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ANTENNA MODULE AND COMMUNICATION APPARATUS INCLUDING THE SAME

Abstract

An antenna module is configured to receive a signal from a baseband circuit and to radiate a radio wave. The antenna module includes a dielectric substrate, radiating elements, and a connector. The dielectric substrate includes planar sections having different normal directions. A first radiating element is disposed in or on the planar section. A second radiating element is disposed in or on the planar section. The antenna module is configured to transfer a radio-frequency signal to a third radiating element, which is externally disposed, via the connector. The size of the second radiating element is smaller than that of the third radiating element.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] The present application is a continuation of international application No. PCT/JP2023/034027, filed Sep. 20, 2023, and claims priority to Japanese patent application 2022-183529, filed Nov. 16, 2022, the entire contents of each of which being incorporated herein by reference.

BACKGROUND
1. Technical Field
[0002] The present disclosure relates to an antenna module and a communication apparatus including the same, and more particularly, to a technology for reducing the height of an antenna module.
2. Description of the Related Art
[0003] International Publication No. 2020/031776 discloses the following antenna module. Two substrates whose normal directions are different from each other are disposed to form a substantially L-like shape, so that the antenna module can radiate a radio wave in two directions. Additionally, in each substrate, two radiating elements of different sizes are stacked on each other, so that the antenna module can support dual-band transmission to radiate a radio wave of two frequency bands.
SUMMARY
[0004] The above-described type of antenna module may be applicable to a mobile communication apparatus represented by a mobile phone or a smartphone. In accordance with a reduced size of a mobile communication apparatus and/or highly densified internal devices inside the communication apparatus, an even smaller and thinner antenna module is desired.
[0005] When the antenna module is disposed in a smartphone, for example, to radiate a radio wave in the direction of the side surface of the smartphone, the area of a substrate is decreased in accordance with a smaller height of the antenna module. For a patch antenna using a planar radiating element, a smaller area of the substrate, that is, a smaller area of a ground electrode, may lower the antenna gain. In particular, for a dual-band antenna module that can radiate a radio wave of two frequency bands, a smaller area of the ground electrode may be more likely to influence the antenna gain of the antenna on the lower frequency side including a relatively large radiating element.
[0006] The present disclosure has been made to address the above-described issue. Embodiments are directed to making it less likely to lower the gain of an antenna on a lower frequency side in a dual-band antenna module that can radiate a radio wave in two different directions.
[0007] An antenna module according to an aspect of the present disclosure includes a dielectric substrate, first through third radiating elements, and a first connector. The dielectric substrate includes first and second planar sections. The normal direction to the first planar section and that to the second planar section are different from each other. The first and second radiating elements are disposed in or on the first planar section. The third radiating element is disposed in or on the second planar section. The antenna module is able to transfer a radio-frequency signal to a fourth

