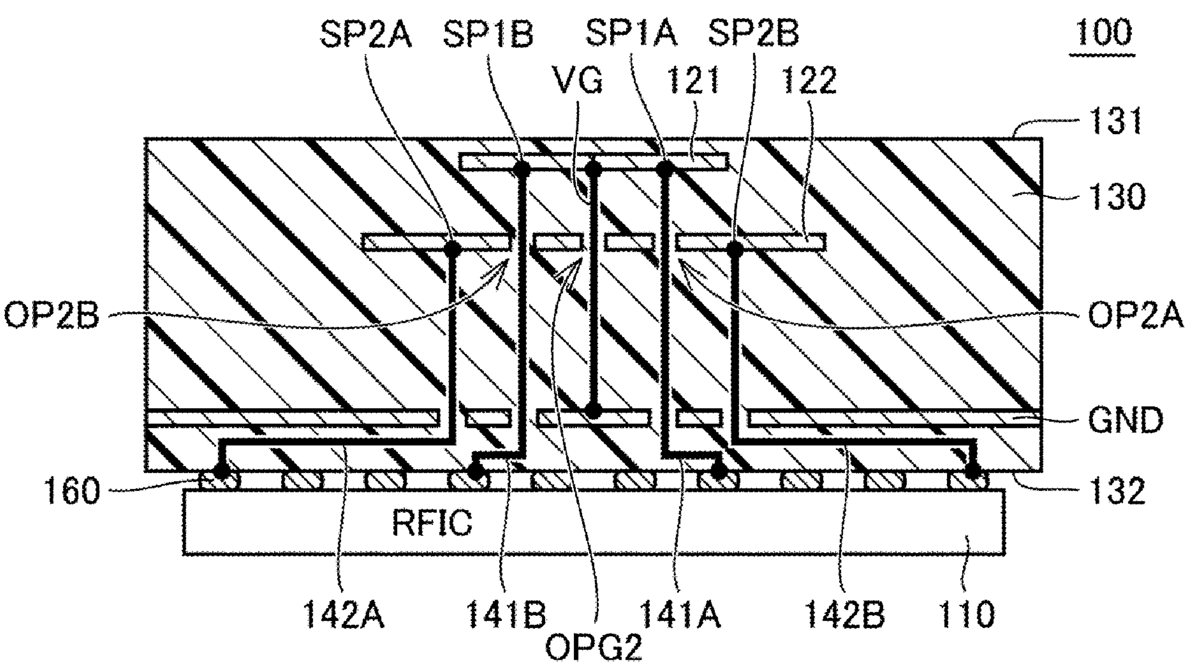


FIG.1

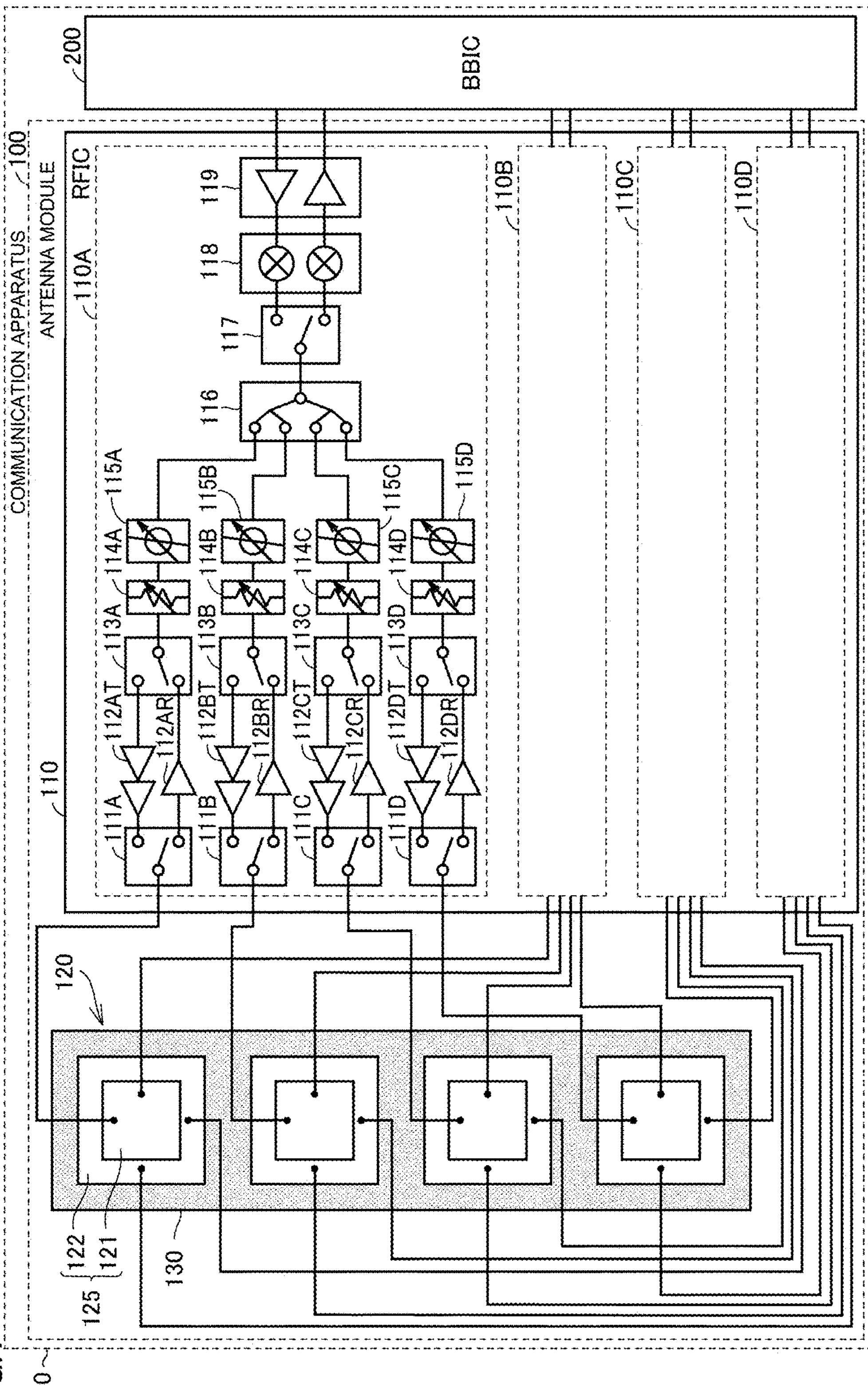

10
COMMUNICATION APPARATUS
100
ANTENNA MODULE
RFIC
110
110A
110B
110C
110D
200
BBIC
111A
111B
111C
111D
112AT
112AR
112BT
112BR
112CT
112CR
112DT
112DR
113A
113B
113C
113D
114A
114B
114C
114D
115A
115B
115C
115D
116
117
118
119
120
121
122
125
130

FIG.2

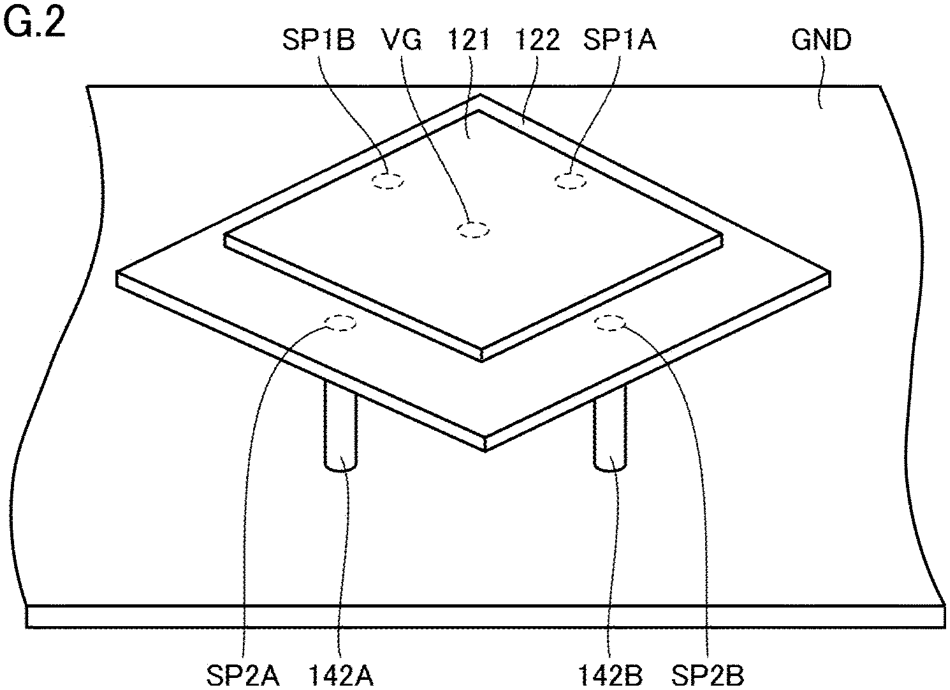

SP1B
VG
121
122
SP1A
GND
SP2A
142A
142B
SP2B

FIG.3

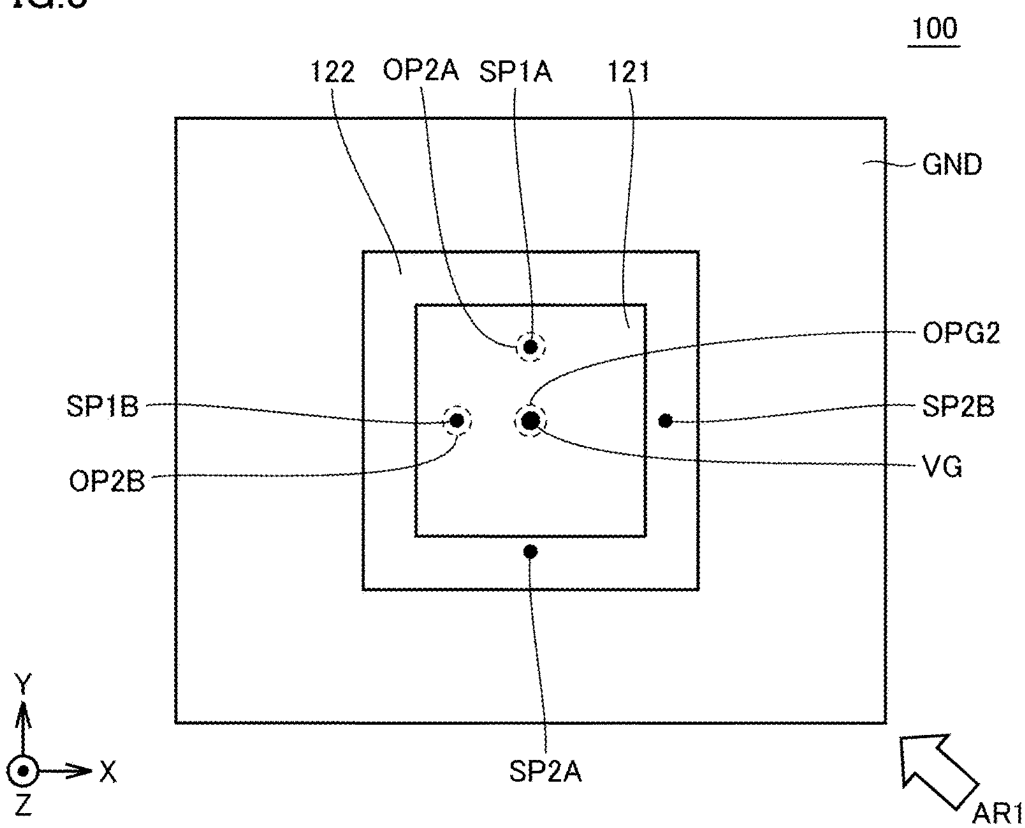
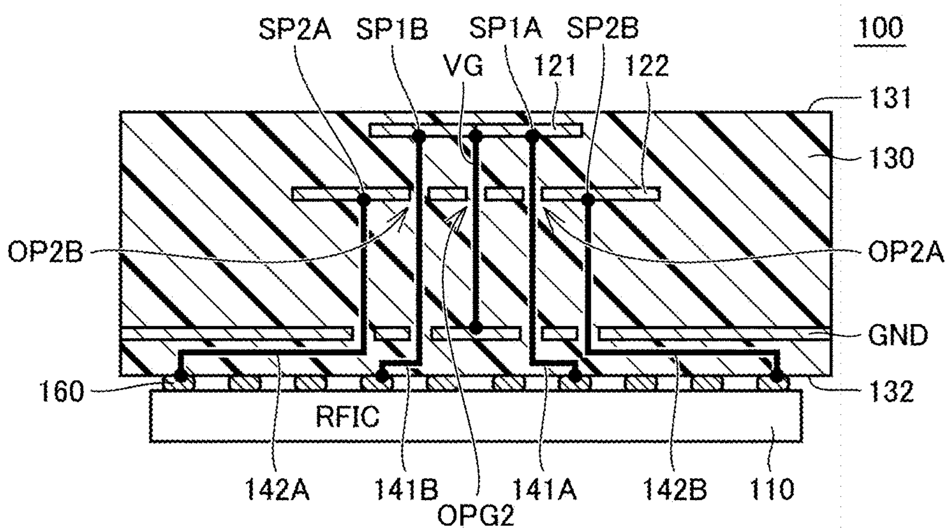