radiating element via the first connector. The fourth radiating element is disposed externally to the dielectric substrate. The size of the first radiating element is smaller than that of the second radiating element. The size of the third radiating element is smaller than that of the fourth radiating element. The fourth radiating element is attachable to and detachable from the first connector.
[0008] An antenna module according to another aspect of the present disclosure is configured to receive a signal from a baseband circuit and to radiate a radio wave. The antenna module includes a dielectric substrate, fifth and sixth radiating elements, and a first connector. The dielectric substrate includes first and second planar sections. The normal direction to the first planar section and that to the second planar section are different from each other. The fifth radiating element is disposed in or on the first planar section. The sixth radiating element is disposed in or on the second planar section. The antenna module is able to transfer a radio-frequency signal to a seventh radiating element via the first connector. The seventh radiating element is externally disposed. The size of the sixth radiating element is smaller than that of the seventh radiating element.
[0009] In an antenna module according to the disclosure, a radiating element (third radiating element) on a relatively high frequency side is only disposed in or on the second planar section of the dielectric substrate. A radio-frequency signal is transferred to a radiating element (fourth radiating element) on a relatively low frequency side by using a connector. With this configuration, the radiating element on the lower frequency side, that is, a relatively large radiating element, which is likely to lower the gain due to a limitation on the area of the substrate, can be disposed outside the dielectric substrate. It is thus possible to suppress the degradation of the antenna gain of the radiating element on the lower frequency side, which is caused by a limitation on the area of the substrate, in a dual-band antenna module that can radiate a radio wave in two different directions.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0010] FIG. **1** is a block diagram of a communication apparatus to which an antenna module of a first embodiment is applied;
[0011] FIG. **2** is a perspective view of the antenna module in FIG. **1**;
[0012] FIG. **3** is a transparent side view of the antenna module in FIG. **2** as viewed from the X-axis direction;
[0013] FIG. **4** is a top view of the antenna module in FIG. **2** as viewed from the Z-axis direction;
[0014] FIG. **5** is a transparent side view of an antenna module according to a second embodiment;
[0015] FIG. **6** is a perspective view of an antenna module according to a modified example;
[0016] FIG. **7** is a transparent side view of the antenna module in FIG. **6** as viewed from the X-axis direction;
[0017] FIG. **8** is a side view of the antenna module in FIG. **6** as viewed from the Y-axis direction; and
[0018] FIG. **9** is a transparent side view of an antenna module according to a third embodiment.
DETAILED DESCRIPTION
[0019] Embodiments of the present disclosure will be described below in detail with reference to the drawings. The same or corresponding elements in the drawings are designated by like reference numeral and an explanation thereof will not be repeated.
First Embodiment
Basic Configuration of Communication Apparatus
[0020] FIG. **1** is a block diagram of a communication apparatus **10** to which an antenna module **100** of a first embodiment is applied. The communication apparatus **10** is a mobile terminal, such as a mobile phone, a smartphone, or a tablet, or a personal computer having a communication function, for example. An example of the frequency band of a radio wave used for the antenna

module **100** of the first embodiment is millimeter bands, such as those having 28 GHZ, 39 GHz, and 60 GHz, for example, as the center frequency. A frequency band other than the millimeter bands may be applied to a radio wave used for the antenna module **100**.

[0021] As shown in FIG. **1**, the communication apparatus **10** includes the antenna module **100** and a baseband integrated circuit (BBIC) **200**. The antenna module **100** includes a radio frequency integrated circuit (RFIC) **110**, which is an example of a feeder device, and an antenna device **120**. The communication apparatus **10** up-converts an intermediate frequency (IF) signal, which is transferred from the BBIC **200** to the antenna module **100**, into a radio-frequency signal and radiates it from the antenna device **120**. The communication apparatus **10** also down-converts a radio-frequency signal received by the antenna device **120** and processes the down-converted signal by using the BBIC **200**.

[0022] The antenna device **120** includes a planar section **131** in or on which radiating elements **121** and **122** are disposed and a planar section **135** in or on which a radiating element **125** is disposed and on which a connector **171** is disposed. As will be discussed with reference to FIG. **2**, the planar sections **131** and **135** form a dielectric substrate **130**. The antenna module **100** may also include a dielectric substrate **150** in or on which a radiating element **126** is disposed.

[0023] In or on each substrate, at least one radiating element is disposed. In the example in FIG. **1**, four radiating elements **121** and four radiating elements **122** are disposed in the planar section **131**. Four radiating elements **125** are disposed in the planar section **135**. Four radiating elements **126** are disposed in the dielectric substrate **150**. The number of radiating elements to be disposed in each substrate is not limited to four. Additionally, in the example in FIG. **1**, the radiating elements in each substrate are aligned and arranged in a linear array form. However, the radiating elements in each substrate may be arranged in a two-dimensional array form. Alternatively, a single radiating element may be disposed in each substrate.

[0024] The radiating elements **121**, **122**, **125**, and **126** are planar patch antennas having a circular, elliptical, or polygonal shape. The first embodiment will be explained, assuming that the radiating elements are microstrip antennas having a substantially square shape.

[0025] In the planar section **131**, the size of the radiating element **121** is smaller than that of the radiating element **122**. The frequency band of a radio wave radiated from the radiating element **121** is thus higher than that from the radiating element **122**. Likewise, the size of the radiating element **125** is smaller than that of the radiating element **126**. The frequency band of a radio wave radiated from the radiating element **125** is thus higher than that from the radiating element **126**. In the antenna module **100** of the first embodiment, the frequency band of a radio wave radiated from the radiating element **121** is the same as that from the radiating element **125**, while the frequency band of a radio wave radiated from the radiating element **122** is the same as that from the radiating element **126**. Hence, the antenna module **100** is what is known as a dual-band antenna module that can radiate a radio wave of two different frequency bands.

[0026] The RFIC **110** includes four feeder circuits **110**A through **110**D. The feeder circuit **110**A is a circuit for supplying a radio-frequency signal to the radiating elements **121** of the planar section **131**. The feeder circuit **110**B is a circuit for supplying a radio-frequency signal to the radiating elements **122** of the planar section **131**. The feeder circuit **110**C is a circuit for supplying a radio-frequency signal to the radiating elements **125** of the planar section **135**. The feeder circuit **110**D is a circuit for supplying a radio-frequency signal to the radiating elements **126** of the dielectric substrate **150**. The internal configurations of the feeder circuits **110**A through **110**D are the same. In FIG. **1**, for easy representation, the detailed configuration is shown only for the feeder circuit **110**A, and those of the feeder circuits **110**B through **110**D are not shown. The function of the feeder circuit **110**A will be explained below as a representative example.

[0027] The feeder circuit **110**A includes switches **111**A through **111**D, **113**A through **113**D, and **117**, power amplifiers **112**AT through **112**DT, low-noise amplifiers **112**AR through **112**DR, attenuators **114**A through **114**D, phase shifters **115**A through **115**D, a signal combiner/splitter **116**, a mixer **118**, and an amplifier circuit **119**.

[0028] When transmitting a radio-frequency signal, the switches **111**A through **111**D and **113**A through **113**D are respectively switched to the power amplifiers **112**AT through **112**DT, and the switch **117** is connected to a transmit amplifier of the amplifier circuit **119**. When receiving a radio-frequency signal, the switches **111**A through **111**D and **113**A through **113**D are respectively switched to the low-noise amplifiers **112**AR through **112**DR, and the switch **117** is connected to a receive amplifier of the amplifier circuit **119**.

[0029] An IF signal transferred from the BBIC **200** is amplified in the amplifier circuit **119** and is up-converted to a radio-frequency signal in the mixer **118**. A transmission signal, which is the up-converted radio-frequency signal, is split into four signals in the signal combiner/splitter **116**, which pass through corresponding signal paths and are supplied to the different radiating elements **121**. The degree of phase shifting in the phase shifters **115**A through **115**D disposed in the signal paths are individually adjusted, thereby making it possible to control the directivity of the waves to be output from the radiating elements **121**. The attenuators **114**A through **114**D adjust the strength of the transmission signal.

[0030] Reception signals, which are radio-frequency signals received by the radiating elements **121**, are transferred to the feeder circuit **110**A of the RFIC **110**, pass through the four different signal paths, and are combined in the signal combiner/splitter **116**. The combined reception signal is down-converted in the mixer **118** and is amplified in the amplifier circuit **119**, and is then transferred to the BBIC **200**.

[0031] A feeder line extending from the feeder circuit **110**D is connected to the connector **171** of the planar section **135**. A feeder cable **180** is connected to the connector **171** to transfer a radio-frequency signal to the radiating elements **126** in the dielectric substrate **150**, which will be discussed later with reference to FIG. **3**. That is, a radio-frequency signal is supplied to the radiating elements **126** from the feeder circuit **110**D via the connector **171**. The dielectric substrate **150** and the radiating elements **126** may be external elements outside the antenna module **100**, in which case, they are detachably attached to the antenna module **100** using the connector **171**.

[0032] The RFIC **110** is formed as, for example, a one-chip integrated circuit (IC) component including the above-described circuit configuration. The RFIC **110** may alternatively be formed as multiple IC components for the individual feeder circuits. Alternatively, the RFIC **110** may be formed as multiple one-chip IC components for the individual radiating elements, each of which corresponds to devices (switches, a power amplifier, a low-noise amplifier, an attenuator, and a phase shifter).