100
122
OP2A
SP1A
121
GND
OPG2
SP1B
SP2B
OP2B
VG
SP2A
Y
X
Z
AR1

FIG.4



SP2A
SP1B
SP1A
SP2B
100
VG
121
122
131
130
OP2B
OP2A
GND
160
132
RFIC
142A
141B
141A
142B
110
OPG2

FIG.5

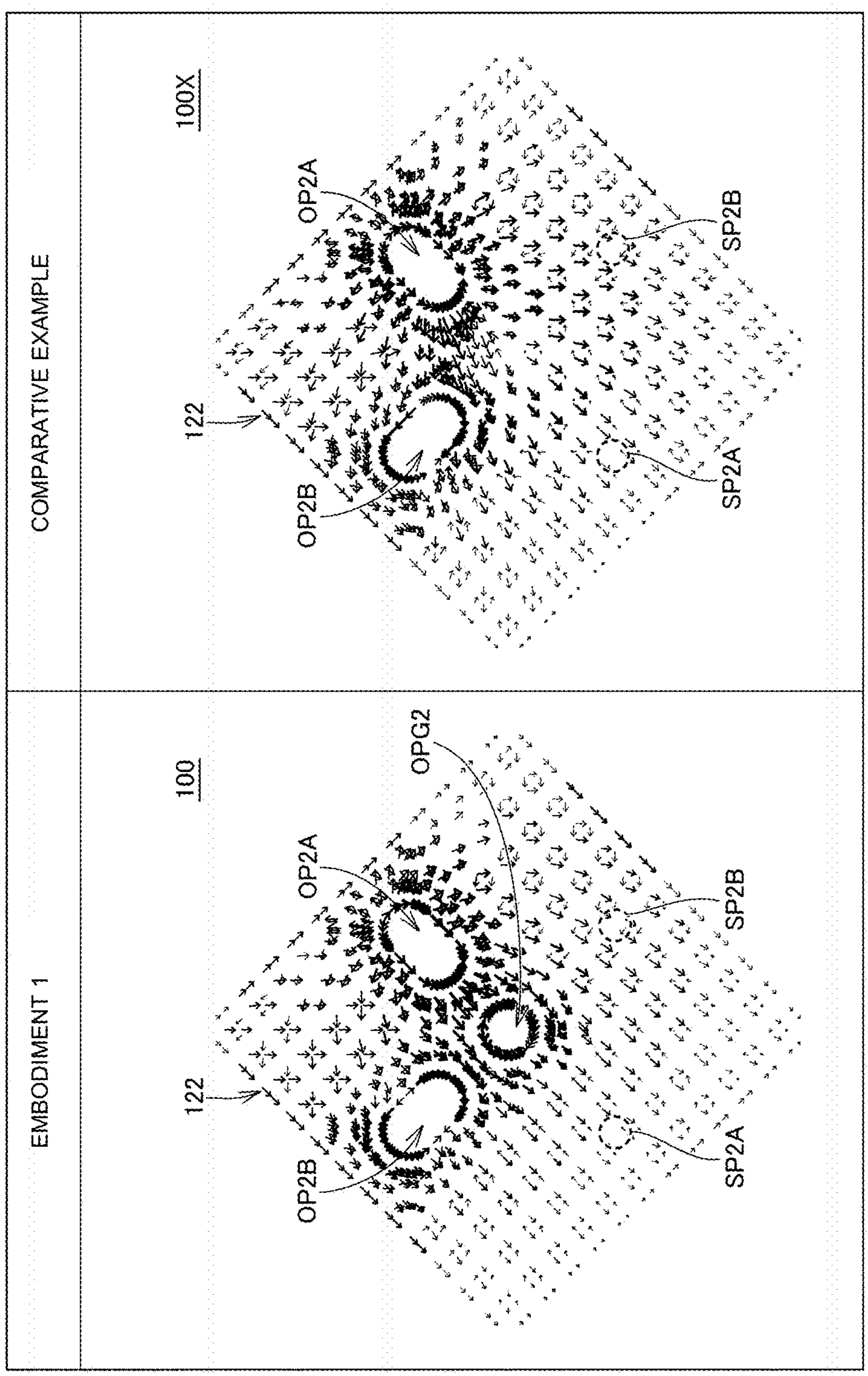

EMBODIMENT 1
COMPARATIVE EXAMPLE
100
100X
122
OP2A
OP2B
OPG2
SP2A
SP2B
122
OP2A
OP2B
SP2A
SP2B

FIG.6

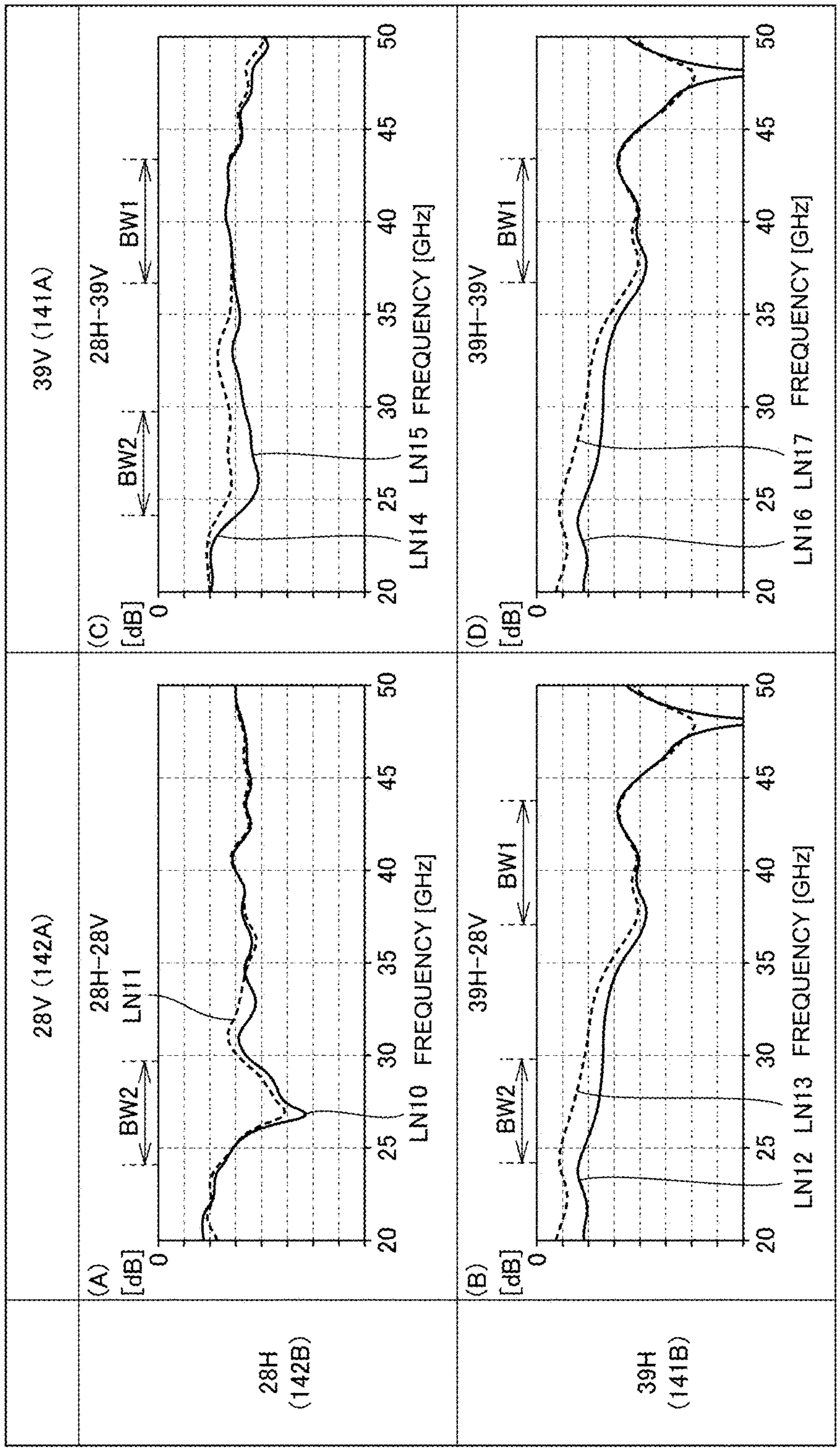

28V (142A)
39V (141A)
28H (142B)
39H (141B)
(A)
28H-28V
(B)
39H-28V
(C)
28H-39V
(D)
39H-39V
[dB]
0
BW1
BW2
LN10
LN11
LN12
LN13
LN14
LN15
LN16
LN17
20
25
30
35
40
45
50
FREQUENCY [GHz]