Structure of Antenna Module

[0033] The detailed configuration of the antenna module **100** according to the first embodiment will be described below with reference to FIGS. **2** through **4**. FIG. **2** is a perspective view of the antenna module **100** according to the first embodiment. FIG. **3** is a transparent side view of the antenna module **100** in FIG. **2** as viewed from the positive direction of the X axis. FIG. **4** is a plan view of the antenna module **100** in FIG. **2** as viewed from the positive direction of the Z axis.

[0034] As illustrated in FIGS. **2** through **4**, the dielectric substrate **130** is constituted by the planar sections **131** and **135**, as discussed above. The planar sections **131** and **135** forming the dielectric substrate **130** are formed of a low temperature co-fired ceramics (LTCC) multilayer substrate, a multilayer resin substrate formed by stacking multiple resin layers made of an epoxy or polyimide resin, for example, a multilayer resin substrate formed by stacking multiple resin layers made of a liquid crystal polymer (LCP) having a lower dielectric constant, a multilayer resin substrate formed by stacking multiple resin layers made of a fluorine resin, a multilayer resin substrate formed by stacking multiple resin layers made of a polyethylene terephthalate (PET) material, or a ceramics multilayer substrate made of ceramics other than the LTCC. The planar sections **131** and **135** may be a single layer substrate instead of a multilayer substrate.

[0035] The planar section **131** is a planar substrate having substantially rectangular main surfaces

132 and **133** that are normal to the Z-axis direction. In FIGS. **2** through **4**, the long sides of the planar section **131** are set to the X axis, while the short sides thereof are set to the Y axis.
[0036] On the main surface **133** of the planar section **131** in the positive direction of the Z axis, a system-in-package (SiP) module **105** and a connector **172** are mounted. In the antenna module **100** of the first embodiment, the SiP module **105** and the connector **172** are disposed on the main surface **133** separately from each other in the X-axis direction. As illustrated in FIGS. **2** and **4**, the SiP module **105** is disposed adjacent to the planar section **135** in the Y-axis direction.
[0037] The connector **172** is a connection member used for connecting the antenna module **100** to an external device, such as a mounting substrate **20**. The connector **172** receives an IF signal from the BBIC **200** disposed on the mounting substrate **20** and transfers the received IF signal to the SiP module **105**.
[0038] The SiP module **105** has a built-in circuit including the RFIC **110** and other devices, such as a power module IC and a power inductor, mounted on a substrate. As shown in FIG. **3**, this built-in circuit is sealed with a resin **107** and is electrically connected to the planar section **131** using a connection member, such as solder bumps **160**. A shield member **106** is provided on the periphery of the SiP module **105** to contain, i.e., prevent leakage of, an electromagnetic wave therein. The shield member **106** can prevent a leakage of an electromagnetic wave generated in the circuit within the SiP module **105** so as to reduce the influence of an electromagnetic wave on external devices. The shield member **106** can also prevent the entry of electromagnetic noise from the outside into the circuit within the SiP module **105**.
[0039] The radiating element **121** is disposed closer to the main surface **132** of the planar section **131** in the negative direction of the Z axis. The radiating element **121** may be disposed on an inner layer of the planar section **131**, as shown in FIG. **3**, or may be exposed on the main surface **132**. In the planar section **131**, a ground electrode GND**1** is disposed on the entirety of a layer, which is positioned closer to the main surface **133** than the radiating element **121** is, so as to face the radiating element **121**. The radiating element **122** is disposed on a layer between the radiating element **121** and the ground electrode GND**1** so as to face the radiating element **121** and the ground electrode GND**1**.
[0040] A radio-frequency signal is transferred from the RFIC **110** to the radiating element **121** via a feeder line **141**. The feeder line **141** extends from a solder bump **160** of the SiP module **105**, passes through the ground electrode GND**1** and the radiating element **122**, and is connected to the radiating element **121**. A radio-frequency signal is transferred from the RFIC **110** to the radiating element **122** via a feeder line **142**. The feeder line **142** extends from a solder bump **160** of the SiP module **105**, passes through the ground electrode GND**1**, and is connected to the radiating element **122**. While the planar section **131** has radiating elements **121** and **122** stacked on each other, as shown in FIG. **3**, the radiating elements **121** and **122** may be separately disposed.
[0041] The planar section **135** is a planar substrate having substantially rectangular main surfaces **136** and **137** that are normal to the Y-axis direction. That is, a normal direction to the planar section **131** is perpendicular to a normal direction to the planar section **135**. The long sides of the planar section **135** are parallel with the X axis and the short sides are parallel with the Z axis. The planar section **135** is connected to the planar section **131** at the side surface of the planar section **131** in the positive direction of the Y axis.
[0042] The planar section **131** is positioned closer to the main surface **137** of the planar section **135**. That is, the dielectric substrate **130** has a substantially U-like shape as viewed from the X-axis direction. The dimension of the planar section **135** in the Y-axis direction is shorter than that of the planar section **131** in the Y-axis direction. The connector **172** on the planar section **131** is disposed at a position at which it does not overlap the planar section **135** placed on the planar section **131** as viewed from the Y-axis direction. Disposing the connector **172** at such a position can reduce the interference of the antenna module **100** with the devices mounted on the mounting substrate **20** when the antenna module **100** is connected to the mounting substrate **20**.

[0043] The connector **171** is disposed on the main surface **137** of the planar section **135** in the negative direction of the Y axis. The connector **171** is disposed on the main surface **137** such that it at least partially overlaps the SiP module **105** as viewed in the Y-axis direction. Disposing the connector **171** in this manner can make the dimension of the antenna module **100** in the Z-axis direction smaller than the configuration in which the connector **171** does not overlap the SiP module **105**, thereby making it possible to reduce the height of the antenna module **100**. As indicated by the broken lines in FIG. **2**, the connector **171** may be disposed on the main surface **133** of the planar section **131**.

[0044] As illustrated in FIG. **3**, a radio-frequency signal to be supplied to the radiating element **126** of the dielectric substrate **150** is transferred from the RFIC **110** to the connector **171** via a feeder line **146**. The feeder line **146** extends from a solder bump **160** of the SiP module **105** to the main surface **133** of the planar section **131** and to the main surface **137** of the planar section **135** and is then connected to the connector **171**. The feeder line **146** may be laid to extend on the inner layers of the planar sections **131** and **135**. A connector **173** provided at an end portion of the feeder cable **180**, which is used to transfer a radio-frequency signal to the radiating element **126** of the dielectric substrate **150**, is connected to the connector **171**.

[0045] The output terminal from the SiP module **105** extends on the main surface **133** in the Y-axis direction, while the input terminal into the connector **171** extends on the main surface **137** in the Z-axis direction. In this manner, the output direction of a signal from the SiP module **105** and the input direction of a signal into the connector **171** are perpendicular to each other, thereby preventing unnecessary coupling between the SiP module **105** and the connector **171**. This can make it less likely to degrade the isolation between the radiating elements of the dielectric substrate **150**.

[0046] As seen in the normal direction to the planar section **135**, that is, in the Y-axis direction, the connector **171** has a substantially rectangular shape having long sides and short sides. In the antenna module **100**, the connector **171** is disposed with its long sides extending along the X-axis direction. In other words, the connector **171** is disposed such that a line extending in the direction of its short sides intersects with the planar section **131**. With this arrangement, the height of the antenna module **100**, that is, the dimension of the antenna module **100** in the Z-axis direction, can be made smaller than the configuration in which the connector **171** is disposed with its long sides extending along the Z-axis direction. This contributes to reducing the height of the antenna module **100**.

[0047] As seen in the normal direction to the planar section **131** (in the Z-axis direction), the connector **171** is adjacent to the SiP module **105** and the planar section **131** in the direction of their short sides (in the Y-axis direction). In other words, the connector **171** is disposed with its long sides facing the long sides of the SiP module **105**. Disposing the SiP module **105** close to the planar section **135** can decrease the length of the feeder line **146** from the SiP module **105** to the connector **171**. This can lower the attenuation of a radio-frequency signal in the feeder line **146**, thereby reducing a transmission loss. Additionally, by disposing the SiP module **105** and the connector **171** with their long sides facing each other, the flexibility in laying the feeder line **146** can be increased when multiple radiating elements **126** are disposed.