FIG.7

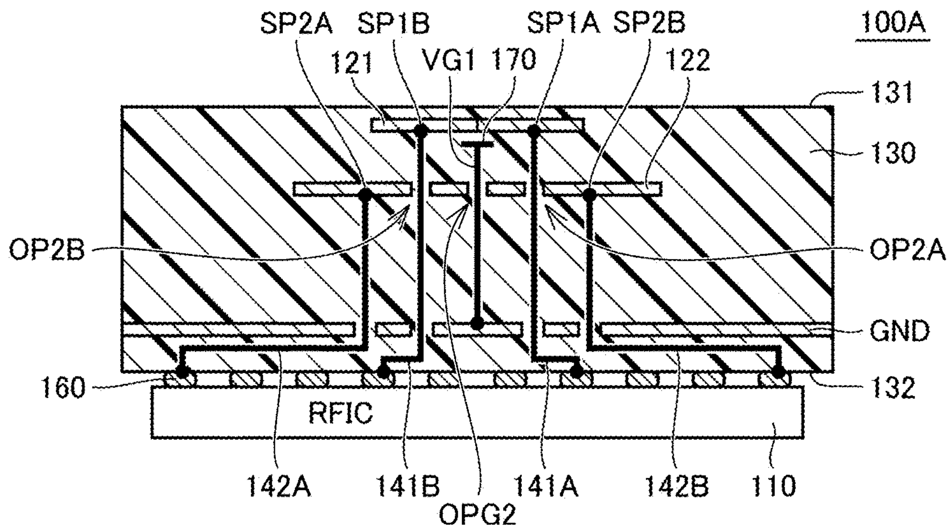

SP2A
SP1B
SP1A
SP2B
100A
121
VG1
170
122
131
130
OP2B
OP2A
GND
160
132
RFIC
142A
141B
141A
142B
110
OPG2

FIG.8

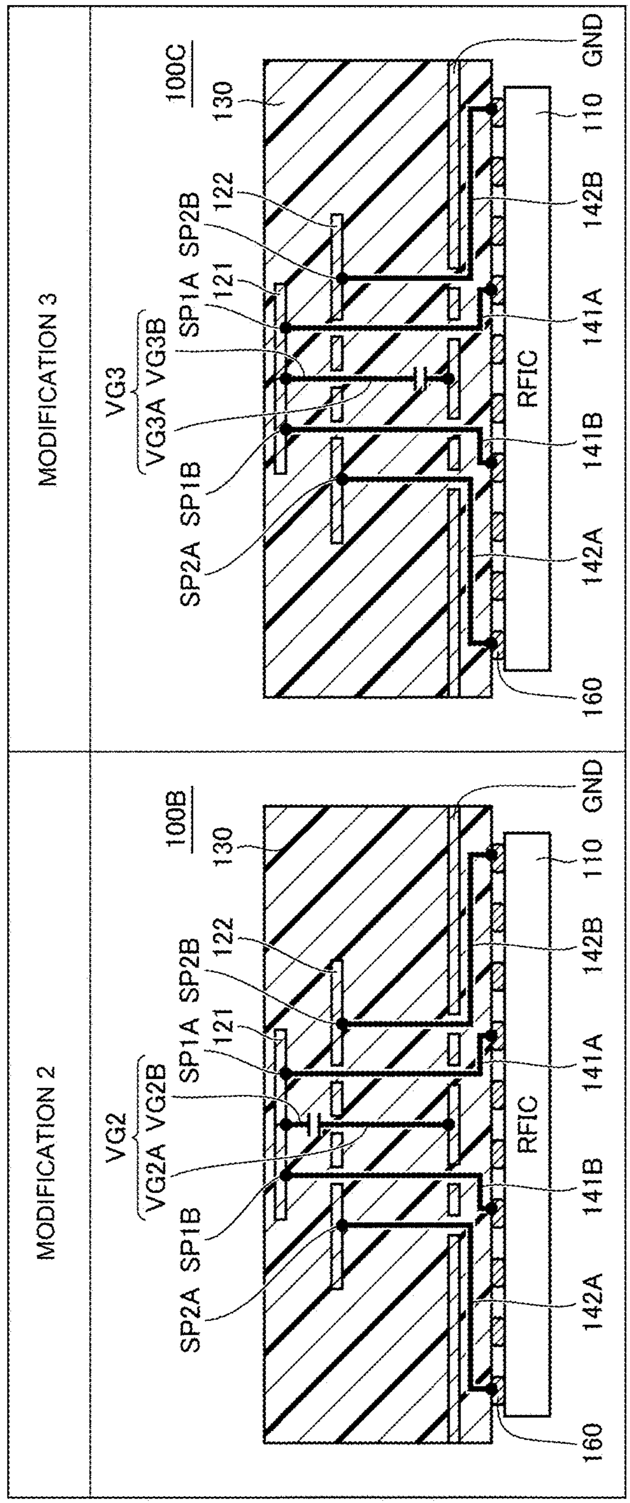

MODIFICATION 2
100B
130
122
SP1A SP2B
121
VG2
VG2A VG2B
SP2A SP1B
GND
110
142B
141A
RFIC
141B
142A
160
MODIFICATION 3
100C
130
122
SP1A SP2B
121
VG3
VG3A VG3B
SP2A SP1B
GND
110
142B
141A
RFIC
141B
142A
160

FIG.9

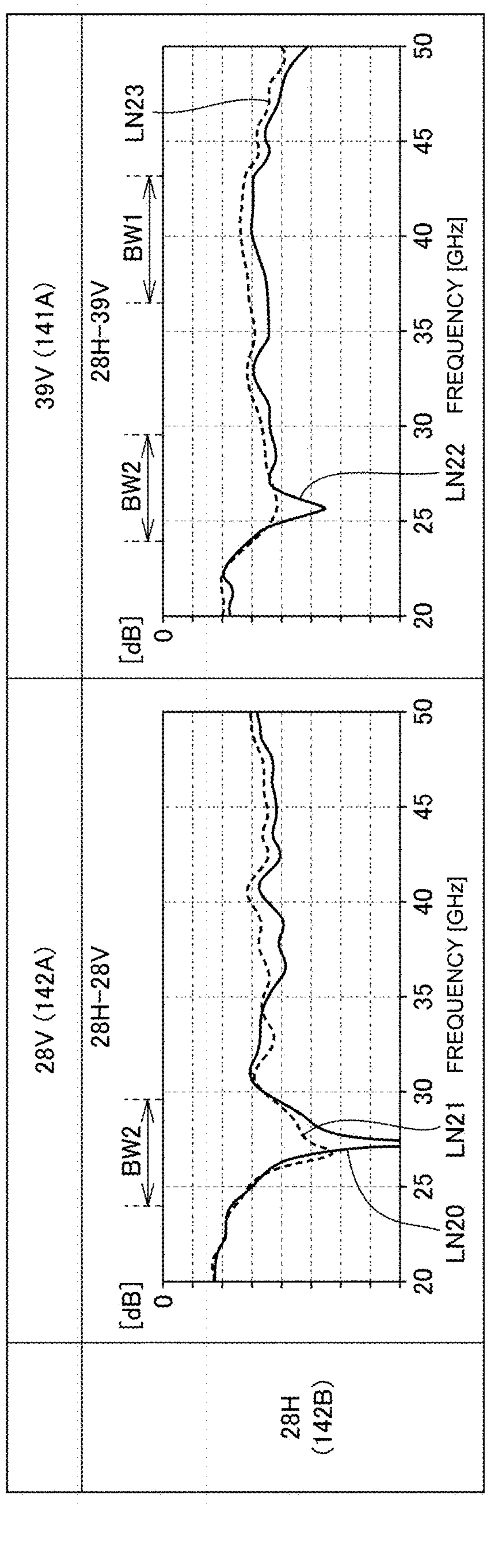

28H
(142B)
28V (142A)
28H-28V
39V (141A)
28H-39V
[dB]
0
BW2
BW1
LN20
LN21
LN22
LN23
20
25
30
35
40
45
50
FREQUENCY [GHz]