[0048] The radiating element **125** is disposed on a layer close to the main surface **136** of the planar section **135** in the positive direction of the Y axis. The radiating element **125** may be disposed inside the planar section **135** as shown in FIG. **3**, or may be exposed on the main surface **136**. On a layer between the radiating element **125** and the main surface **137**, a ground electrode GND**2** is disposed along the entirety of a layer of the planar section **135**. The ground electrode GND**1** of the planar section **131** and the ground electrode GND**2** of the planar section **135** may be disconnected from each other, as shown in FIG. **3**, if they are connected to a ground electrode of the mounting substrate **20**. However, the ground electrodes GND**1** and GND**2** may be directly connected to each other inside the dielectric substrate **130**.

[0049] A radio-frequency signal is supplied from the RFIC **110** to the radiating element **125** via a feeder line **145**. The feeder line **145** extends from a solder bump **160** to a wiring layer between the ground electrode GND**1** and the main surface **133** of the planar section **131**, passes through the ground electrode GND**2** of the planar section **135**, and is connected to the radiating element **125**.
[0050] The dielectric substrate **150** is a substrate provided separately from the dielectric substrate **130**. The dielectric substrate **150** is formed in a planar shape and has substantially rectangular main surfaces **151** and **152**. The dielectric substrate **150** is also formed of an LTCC, for example, as in the dielectric substrate **130**.
[0051] As illustrated in FIG. **3**, the radiating element **126** is disposed on a layer close to the main surface **151** of the dielectric substrate **150**. The radiating element **126** may be disposed on an inner layer of the dielectric substrate **150** or may be exposed on the main surface **151**. A ground electrode GND**3** may be between the radiating element **126** and the main surface **152**. Alternatively, a conducting member of a housing, for example, for a device disposed inside the communication apparatus **10** may be used as the ground electrode GND**3**.
[0052] A connector **174** is disposed on the main surface **152** of the dielectric substrate **150**. The radiating element **126** is connected to the connector **174** using a feeder line **147**. One end portion of the flexible feeder cable **180** is connected to the connector **174**. The connector **173** is connected to the other end portion of the feeder cable **180**. As a result of connecting the connector **173** to the connector **171** mounted on the planar section **135** of the dielectric substrate **130** as described above, a radio-frequency signal is transferred from the RFIC **110** to the radiating element **126** via the feeder cable **180** and the feeder line **147**.
[0053] Since the dielectric substrate **150** is separately provided from the dielectric substrate **130**, a normal direction to the main surface **151**, which is the radiating plane for a radio wave, can be set to a desired direction. FIG. **3** shows a case in which the dielectric substrate **150** is arranged so that the direction of a normal direction to the main surface **151** is the positive direction of the Z axis, as indicated by (A) in FIG. **3**, and a case in which the dielectric substrate **150** is arranged so that the normal direction to the main surface **151** is the positive direction of the Y axis, as indicated by (B) in FIG. **3**.
[0054] In an antenna module that can radiate a radio wave in two directions, such as the above-described antenna module, the dimension of the antenna module in the thickness direction, that is, in the Z-axis direction, may be limited to a small size in accordance with a thinner communication apparatus including the antenna module. In this case, in particular, the area of the substrate on which the radiating element radiating a radio wave in the direction of the side surface of the communication apparatus is disposed, and more specifically, the area of the ground electrode, is limited to a small size.
[0055] When a planar patch antenna is used as the radiating element, as the ground electrode has a smaller area, the antenna gain typically tends to be lowered. Accordingly, if the height of the antenna module is decreased, the antenna characteristics are likely to be degraded. Especially for a stack-type dual-band patch antenna, a smaller area of the ground electrode may be more likely to influence the antenna gain of a relatively large radiating element on the lower frequency side.
[0056] To address this issue, in the antenna module **100** of the first embodiment, regarding the radiating elements which radiate a radio wave in the direction of the side surface, the radiating element **125** on the higher frequency side is only disposed on the fixed dielectric substrate **130**, while the radiating element **126** on the lower frequency side is disposed on the dielectric substrate **150**, which is separately provided from the dielectric substrate **130**. Then, the connector **171** is provided on the dielectric substrate **130** to transfer a radio-frequency signal to the radiating element **126** of the separately provided dielectric substrate **150**.
[0057] With the above-described configuration, in the communication apparatus **10**, the flexibility in arranging the radiating element **126** on the lower frequency side can be enhanced. By providing the radiating element **126** externally to the dielectric substrate and separate from the radiating

element **125**, the radiating element **126** can be disposed where more space is available in the communication apparatus **10**. This can ease the limitation on the area of the ground electrode for the radiating element **126**, compared with the configuration in which the radiating element **126** and the radiating element **125** are stacked. Hence, in a dual-band antenna module that can radiate a radio wave in two different directions, the antenna gain on the lower frequency side is less likely to be lowered.

[0058] The planar section **131** and the planar section **135** in the first embodiment respectively correspond to a first planar section and a second planar section in the disclosure. The radiating elements **121**, **122**, **125**, and **126** in the first embodiment respectively correspond to a first radiating element, a second radiating element, a third radiating element, and a fourth radiating element in the disclosure. The connector **171** and the connector **172** in the first embodiment respectively correspond to a first connector and a second connector in the disclosure. The SiP module **105** in the first embodiment corresponds to a control circuit in the disclosure. The main surfaces **132**, **133**, **136**, and **137** respectively correspond to a first surface, a second surface, a third surface, and a fourth surface in the disclosure.

Second Embodiment

[0059] In a second embodiment, an example in which a dielectric substrate is formed by using a flexible substrate having flexibility will be described below.

[0060] FIG. **5** is a transparent side view of an antenna module **100**A according to the second embodiment. The antenna module **100**A is different from the antenna module **100** of the first embodiment mainly in that the dielectric substrate **130** is replaced by a dielectric substrate **130**A. The configurations of the other elements in the antenna module **100**A are basically similar to those of the antenna module **100**, and an explanation of these elements will not be repeated. For easy representation, some of the same elements as those in FIG. **3** are not shown in FIG. **5**.

[0061] As illustrated in FIG. **5**, the dielectric substrate **130**A of the antenna module **100**A is constituted by a flexible substrate **191** and substrates **192** and **193**. The flexible substrate **191** is a planar-shaped multilayer substrate made of a flexible resin. The flexible substrate **191** can bend so that the normal direction to the main surface is variable. In the antenna module **100**A, as shown in FIG. **5**, the flexible substrate **191** is bent from a portion extending in the Y-axis direction and then extends in the Z-axis direction. A ground electrode GND**4** is provided on the entirety of an inner layer of the flexible substrate **191**.

[0062] The dielectric substrate **130**A includes a planar section **131**A extending in the Y-axis direction, a planar section **135**A extending in the Z-axis direction, and a connecting section **195** that connects the planar sections **131**A and **135**A to each other. The connecting section **195** corresponds to a bending portion of the flexible substrate **191**.

[0063] The planar section **131**A also includes the substrate **193** at a position corresponding to a portion of the flexible substrate **191** extending in the Y-axis direction. The substrate **193** is disposed on the main surface of the flexible substrate **191** in the negative direction of the Z axis. The substrate **193** is also formed of an LTCC or a resin, for example, as in the dielectric substrate **130** of the antenna module **100** of the first embodiment. As shown herein, radiating elements **121** and **122** are disposed in the substrate **193**. Alternatively the radiating elements **121** and **122** may be disposed in the flexible substrate **191**.

[0064] In an exemplary embodiment, the flexible substrate **191** and the substrate **193** are made of a material having a low dielectric constant. Using a material having a lower dielectric constant for the substrate **193** decreases the stray capacitance of conducting members, such as feeder lines and connection terminals, inside the substrate **193**, thereby weakening the coupling force of a signal between adjacent conducting members. This can improve the isolation characteristics between the SiP module **105** and the connector **172**.