FIG.10

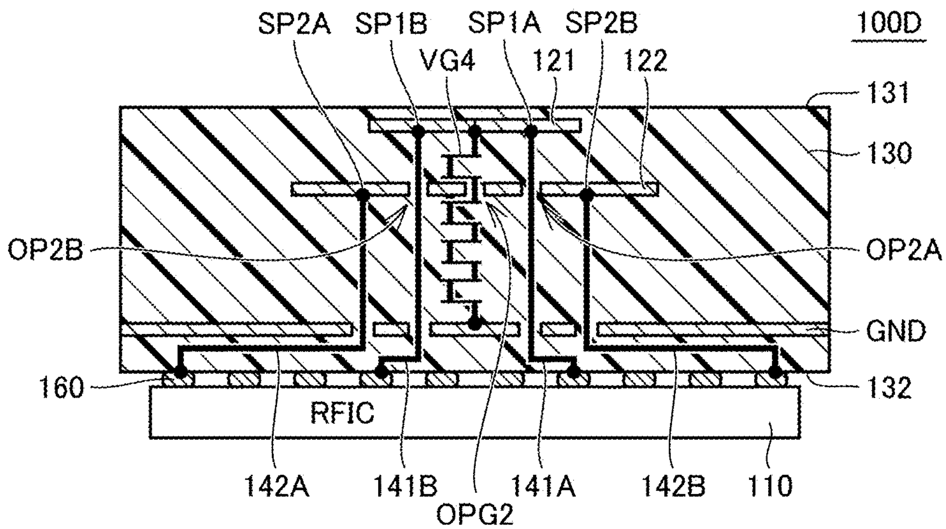

SP2A
SP1B
SP1A
SP2B
100D
VG4
121
122
131
130
OP2B
OP2A
GND
160
132
RFIC
142A
141B
141A
142B
110
OPG2

FIG.11

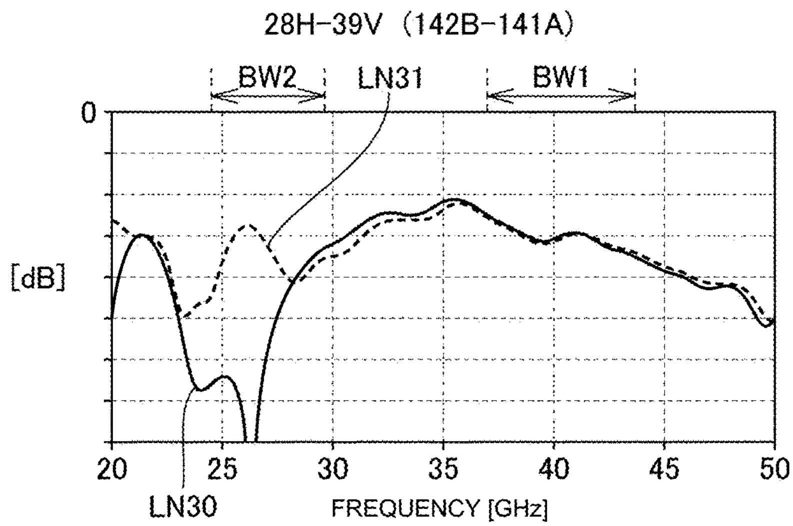
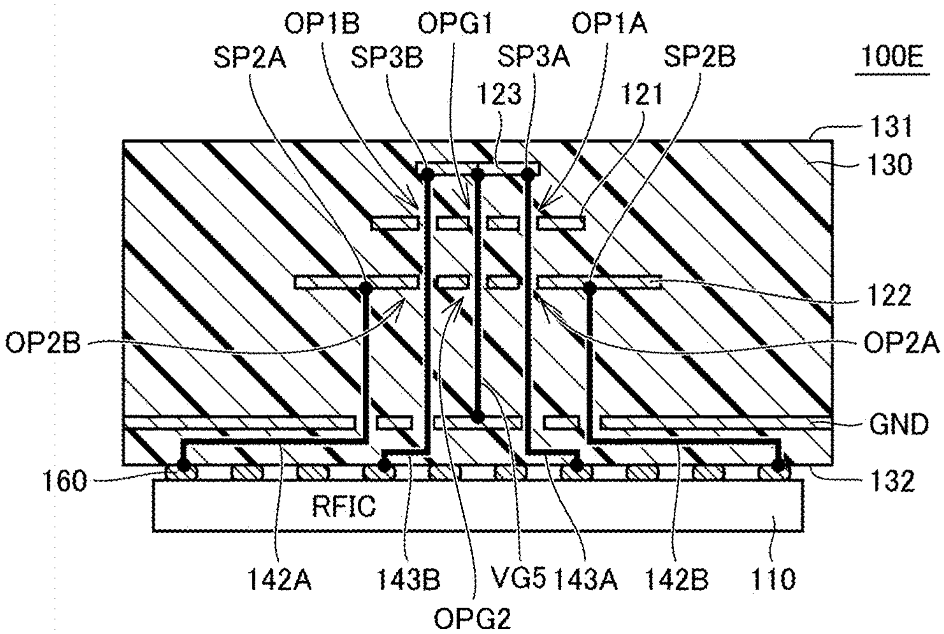
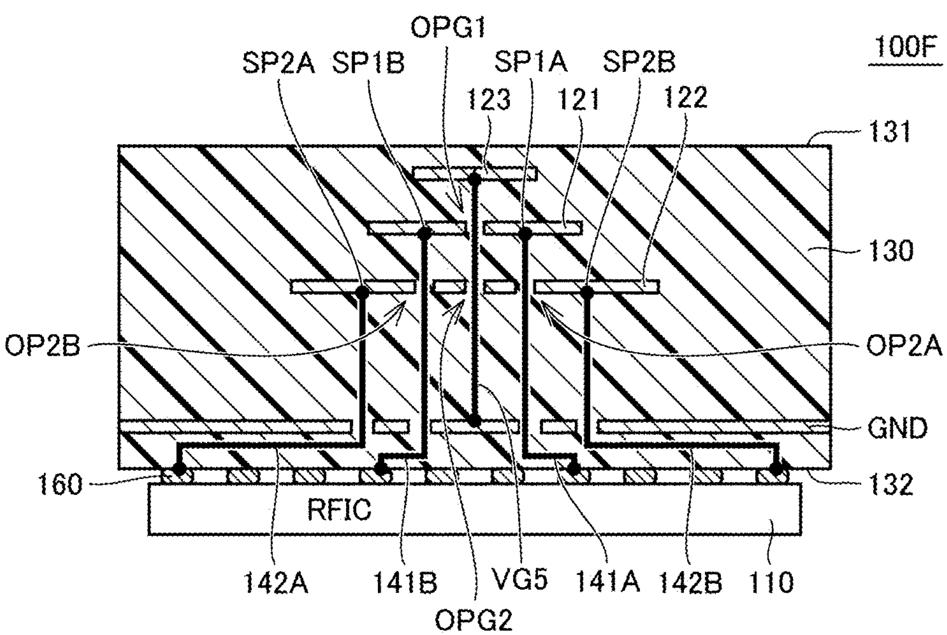

28H-39V (142B-141A)
BW2
LN31
BW1
0
[dB]
20
25
30
35
40
45
50
LN30
FREQUENCY [GHz]

FIG.12



OP1B
OPG1
OP1A
SP2A
SP3B
SP3A
SP2B
100E
123
121
131
130
122
OP2B
OP2A
GND
160
132
RFIC
142A
143B
VG5
143A
142B
110
OPG2

FIG.13



OPG1
SP2A
SP1B
SP1A
SP2B
100F
123
121
122
131
130
OP2B
OP2A
GND
160
132
RFIC
142A
141B
VG5
141A
142B
110
OPG2

ANTENNA MODULE AND COMMUNICATION DEVICE EQUIPPED WITH THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a continuation of International Application PCT/JP2023/033504, filed Sep. 14, 2023, which contains subject matter related to Japanese priority document JP 2022-193790, filed Dec. 2, 2022, the entire contents of each of which being incorporated by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to an antenna module and a communication device equipped with the same and, more specifically, to a technique for improving isolation in the antenna module.

BACKGROUND ART

[0003] U.S. Patent Application Publication No. 2021/0367358 (Patent Document 1) discloses a dual-band, dual-polarization patch antenna that can radiate two different radio waves and radiate radio waves in two different polarization directions. In the patch antenna, to improve isolation between feed pins for respective radiating elements, a ground pin is connected to the central portions of two stacked radiating elements.

CITATION LIST

Patent Document

[0004] Patent Document 1: U.S. Patent Application Publication No. 2021/0367358

SUMMARY

Technical Problems

[0005] Antenna modules, such as that described above, may be used in mobile communication devices, typified by mobile phones or smartphones. In such mobile communication devices, communication using radio waves in a plurality of frequency bands is conducted to improve communication quality and communication speed. Meanwhile, and among other things, the need for improved antenna characteristics remains high, and there is demand for further improvement in isolation between different frequency bands.

[0006] The present disclosure has been made to deal with such an issue, as well as other issues, and aims to improve isolation between feed ports in a dual-band antenna module.

Solutions to Problems

[0007] As a non-limiting example, an antenna module according to a first aspect of the present disclosure includes a dielectric substrate, a ground electrode disposed in the dielectric substrate, a flat-plate-shaped first radiating element, a flat-plate-shaped second radiating element, a first feed line, a second feed line, and a via electrode connected to the ground electrode. The first radiating element is disposed opposite the ground electrode in the dielectric substrate. The second radiating element is disposed between the first radiating element and the ground electrode. The first feed line extends through the second radiating element and conveys a radio-frequency signal to the first radiating element. The second feed line conveys a radio-frequency signal to the second radiating element. The first feed line is electrically coupled to the first radiating element at a position offset from a center of the first radiating element in a first direction. The second feed line is electrically coupled to the second radiating element at a position offset from a center of the second radiating element in a second direction different from the first direction. A size of the second radiating element is larger than a size of the first radiating element. An opening portion is formed in a central portion of the second radiating element. The via electrode extends through the opening portion of the second radiating element and is electrically coupled to a central portion of the first radiating element.

[0008] An antenna module according to a second aspect of the present disclosure includes a dielectric substrate, a ground electrode disposed in the dielectric substrate, a flat-plate-shaped first radiating element, a flat-plate-shaped second radiating element, a first feed line, a second feed line, and a via electrode connected to the ground electrode. The first radiating element is disposed opposite the ground electrode in the dielectric substrate. The second radiating element is disposed between the first radiating element and the ground electrode. The first feed line extends through the second radiating element and conveys a radio-frequency signal to the first radiating element. The second feed line conveys a radio-frequency signal to the second radiating element. The first feed line is electrically coupled to the first radiating element at a position offset from a center of the first radiating element in a first direction. The second feed line is electrically coupled to the second radiating element at a position offset from a center of the second radiating element in a second direction different from the first direction. A size of the second radiating element is larger than a size of the first radiating element. An opening portion is formed in a central portion of the second radiating element. The via electrode extends through the opening portion of the second radiating element.

[0009] An antenna module according to a third aspect of the present disclosure includes a dielectric substrate, a ground electrode disposed in the dielectric substrate, a flat-plate-shaped first radiating element, a flat-plate-shaped second radiating element, a first feed line, a second feed line, and a via electrode having a first end portion and a second end portion. The first radiating element is disposed opposite the ground electrode in the dielectric substrate. The second radiating element is disposed between the first radiating element and the ground electrode. The first feed line extends through the second radiating element and conveys a radio-frequency signal to the first radiating element. The second feed line conveys a radio-frequency signal to the second radiating element. The first feed line is electrically coupled to the first radiating element at a position offset from a center of the first radiating element in a first direction. The second feed line is electrically coupled to the second radiating element at a position offset from a center of the second radiating element in a second direction different from the first direction. A size of the second radiating element is larger than a size of the first radiating element. An opening portion is formed in a central portion of the second radiating element. The first end portion of the via electrode is connected to the ground electrode. The second end portion of the via electrode is in a position of the second radiating element or in a position between the second radiating element and the first radiating element in a normal direction of the dielectric substrate. When viewed in plan from the normal direction of the dielectric substrate, the second end portion overlaps the opening portion.

Advantageous Effects of Disclosure

[0010] The antenna module according to the present disclosure includes two stacked radiating elements, and a radio-frequency signal to a high frequency-side radiating element (first radiating element) passes through a low frequency-side radiating element (second radiating element) and is transmitted to the first radiating element. The via electrode connected to the ground electrode extends through the opening portion formed in the central portion of the second radiating element and is electrically coupled to the central portion of the first radiating element. Such a configuration changes a current distribution in the second radiating element. Specifically, when a radio-frequency signal is fed to the first radiating element, current concentrates around the opening portion in the central portion in the second radiating element. This reduces the current flowing from the feed line going to the first radiating element to a feed point of the second radiating element in comparison with a case where there is no via electrode. This can improve isolation between feed ports.

BRIEF DESCRIPTION OF DRAWINGS

[0011] FIG. **1** is a block diagram of a communication device in which an antenna module according to Embodiment 1 is used.

[0012] FIG. **2** is a perspective view of the antenna module illustrated in FIG. **1**.

[0013] FIG. **3** is a plan view of the antenna module illustrated in FIG. **1**.

[0014] FIG. **4** is a side perspective view of the antenna module illustrated in FIG. **3** as viewed from an arrow AR**1**.

[0015] FIG. **5** includes diagrams illustrating a current distribution in a low frequency-side radiating element exhibited when power is fed to a high frequency-side radiating element in antenna modules according to Embodiment 1 and Comparative Example 1.

[0016] FIG. **6** includes graphs illustrating isolation characteristics between feed ports in the antenna modules according to Embodiment 1 and Comparative Example 1.

[0017] FIG. **7** is a side perspective view of an antenna module according to Modification 1.

[0018] FIG. **8** includes side perspective views of antenna modules according to Modification 2 and Modification 3.

[0019] FIG. **9** includes graphs illustrating isolation characteristics in the antenna module according to Modification 2.

[0020] FIG. **10** is a side perspective view of an antenna module according to Modification 4.

[0021] FIG. **11** is a graph illustrating isolation characteristics in the antenna module according to Modification 4.

[0022] FIG. **12** is a side perspective view of an antenna module according to Embodiment 2.

[0023] FIG. **13** is a side perspective view of an antenna module according to Modification 5.

DESCRIPTION OF EMBODIMENTS

[0024] Hereinafter, embodiments of the present disclosure will be described in detail with reference to the drawings. The same or corresponding components in the drawings are denoted by the same reference numerals, and the description thereof is not repeated.

Embodiment 1

(Basic Configuration of Communication Device)

[0025] FIG. **1** is a block diagram of a communication device **10** in which an antenna module **100** according to this embodiment is used. The communication device **10** is, for example, a mobile terminal, such as a mobile phone, smartphone, or tablet, or a personal computer having a communication function. Although examples of a frequency band of radio waves used in the antenna module **100** according to this embodiment include radio waves in millimeter-wave bands with center frequencies of, for example, 28 GHz, 39 GHz, and 60 GHz, radio waves in a frequency band other than the above-described bands can also be used.

[0026] Referring to FIG. **1**, the communication device **10** includes the antenna module **100**, and a BBIC **200**, which is a baseband signal processing circuit. The antenna module **100** includes a radio frequency IC (RFIC) **110**, which is an example of a feed device, and an antenna device **120**. The communication device **10** up-converts an intermediate frequency signal transmitted from the BBIC **200** to the antenna module **100** into a radio-frequency signal and radiates the radio-frequency signal from the antenna device **120**. Also, the communication device **10** down-converts a radio-frequency signal received by the antenna device **120** into an intermediate frequency signal and processes the signal in the BBIC **200**. In this context, the communication apparatus **100** is a transceiver, with receiver and transmitter components.

[0027] The antenna device **120** includes a dielectric substrate **130**, and a plurality of antenna elements **125** disposed in the dielectric substrate **130**. Although FIG. **1** illustrates an example of an array configuration in which four antenna elements **125** are disposed in a line in the dielectric substrate **130**, the number of antenna elements **125** is not limited to this. In the dielectric substrate **130**, a single antenna element **125** may be disposed, or a plurality of antenna elements **125** other than four antenna elements **125** may be disposed. Alternatively, the antenna elements **125** may be arranged in a two-dimensional array configuration.

[0028] Each antenna element **125** includes flat-plate-shaped radiating elements **121** and **122** that are different in size from each other. The radiating elements **121** and **122** are flat-plate-shaped patch antennas of circular, elliptical, or polygonal shape. In Embodiment 1, as an example, a case will be described where each radiating element is a microstrip antenna of substantially square shape. As described later with reference to FIGS. **2** to **4**, in the dielectric substrate **130**, the radiating elements **121** and **122** are disposed in a stacked configuration so as to be spaced away from each other in a normal direction of the dielectric substrate **130**.

[0029] The size of the radiating element **121** is smaller than the size of the radiating element **122**. For this reason, a frequency band of a radio wave radiated from the radiating element **121** is higher than a frequency band of a radio wave radiated from the radiating element **122**. That is, the antenna module **100** is a so-called dual-band antenna module capable of radiating radio waves in two different frequency bands. In an example in Embodiment 1, the frequency band of a radio wave radiated from the radiating element **121** is a 39 GHz band (37.0 GHz to 43.5 GHz), and the frequency band of a radio wave radiated from the radiating element **122** is a 28 GHz band (24.25 GHz to 29.5 GHz).

[0030] Furthermore, in each of the radiating elements **121** and **122**, two feed points offset from an element center in different directions are disposed, and a radio-frequency signal is fed from the RFIC **110** to each feed point. That is, the antenna module **100** is a so-called dual-polarization antenna module capable of radiating radio waves in two different polarization directions. In the example in Embodiment 1, each of the radiating elements **121** and **122** is configured to be capable of radiating radio waves in two polarization directions (first polarization direction, second polarization direction) that are orthogonal to each other.

[0031] The RFIC **110** includes four feed circuits **110**A to **110**D. The feed circuit **110**A is a circuit that feeds a radio-frequency signal for the first polarization direction of the radiating element **121**. The feed circuit **110**B is a circuit that feeds a radio-frequency signal for the second polarization direction of the radiating element **121**. The feed circuit **110**C is a circuit that feeds a radio-frequency signal for the first polarization direction of the radiating element **122**. The feed circuit **110**D is a circuit that feeds a radio-frequency signal for the second polarization direction of the radiating element **122**. Note that the feed circuits **110**A to **110**D have the same internal configuration. Thus, FIG. **1** illustrates a detailed configuration of only the feed circuit **110**A for ease of explanation, and configurations of the feed circuits **110**B to **110**D are omitted. For illustration purposes, an exemplary function of the feed circuit **110**A will be described below.

[0032] The feed circuit **110**A includes switches **111**A to **111**D, **113**A to **113**D, and **117**, power amplifiers **112**AT to **112**DT, low noise amplifiers **112**AR to **112**DR, attenuators **114**A to **114**D, phase shifters **115**A to **115**D, a signal combiner/splitter **116**, a mixer **118**, and an amplifier circuit **119**.

[0033] When a radio-frequency signal is transmitted, the switches **111**A to **111**D and **113**A to **113**D are switched to power amplifiers **112**AT to **112**DT sides, and the switch **117** is connected to a transmission-side amplifier of the amplifier circuit **119**. When a radio-frequency signal is received, the switches **111**A to **111**D and **113**A to **113**D are switched to low noise amplifiers **112**AR to **112**DR sides, and the switch **117** is connected to a reception-side amplifier of the amplifier circuit **119**.

[0034] An intermediate frequency signal transmitted from the BBIC **200** is amplified by the amplifier circuit **119** and is up-converted by the mixer **118**. A transmission signal that is an up-converted radio-frequency signal is split into four signals by the signal combiner/splitter **116**, and the signals pass through their corresponding signal paths and are fed as power to the respective different radiating elements **121**. The directivities of radio waves output from the radiating elements **121** can be adjusted by adjusting the degrees of phase shift of the phase shifters **115**A to **115**D disposed in the respective signal paths individually. Furthermore, the attenuators **114**A to **114**D adjust the intensity of a transmission signal.

[0035] Reception signals that are radio-frequency signals received by the respective radiating elements **121** are transmitted to the feed circuit **110**A of the RFIC **110**, pass through four different signal paths, and are combined in the signal combiner/splitter **116**. The combined reception signal is down-converted into an intermediate frequency signal by the mixer **118**, then amplified by the amplifier circuit **119**, and transmitted to the BBIC **200**.

[0036] The RFIC **110** is formed as, for example, a single-chip integrated circuit component including the above-described circuit configuration. Alternatively, the RFIC **110** may be formed as an individual integrated circuit component for each feed circuit. Furthermore, devices (switch, power amplifier, low noise amplifier, attenuator, and phase shifter) corresponding to each radiating element may be formed as a single-chip integrated circuit component for the corresponding radiating element.

(Structure of Antenna Module)

[0037] Next, a configuration of the antenna module **100** according to Embodiment 1 will be described in detail with reference to FIGS. **2** to **4**. FIG. **2** is a perspective view of the antenna module **100** according to Embodiment 1. FIG. **3** is a plan view of the antenna module **100** as viewed from the normal direction of the dielectric substrate **130**. FIG. **4** is a side perspective view of the antenna module **100** as viewed from a direction of an arrow AR**1** in FIG. **3**.

[0038] Note that FIGS. **2** and **3** illustrate an internal configuration with a dielectric of the dielectric substrate **130** being removed for ease of understanding. Furthermore, as illustrated in FIG. **3**, the normal direction of the dielectric substrate **130** and radiating elements **121** and **122** is a Z-axis direction, a direction along one side of two adjacent sides of the radiating elements **121** and **122** is an X axis, and a direction along the other side is a Y axis. In each figure, in some cases, a positive direction of a Z axis may be referred to as an upper side, and a negative direction may be referred to as a lower side.

[0039] Referring to FIGS. **2** to **4**, the antenna module **100** further includes feed lines **141**A, **141**B, **142**A, and **142**B, a ground electrode GND, and a via electrode VG, in addition to the RFIC **110**, the antenna element **125**, and the dielectric substrate **130**.

[0040] The dielectric substrate **130** is, for example, a Low Temperature Co-fired Ceramics (LTCC) multilayer substrate, a multilayer resin substrate formed by laminating a plurality of resin layers made of resin, such as epoxy or polyimide, a multilayer resin substrate formed by laminating a plurality of resin layers made of a Liquid Crystal Polymer (LCP) having a lower dielectric constant, a multilayer resin substrate formed by laminating a plurality of resin layers made of fluorine-based resin, a multilayer resin substrate formed by laminating a plurality of resin layers made of a polyethylene terephthalate (PET) material, or a ceramic multilayer substrate other than LTCC. Note that the dielectric substrate **130** does not necessarily have a multilayer structure and may be a single-layer substrate.

[0041] At a position close to an upper surface **131** of the dielectric substrate **130**, the radiating element **121** is disposed. The radiating element **121** may be disposed so as to be exposed at the surface of the dielectric substrate **130**, or may be disposed at an inner layer of the dielectric substrate **130** as illustrated in an example in FIG. **4**. At a position close to a lower surface **132** of the dielectric substrate **130**, the ground electrode GND is disposed over the entire surface of the dielectric substrate **130**. The radiating element **121** is disposed opposite the ground electrode. Furthermore, the RFIC **110** is mounted on the lower surface **132** of the dielectric substrate **130** with solder bumps **160**. Note that the RFIC **110** may be mounted on the dielectric substrate **130** by using a connector disposed in the RFIC **110** in place of the solder bumps. Alternatively, the RFIC **110** may be disposed in or on a wiring board of a device where the antenna module **100** is installed and feed a radio-frequency signal from there to a radiating element via a connector.

[0042] The radiating element **122** is disposed between the radiating element **121** and the ground electrode GND in the dielectric substrate **130**. The radiating element **122** is disposed opposite the dielectric substrate **130** and the radiating element **121**. When the dielectric substrate **130** is viewed in plan from the normal direction as illustrated in FIG. **3**, the radiating elements **121** and **122** are disposed such that the element centers coincide with each other and they overlap each other.

[0043] Radio-frequency signals are fed from the RFIC **110** to the radiating element **121** via the feed lines **141**A and **141**B. The feed line **141**A extends from the RFIC **110** to a position under the radiating element **121** in a dielectric layer on a lower surface **132** side below the ground electrode GND, then extends through the ground electrode GND and an opening portion OP**2**A of the radiating element **122**, and is connected to a feed point SP**1**A of the radiating element **121**. Similarly, the feed line **141**B extends from the RFIC **110** to a position under the radiating element **121** in the dielectric layer on the lower surface **132** side below the ground electrode GND, then extends through the ground electrode GND and an opening portion OP**2**B of the radiating element **122**, and is connected to a feed point SP**1**B of the radiating element **121**.

[0044] As illustrated in FIG. **3**, the feed point SP**1**A is offset from the element center of the radiating element **121** in a positive direction of the Y axis. When a radio-frequency signal is fed to the feed point SP**1**A, a radio wave with a polarization direction along the Y axis is radiated from the radiating element **121** in the Z-axis direction. Furthermore, the feed point SP**1**B is offset from the element center of the radiating element **121** in a negative direction of the X axis. When a radio-frequency signal is fed to the feed point SP**1**B, a radio wave with a polarization direction along the X axis is radiated from the radiating element **121** in the Z-axis direction.

[0045] Radio-frequency signals are fed from the RFIC **110** to the radiating element **122** via the feed lines **142**A and **142**B. The feed line **142**A extends from the RFIC **110** to a position under the radiating element **122** in the dielectric layer on the lower surface **132** side below the ground electrode GND, then extends through the ground electrode GND, and is connected to a feed point SP**2**A of the radiating element **122**. Similarly, the feed line **142**B extends from the RFIC **110** to a position under the radiating element **122** in the dielectric layer on the lower surface **132** side below the ground electrode GND, then extends through the ground electrode GND, and is connected to a feed point SP**2**B of the radiating element **122**.

[0046] As illustrated in FIG. **3**, the feed point SP**2**A is offset from the element center of the radiating element **122** in a negative direction of the Y axis. When a radio-frequency signal is fed to the feed point SP**2**A, a radio wave with a polarization direction along the Y axis is radiated from the radiating element **122** in the Z-axis direction. Furthermore, the feed point SP**2**B is offset from the element center of the radiating element **122** in a positive direction of the X axis. When a radio-frequency signal is fed to the feed point SP**2**B, a radio wave with a polarization direction along the X axis is radiated from the radiating element **122** in the Z-axis direction.

[0047] The via electrode VG connects the ground electrode GND and the radiating element **121**. In other words, a lower-side end portion (first end portion) of the via electrode VG is connected to the ground electrode GND, and an upper-side end portion (second end portion) of the via electrode VG is connected to the radiating element **121**. The via electrode VG extends through an opening portion OPG**2** formed in a central portion of the radiating element **122** from the ground electrode GND and is connected to the center of the radiating element **121**. Note that, in the opening portion OPG**2**, the via electrode VG is not in contact with the radiating element **122**.

(Antenna Characteristics)

[0048] In a stack-type antenna module, such as that described above, when radio-frequency signals are fed to the high frequency-side radiating element **121** via the feed lines **141**A and **141**B, current also flows to the radiating element **122** functioning as a ground electrode for the radiating element **121**. At this time, in the radiating element **122**, when current flows to paths connecting the opening portions OP**2**A and OP**2**B of the radiating element **122** through which the feed lines **141**A and **141**B extend and the feed points SP**2**A and SP**2**B of the radiating element **122**, coupling may be generated between a high frequency-side feed path and a low frequency-side feed path, and isolation characteristics may decrease.

[0049] Here, in the antenna module **100** according to Embodiment 1, as described above, the via electrode VG connected to the center of the radiating element **121** extends through the opening portion OPG**2** formed in the central portion of the radiating element **122** and is connected to the ground electrode GND. When the via electrode VG at a ground potential is adjacent to the opening portion OPG**2** without being in contact with the opening portion OPG**2** in this way, a capacitor is formed between an edge portion of the opening portion OPG**2** and the via electrode VG, and thus current concentrates at the edge portion of the opening portion OPG**2**. In particular, for radio-frequency signals, current is likely to concentrate at an edge portion of a conductor due to edge effects, and thus the above-described disposition of the via electrode VG facilitates the concentration of current at the edge portion of the opening portion OPG**2**.

[0050] This changes a current distribution on the radiating element **122**. A current density increases at edge portions of the opening portions OP**2**A and OP**2**B through which the feed lines **141**A and **141**B extend and the opening portion OPG**2** through which the via electrode VG extends, as well as between these opening portions, and a current density in the other portions relatively decreases. As a result, in comparison with a case where there is no via electrode VG, current that flows to paths connecting the opening portions OP**2**A and OP**2**B of the radiating element **122** through which the feed lines **141**A and **141**B extend and the feed points SP**2**A and SP**2**B of the radiating element **122** decreases, enabling an improvement in isolation between feed ports in different frequency bands.

[0051] FIG. **5** includes diagrams illustrating examples of simulations of a current distribution in the low frequency-side radiating element **122** exhibited when power is fed to the high frequency-side radiating element **121** in the antenna module **100** according to Embodiment 1 and an antenna module **100**X according to Comparative Example 1 including no via electrode VG. In FIG. **5**, an arrow marked in the plane of the radiating element **122** indicates a direction of current, and the size of the arrow indicates the intensity of the current.

[0052] As illustrated in FIG. **5**, in Comparative Example 1, current intensity around the opening portions OP**2**A and OP**2**B through which the feed lines **141**A and **141**B extend is high, and current between the opening portions OP**2**A and OP**2**B is somewhat strong.

[0053] On the other hand, in the configuration in Embodiment 1, current intensity is large at the edge portion of the opening portion OPG**2** through which the via electrode VG passes in addition to the opening portions OP**2**A and OP**2**B. That is, current concentrates in proximity to and around the opening portions OP**2**A and OP**2**B and opening portion OPG**2** of the radiating element **122**. Furthermore, along with this, a direction of current flowing in the vicinity of the feed points SP**2**A and SP**2**B of the radiating element **122** changes, and current intensity is somewhat low. That is, isolation between the feed lines **141**A and **141**B and the feed lines **142**A and **142**B is improved.

[0054] FIG. **6** includes graphs illustrating simulation results of isolation characteristics between feed ports in the antenna module **100** according to Embodiment 1 and the antenna module **100**X according to Comparative Example 1. In each graph in FIG. **6**, a solid line (LN**10**, LN**12**, LN**14**, LN**16**) indicates a case of the antenna module **100** according to Embodiment 1, and a dashed line (LN**11**, LN**13**, LN**15**, LN**17**) indicates a case of the antenna module **100**X according to Comparative Example 1. In FIG. **6**, note that feed ports corresponding to the feed lines **141**A and **141**B are respectively denoted by 39V and 39H and feed ports corresponding to the feed lines **142**A and **142**B are respectively denoted by 28V and 28H. Furthermore, a frequency band on a high frequency side is denoted by BW**1**, and a frequency band on a low frequency side is denoted by BW**2**.

[0055] Referring to FIG. **6**, a graph (A) illustrates isolation characteristics between the low frequency-side feed lines **142**A and **142**B. In the graph (A), it can be seen that the isolation characteristics in the antenna module **100** according to Embodiment 1 are improved in comparison with those in the antenna module **100**X according to Comparative Example 1 in the frequency band BW**2** on the low frequency side.

[0056] A graph (B) illustrates isolation characteristics between the low frequency-side feed line **142**A and the high frequency-side feed line **141**B. Furthermore, a graph (C) illustrates isolation characteristics between the low frequency-side feed line **142**B and the high frequency-side feed line **141**A. In both the graphs (B) and (C), a little improvement effect is seen in the frequency band BW**1**, whereas the isolation characteristics in the antenna module **100** are improved in comparison with those in the antenna module **100**X in both the frequency bands BW**1** and BW**2**.

[0057] A graph (D) illustrates isolation characteristics between the high frequency-side feed lines **141**A and **141**B. In the graph (D) as well, the isolation characteristics in the antenna module **100** are improved in comparison with those in the antenna module **100**X in the frequency band BW**1** on the high frequency side.

[0058] As described above, in a stack-type dual-band, dual-polarization antenna module, a via electrode extending through an opening portion formed in a central portion of a low frequency-side radiating element and electrically connecting a high frequency-side radiating element and a ground electrode is provided, thereby enabling an improvement in isolation characteristics between different polarized waves in the same frequency band and a different frequency band.

[0059] Incidentally, although, in the antenna module **100**, both the radiating elements **121** and **122** are of a dual-polarization type, they do not necessarily have to be of the dual-polarization type. Even in an antenna module in which each radiating element is of a single-polarization type, isolation characteristics can be improved as long as a polarization direction of a radio wave radiated from the radiating element **121** differs from a polarization direction of a radio wave radiated from the radiating element **122**.

[0060] "Radiating elements **121** and **122**" in Embodiment 1 respectively correspond to "first radiating element" and "second radiating element" in the present disclosure. "Feed lines **141**A and **141**B" in Embodiment 1 respectively correspond to "first feed line" and "third feed line" in the present disclosure. "Feed lines **142**A and **142**B" in Embodiment 1 respectively correspond to "second feed line" and "fourth feed line" in the present disclosure. In Embodiment 1, "positive direction of the Y axis" and "negative direction of the Y axis" respectively correspond to "first direction" and "fourth direction" in the present disclosure, and "negative direction of the X axis" and "positive direction of the X axis" respectively correspond to "second direction" and "third direction" in the present disclosure.

Modifications 1 to 3

[0061] In the antenna module **100** according to Embodiment 1, although the via electrode VG is directly connected to the radiating element **121**, the via electrode VG and the radiating element **121** do not necessarily have to be directly connected to each other as long as they are electrically coupled to each other. FIG. **7** is a side perspective view of an antenna module **100**A according to Modification 1. The antenna module **100**A differs from the antenna module **100** according to Embodiment 1 illustrated in FIG. **4** in that the via electrode VG is replaced with a via electrode VG**1**, and all other components except for the via electrode VG**1** are the same as those in FIG. **4**. In FIG. **7**, a repeated description of elements that are the same as those in FIG. **4** is not given.

[0062] The via electrode VG**1** is not directly connected to the radiating element **121**, but is capacitively coupled to the radiating element **121** via a flat-plate electrode **170** disposed opposite the radiating element **121**.

[0063] Note that a position of the flat-plate electrode **170**, that is, a position of the upper-side end portion (second end portion) of the via electrode VG**1** may be the same position as the radiating element **122** or any position between the radiating element **122** and the radiating element **121** in the normal direction of the dielectric substrate **130**. At this time, when viewed in plan from the normal direction of the dielectric substrate **130**, the second end portion of the via electrode VG**1** overlaps the opening portion OPG**2** of the radiating element **122**.

[0064] Furthermore, a position of capacitive coupling in the via electrode is not limited to a boundary portion with the radiating element **121**. For example, as with an antenna module **100**B according to Modification 2 and an antenna module **100**C according to Modification 3 in FIG. **8**, a via electrode may be divided at some point, and capacitive coupling may be provided at a portion where the division is made.

[0065] A via electrode VG**2** in the antenna module **100**B according to Modification 2 includes a first portion VG**2**A connected to the ground electrode GND, and a second portion VG**2**B connected to the radiating element **121**. The first portion VG**2**A and the second portion VG**2**B are capacitively coupled to each other in a layer between the radiating element **121** and the radiating element **122**.

[0066] A via electrode VG**3** in the antenna module **100**C according to Modification 3 includes a first portion VG**3**A connected to the ground electrode GND, and a second portion VG**3**B connected to the radiating element **121**. The first portion VG**3**A and the second portion VG**3**B are capacitively coupled to each other in a layer between the radiating element **122** and the ground electrode GND.

[0067] FIG. **9** includes graphs illustrating an example of isolation characteristics in the above-described antenna module **100**B according to Modification 2. FIG. **9** illustrates isolation characteristics between the low frequency-side feed lines **142**A and **142**B and isolation characteristics between the low frequency-side feed line **142**B and the high frequency-side feed line **141**A in the antenna module **100**B as compared with those in the antenna module **100** according to Embodiment 1. In FIG. **9**, a solid line (LN**20**, LN**22**) indicates a case of the antenna module **100**B according to Modification 2, and a dashed line (LN**21**, LN**23**) indicates a case of the antenna module **100** according to Embodiment 1.

[0068] As illustrated in FIG. **9**, in the antenna module **100**B according to Modification 2, the isolation characteristics between the feed lines **142**A and **142**B in the frequency band BW**2** and the isolation characteristics between the feed lines **141**A and **142**B in the frequency bands BW**1** and BW**2** are improved in comparison with those in the antenna module **100** according to Embodiment 1.

[0069] As described above, even in a configuration in which a via electrode is partially capacitively coupled, when the via electrode extends through the opening portion OPG**2** formed in the central portion of the radiating element **122**, current concentrates at the edge portion of the opening portion OPG**2** of the radiating element **122** as illustrated in FIG. **5**, enabling an improvement in isolation characteristics between feed ports. Note that a phase of current that flows through the via electrode can change depending on the position of capacitive coupling in the via electrode. For that reason, the position of capacitive coupling suitable for improvement in isolation characteristics may differ depending on the frequency band of a radio wave to be radiated. In other words, when the position of capacitive coupling is set in accordance with the frequency band of a radio wave to be radiated, isolation characteristics can be adjusted.

Modification 4

[0070] In each embodiment described above, the via electrode extends in a straight line from the ground electrode GND toward the radiating element **121**. In Modification 4, a configuration will be described in which vias in different layers that constitute the via electrode are offset between the ground electrode GND and the radiating element **121**.

[0071] FIG. **10** is a side perspective view of an antenna module **100**D according to Modification 4. In the antenna module **100**D, the via electrode VG in the antenna module **100** according to Embodiment 1 is replaced with a via electrode VG**4**, and all other components are the same as those in the antenna module **100**. In FIG. **10**, a repeated description of elements that are the same as those in FIG. **4** is not given.

[0072] Referring to FIG. **10**, the via electrode VG**4** includes a plurality of vias and a plurality of flat-plate electrodes in the form of strips that are disposed alternately. For that reason, when the antenna module **100**D is viewed from the side, in the via electrode VG**4**, vias in different layers that constitute the via electrode VG**4** are offset between the ground electrode GND and the radiating element **121**. In other words, the via electrode VG**4** is disposed so as to extend in a zigzag line from the ground electrode GND toward the radiating element **121**. At this time, the path length of the via electrode VG**4** can be changed by adjusting the length of each flat-plate electrode. When the path length of the via electrode VG**4** is changed, an inductance value of the via electrode VG**4** changes, and impedance changes. Thus, when the shape of the via electrode VG**4** is changed in accordance with, for example, the frequency band of a radio wave to be radiated, isolation characteristics can be adjusted.

[0073] In FIG. **10**, for ease of explanation of the structure of the via electrode VG**4**, note that the flat-plate electrodes in the via electrode VG**4** are drawn so as to extend in a lateral direction (that is, a direction from the feed point SP**1**A toward the feed point SP**1**B) in FIG. **10**. However, in a case where the antenna module **100**D is of a dual-polarization type, to equalize the influence on two polarized waves, it is desirable that the direction in which the flat-plate electrodes of the via electrode VG**4** extend be a direction to a position equidistant from the feed point SP**1**A and the feed point SP**1**B. In other words, it is desirable that the flat-plate electrodes of the via electrode VG**4** extend in the direction of the arrow AR**1** illustrated in FIG. **3**.

[0074] Alternatively, in addition to a configuration in which the via electrode includes vias offset in two layers, a portion where partial capacitive coupling is provided may be provided in the via electrode as in Modifications 1 to 3, and isolation characteristics may be adjusted by changing a capacitance value together with an inductance value.

[0075] FIG. **11** is a graph illustrating isolation characteristics in the antenna module **100**D according to Modification 4. FIG. **11** illustrates, as an example, isolation characteristics between the high frequency-side feed line **141**A and the low frequency-side feed line **142**B. In FIG. **11**, a solid line LN**30** indicates a case of the antenna module **100**D according to Modification 4, and a dashed line LN**31** indicates a case of the antenna module **100** according to Embodiment 1.

[0076] As illustrated in FIG. **11**, although both the antenna modules **100**D and **100** are comparable in terms of isolation characteristics in the frequency band BW**1** on the high frequency side, the isolation characteristics in the antenna module **100**D according to Modification 4 are improved in comparison with those in the antenna module **100** in the frequency band BW**2** on the low frequency side.

[0077] As described above, the configuration in which vias in different layers that constitute the via electrode are offset between the ground electrode GND and the radiating element **121** enables isolation characteristics to be improved in comparison with the case where the via electrode extends in a straight line.

Embodiment 2

[0078] In Embodiment 1 and Modifications 1 to 4, the configuration has been described in which two feed elements are disposed in a stacked configuration. In Embodiment 2 and Modification 5 to be described, a configuration will be described in which a parasitic element is disposed in a stacked configuration in addition to two feed elements.

[0079] FIG. **12** is a side perspective view of an antenna module **100**E according to Embodiment 2. In the antenna module **100**E, in addition to the antenna module **100** according to Embodiment 1, a radiating element **123** is further disposed closer to the upper surface **131** of the dielectric substrate **130** than the radiating element **121**. Furthermore, in the antenna module **100**E, feed lines **143**A and **143**B and a via electrode VG**5** are provided in place of the feed lines **141**A and **141**B and the via electrode VG of the antenna module **100**.

[0080] In the antenna module **100**E, the radiating element **121** is a parasitic element, and the radiating element **123** is a feed element. In the radiating element **121**, opening portions OPG**1**, OP**1**A, and OP**1**B are formed.

[0081] The feed line **143**A extends through the opening portion OP**2**A of the radiating element **122** and the opening portion OP**1**A of the radiating element **121** from the RFIC **110** and is connected to a feed point SP**3**A of the radiating element **123**. The feed line **143**B extends through the opening portion OP**2**B of the radiating element **122** and the opening portion OP**1**B of the radiating element **121** from the RFIC **110** and is connected to a feed point SP**3**B of the radiating element **123**. Furthermore, the via electrode VG**5** extends through the opening portion OPG**2** formed in the central portion of the radiating element **122** and the opening portion OPG**1** formed in a central portion of the radiating element **121** and is electrically coupled to the center of the radiating element **123**. Note that the via electrode VG**5** may be capacitively coupled to the radiating element **123**.

[0082] The size of the radiating element **123** is smaller than the size of the radiating element **121**. Thus, when radio-frequency signals corresponding to a resonant frequency of the radiating element **123** are fed to the radiating element **123** via the feed lines **143**A and **143**B, radio waves in a higher frequency band than that of the radiating element **121** are radiated from the radiating element **123**. Furthermore, when radio-frequency signals corresponding to a resonant frequency of the radiating element **121** are fed to the feed lines **143**A and **143**B, radio waves are radiated from the radiating element **121**. In other words, the antenna module **100**E can function as a triple-band antenna module capable of radiating radio waves in three different frequency bands (for example, 28 GHz, 39 GHz, and 60 GHz).

[0083] Incidentally, when the resonant frequency of the radiating element **123** is set to a frequency (for example, 46 GHz) that is slightly higher than the frequency band of the radiating element **121** and at which the radiating element **121** can also resonate, the frequency band of the radiating element **121** can be effectively expanded.

[0084] Furthermore, "radiating elements **121**, **122**, and **123**" in Embodiment 2 respectively correspond to "third radiating element", "second radiating element", and "first radiating element" in the present disclosure. "Feed line **143**A" and "feed line **143**B" in Embodiment 2 respectively correspond to "first feed line" and "third feed line" in the present disclosure.

Modification 5

[0085] In Modification 5, a configuration will be described in which a parasitic element is disposed closer to the upper surface of the dielectric substrate than two feed elements.

[0086] FIG. **13** is a side perspective view of an antenna module **100**F according to Modification 5. In the antenna module **100**F, as with the antenna module **100**E according to Embodiment 2, the radiating element **123** that is smaller in size than the radiating element **122** is further disposed closer to the upper surface **131** of the dielectric substrate **130** than the radiating element **121**. In the antenna module **100**F, however, the radiating elements **121** and **122** are feed elements, and the radiating element **123** is a parasitic element.

[0087] More specifically, in the radiating element **121**, as with the antenna module **100** according to Embodiment 1, radio-frequency signals are fed to the feed points SP**1**A and SP**1**B via the feed lines **141**A and **141**B, respectively. Furthermore, in the radiating element **122**, radio-frequency signals are fed to the feed points SP**2**A and SP**2**B via the feed lines **142**A and **142**B, respectively. The via electrode VG**5** extends through the opening portion OPG**2** formed in the central portion of the radiating element **122** and the opening portion OPG**1** formed in the central portion of the radiating element **121** and is electrically coupled to the center of the radiating element **123**.

[0088] In the case of the antenna module **100**F, no radio-frequency signals can be fed to the radiating element **123** individually as in the antenna module **100**E according to Embodiment 2. In the antenna module **100**F, the size of the radiating element **123** is set to be slightly smaller than the size of the radiating element **121**, and, when a radio-frequency signal is fed to the radiating element **121**, the radiating element **123** is also configured to resonate. This enables the frequency band of the radiating element **121** to be expanded toward high frequencies.

[0089] Furthermore, "radiating elements **121**, **122**, and **123**" in Modification 5 respectively correspond to "first radiating element", "second radiating element", and "fourth radiating element" in the present disclosure.

Aspects

[0090] (1) An antenna module according to an aspect includes a dielectric substrate, a ground electrode disposed in the dielectric substrate, a flat-plate-shaped first radiating element, a flat-plate-shaped second radiating element, a first feed line, a second feed line, and a via electrode connected to the ground electrode. The first radiating element is disposed opposite the ground electrode in the dielectric substrate. The second radiating element is disposed between the first radiating element and the ground electrode. The first feed line extends through the second radiating element and transmits a radio-frequency signal to the first radiating element. The second feed line transmits a radio-frequency signal to the second radiating element. The first feed line is electrically coupled to the first radiating element at a position offset from a center of the first radiating element in a first direction. The second feed line is electrically coupled to the second radiating element at a position offset from a center of the second radiating element in a second direction different from the first direction. A size of the second radiating element is larger than a size of the first radiating element. An opening portion is formed in a central portion of the second radiating element. The via electrode extends through the opening portion of the second radiating element and is electrically coupled to a central portion of the first radiating element.

[0091] (2) In the antenna module according to (1), the via electrode is connected to the first radiating element.

[0092] (3) In the antenna module according to (1), the via electrode is capacitively coupled to the first radiating element.

[0093] (4) In the antenna module according to any one of (1) to (3), the via electrode includes a first portion connected to the ground electrode, and a second portion capacitively coupled to the first portion and disposed between the first portion and the first radiating element.

[0094] (5) In the antenna module according to any one of (1) to (4), in the via electrode, vias in different layers that constitute the via electrode are offset between the ground electrode and the first radiating element.

[0095] (6) The antenna module according to any one of (1) to (5) further includes a third feed line that extends through the second radiating element and transmits a radio-frequency signal to the first radiating element. The third feed line is electrically coupled to the first radiating element at a position offset from the center of the first radiating element in a third direction.

[0096] (7) The antenna module according to (6) further includes a fourth feed line that transmits a radio-frequency signal to the second radiating element. The fourth feed line is electrically coupled to the second radiating element at a position offset from the center of the second radiating element in a fourth direction different from the second direction.

[0097] (8) In the antenna module according to (7), when viewed in plan from a normal direction of the dielectric substrate, the center of the first radiating element and the center of the second radiating element overlap each other. The third direction is an opposite direction to the second direction with respect to the center of the first radiating element. The fourth direction is an opposite direction to the first direction with respect to the center of the first radiating element.

[0098] (9) In the antenna module according to (8), when viewed in plan from the normal direction of the dielectric substrate, the first direction is orthogonal to the third direction.

[0099] (10) The antenna module according to (1) further includes a flat-plate-shaped third radiating element disposed between the first radiating element and the second radiating element. The first feed line and the via electrode extend through the third radiating element and reach the first radiating element. A size of the third radiating element is larger than the size of the first radiating element and is smaller than the size of the second radiating element.

[0100] (11) In the antenna module according to (1), the dielectric substrate has a first surface and a second surface facing each other. The ground electrode is disposed closer to the second surface than the first radiating element. The antenna module further includes a flat-plate-shaped fourth radiating element disposed closer to the first surface than the first radiating element. A size of the fourth radiating element is smaller than the size of the first radiating element.

[0101] (12) In the antenna module according to (11), the via electrode extends through the first radiating element and is electrically coupled to a central portion of the fourth radiating element.

[0102] (13) An antenna module according to an aspect includes a dielectric substrate, a ground electrode disposed in the dielectric substrate, a flat-plate-shaped first radiating element, a flat-plate-shaped second radiating element, a first feed line, a second feed line, and a via electrode connected to the ground electrode. The first radiating element is disposed opposite the ground electrode in the dielectric substrate. The second radiating element is disposed between the first radiating element and the ground electrode. The first feed line extends through the second radiating element and transmits a radio-frequency signal to the first radiating element. The second feed line transmits a radio-frequency signal to the second radiating element. The first feed line is electrically coupled to the first radiating element at a position offset from a center of the first radiating element in a first direction. The second feed line is electrically coupled to the second radiating element at a position offset from a center of the second radiating element in a second direction different from the first direction. A size of the second radiating element is larger than a size of the first radiating element. An opening portion is formed in a central portion of the second radiating element. The via electrode extends through the opening portion of the second radiating element.

[0103] (14) An antenna module according to an aspect includes a dielectric substrate, a ground electrode disposed in the dielectric substrate, a flat-plate-shaped first radiating element, a flat-plate-shaped second radiating element, a first feed line, a second feed line, and a via electrode having a first end portion and a second end portion. The first radiating element is disposed opposite the ground electrode in the dielectric substrate. The second radiating element is disposed between the first radiating element and the ground electrode. The first feed line extends through the second radiating element and transmits a radio-frequency signal to the first radiating element. The second feed line transmits a radio-frequency signal to the second radiating element. The first feed line is electrically coupled to the first radiating element at a position offset from a center of the first radiating element in a first direction. The second feed line is electrically coupled to the second radiating element at a position offset from a center of the second radiating element in a second direction different from the first direction. A size of the second radiating element is larger than a size of the first radiating element. An opening portion is formed in a central portion of the second radiating element. The first end portion of the via electrode is connected to the ground electrode. The second end portion of the via electrode is in a position of the second radiating element or in a position between the second radiating element and the first radiating element in a normal direction of the dielectric substrate. When viewed in plan from the normal direction of the dielectric substrate, the second end portion overlaps the opening portion.

[0104] (15) The antenna module according to any one of (1) to (14) further includes a feed device that feeds a radio-frequency signal to the first radiating element and the second radiating element.

[0105] (16) A communication device according to an aspect includes the antenna module according to any one of (1) to (15).

[0106] The embodiments disclosed here are to be considered to be illustrative and not restrictive in any respect. The scope of the present invention is defined not by the above description of the embodiments, but by the claims, and is intended to include all changes made within the meaning and scope equivalent to the claims.

REFERENCE SIGNS LIST

[0107] **10** communication device, **100**, **100**A to **100**F, **100**X antenna module, **110** RFIC, **110**A to **110**D feed circuit, **111**A to **111**D, **113**A to **113**D, **117** switch, **112**AR to **112**DR low noise amplifier, **112**AT to **112**DT power amplifier, **114**A to **114**D attenuator, **115**A to **115**D phase shifter, **116** signal combiner/splitter, **118** mixer, **119** amplifier circuit, **120** antenna device, **121** to **123** radiating element, **125** antenna element, **130** dielectric substrate, **131** upper surface, **132** lower surface, **141**A to **143**A, **141**B to **143**B feed line, **160** solder bump, **170** flat-plate electrode, **200** BBIC, BW**1**, BW**2** frequency band, GND ground electrode, OP**1**A, OP**1**B, OP**2**A, OP**2**B, OPG**1**, OPG**2** opening portion, SP**1**A to SP**3**A, SP**1**B to SP**3**B feed point, VG, VG**1** to VG**5** via electrode, VG**2**A, VG**3**A first portion, VG**2**B, VG**3**B second portion

1. An antenna module comprising:

a dielectric substrate;

a ground electrode disposed in the dielectric substrate;

a flat-plate-shaped first radiating element disposed opposite the ground electrode in the dielectric substrate;

a flat-plate-shaped second radiating element disposed between the first radiating element and the ground electrode;

a first feed line extending through the second radiating element and configured to convey radio-frequency signals to the first radiating element;

a second feed line configured to convey radio-frequency signals to the second radiating element; and

a via electrode connected to the ground electrode,

wherein the first feed line is electrically coupled to the first radiating element at a position offset in a first direction from a center of the first radiating element,

wherein the second feed line is electrically coupled to the second radiating element at a position offset in a second direction different from the first direction with respect to a center of the second radiating element,

wherein a size of the second radiating element is larger than a size of the first radiating element,

wherein an opening portion is formed in a central portion of the second radiating element, and

wherein the via electrode extends through the opening portion of the second radiating element and is electrically coupled to a central portion of the first radiating element.

2. The antenna module according to claim **1**,

wherein the via electrode is connected to the first radiating element.

3. The antenna module according to claim **1**,

wherein the via electrode is capacitively coupled to the first radiating element.

4. The antenna module according to claim **1**,

wherein the via electrode includes

a first portion connected to the ground electrode, and

a second portion capacitively coupled to the first portion and disposed between the first portion and the first radiating element.

5. The antenna module according to claim **1**,

wherein, in the via electrode, vias in different layers that constitute the via electrode are offset between the ground electrode and the first radiating element.

6. The antenna module according claim **1**, further comprising:

a third feed line extending through the second radiating element and configured to convey radio-frequency signals to the first radiating element,

wherein the third feed line is electrically coupled to the first radiating element at a position offset in a third direction different from the first direction with respect to the center of the first radiating element.

7. The antenna module according claim **5**, further comprising:

a third feed line extending through the second radiating element and configured to convey radio-frequency signals to the first radiating element,

wherein the third feed line is electrically coupled to the first radiating element at a position offset in a third direction different from the first direction with respect to the center of the first radiating element.

8. The antenna module according to claim **6**, further comprising:

a fourth feed line configured to convey radio-frequency signals to the second radiating element,

wherein the fourth feed line is electrically coupled to the second radiating element at a position offset in a fourth direction different from the second direction with respect to the center of the second radiating element.

9. The antenna module according to claim **7**, further comprising:

a fourth feed line configured to convey radio-frequency signals to the second radiating element,

wherein the fourth feed line is electrically coupled to the second radiating element at a position offset in a fourth direction different from the second direction with respect to the center of the second radiating element.

10. The antenna module according to claim **8**,

wherein, when viewed in plan from a normal direction of the dielectric substrate, the center of the first radiating element and the center of the second radiating element overlap each other,

wherein the third direction is an opposite direction to the second direction with respect to the center of the first radiating element, and

wherein the fourth direction is an opposite direction to the first direction with respect to the center of the first radiating element.

11. The antenna module according to claim **10**,

wherein, when viewed in plan from the normal direction of the dielectric substrate, the first direction is orthogonal to the third direction, and the second direction is orthogonal to the fourth direction.

12. The antenna module according to claim **1**, further comprising:

a flat-plate-shaped third radiating element disposed between the first radiating element and the second radiating element,

wherein the first feed line and the via electrode extend through the third radiating element and reach the first radiating element, and

wherein a size of the third radiating element is larger than the size of the first radiating element and is smaller than the size of the second radiating element.

13. The antenna module according to claim **1**,

wherein the dielectric substrate has a first surface and a second surface that face each other,

wherein the ground electrode is disposed closer to the second surface than the first radiating element,

wherein the antenna module further comprises a flat-plate-shaped fourth radiating element disposed closer to the first surface than the first radiating element, and

wherein a size of the fourth radiating element is smaller than the size of the first radiating element.

14. The antenna module according to claim **13**,

wherein the via electrode extends through the first radiating element and is electrically coupled to a central portion of the fourth radiating element.

15. An antenna module comprising:

a dielectric substrate;

a ground electrode disposed in the dielectric substrate;

a flat-plate-shaped first radiating element disposed opposite the ground electrode in the dielectric substrate;

a flat-plate-shaped second radiating element disposed between the first radiating element and the ground electrode;

a first feed line extending through the second radiating element and configured to convey radio-frequency signals to the first radiating element;

a second feed line configured to convey radio-frequency signals to the second radiating element; and

a via electrode connected to the ground electrode,

wherein the first feed line is electrically coupled to the first radiating element at a position offset in a first direction from a center of the first radiating element,

wherein the second feed line is electrically coupled to the second radiating element at a position offset in a second direction different from the first direction with respect to a center of the second radiating element,

wherein a size of the second radiating element is larger than a size of the first radiating element,

wherein an opening portion is formed in a central portion of the second radiating element, and

wherein the via electrode extends through the opening portion of the second radiating element.

16. An antenna module comprising:

a dielectric substrate;

a ground electrode disposed in the dielectric substrate;

a flat-plate-shaped first radiating element disposed opposite the ground electrode in the dielectric substrate;

a flat-plate-shaped second radiating element disposed between the first radiating element and the ground electrode;

a first feed line extending through the second radiating element and configured to convey radio-frequency signals to the first radiating element;

a second feed line configured to convey radio-frequency signals to the second radiating element; and

a via electrode having a first end portion and a second end portion,

wherein the first feed line is electrically coupled to the first radiating element at a position offset in a first direction from a center of the first radiating element,

wherein the second feed line is electrically coupled to the second radiating element at a position offset in a second direction different from the first direction with respect to a center of the second radiating element,

wherein a size of the second radiating element is larger than a size of the first radiating element,

wherein an opening portion is formed in a central portion of the second radiating element,

wherein the first end portion of the via electrode is connected to the ground electrode,

wherein the second end portion of the via electrode is in a position of the second radiating element or in a position between the second radiating element and the first radiating element in a normal direction of the dielectric substrate, and

wherein, when viewed in plan from the normal direction of the dielectric substrate, the second end portion overlaps the opening portion.

17. The antenna module according claim **1**, further comprising:

a feed device configured to feed a radio-frequency signal to the first radiating element and the second radiating element.

18. A communication device comprising

the antenna module according to claim **1**.

19. A communication device comprising

the antenna module according to claim **15**.

20. A communication device comprising

the antenna module according to claim **16**.

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