[0065] The planar section **135**A also includes the substrate **192** at a position corresponding to a portion of the flexible substrate **191** extending in the Z-axis direction. The substrate **192** is disposed on the main surface of the flexible substrate **191** in the positive direction of the Y axis. The substrate **192** is also formed of an LTCC or a resin, for example, as in the substrate **193**. A radiating element **125** is disposed in the substrate **192**. The substrate **192** is made of a material having a higher dielectric constant than that of the flexible substrate **191** and the substrate **193**. Using a material having a higher dielectric constant for the substrate **192** can make the size of the radiating element **125** smaller. This can decrease the area of the flexible substrate **191**, that is, the dimension in the Z-axis direction, compared with the configuration in which a material having a lower dielectric constant is used for the substrate **192**. This contributes to reducing the height of the antenna module **100**A.

[0066] In the planar section **131**A, the SiP module **105** is mounted on the main surface of the flexible substrate **191** in the positive direction of the Z axis. A radio-frequency signal is supplied from the SiP module **105** to each radiating element.

[0067] In the planar section **135**A, a connector **171**, which is used for connecting the feeder cable **180**, is disposed on the main surface of the flexible substrate **191** in the negative direction of the Y axis. The feeder cable **180** can transfer a radio-frequency signal from the SiP module **105** to a radiating element **126** disposed in a dielectric substrate **150** separately provided from the dielectric substrate **130**A.

[0068] As described above, the flexible substrate **191** is used for the dielectric substrate **130**A, and also, the substrate **192** made of a material having a relatively high dielectric constant is disposed in the planar section **135**A and the radiating element **125** is disposed in the substrate **192**, thereby making it possible to reduce the size of the radiating element **125**. This can reduce the height of the antenna module **100**A. Additionally, the radiating element **126** on the lower frequency side is disposed in the dielectric substrate **150**, which is separately provided from the dielectric substrate **130**A, and a radio-frequency signal is supplied to the radiating element **126** by using the feeder cable **180**. This can make it less likely to lower the antenna gain on the lower frequency side.

[0069] In the antenna module **100** in the first embodiment, too, the planar section **135** may be made of a material having a high dielectric constant, thereby making the size of the radiating element **125** smaller and reducing the height of the antenna module **100**.

[0070] The planar section **131**A and the planar section **135**A in the second embodiment respectively correspond to the first planar section and the second planar section in the disclosure. The flexible substrate **191** and the substrate **192** in the second embodiment respectively correspond to a first member and a second member in the disclosure. The substrate **193** in the second embodiment corresponds to the first member in the disclosure.

Modified Example

[0071] An antenna module **100**B of a modified example will now be described below with reference to FIGS. **6** through **8**. In the antenna module **100**B of the modified example, a dielectric substrate in which radiating elements are disposed is formed of a flexible substrate. FIG. **6** is a perspective view of the antenna module **100**B of the modified example. FIG. **7** is a transparent side view of the antenna module **100**B in FIG. **6** as viewed from the X-axis direction. FIG. **8** is a transparent side view of the antenna module in FIG. **6** as viewed from the Y-axis direction.

[0072] As illustrated in FIGS. **6** through **8**, a dielectric substrate **130**B of the antenna module **100**B includes planar sections **131**B and **135**B and a connecting section **195**B.

[0073] The planar section **135**B is connected to the connecting section **195**B, which is bent from the planar section **131**B, and is located so that the inner surface (surface in the negative direction of the Y axis) of the planar section **135**B faces the side surface of a mounting substrate **20**. In the planar section **135**B, multiple notches **197** are formed in the dielectric substrate having a substantially rectangular shape. The connecting section **195**B is connected to the notches **197**. In other words, in the portions of the planar section **135**B in which the notches **197** are not formed, projecting portions **196** are provided. Each projecting portion **196** projects from the boundary where the connecting section **195**B and the planar section **135**B are connected and extends along the planar section **135**B in the direction to face the planar section **131**B (that is, in the negative direction of the Z axis).

[0074] In the antenna module **100**B, four radiating elements **121** are disposed on the surface of the planar section **131**B along the X-axis direction. Radiating elements **122** are disposed on an inner layer of the planar section **131**B so as to be associated with the radiating elements **121**. A radio-frequency signal is supplied from the SiP module **105** to the radiating elements **121** via a feeder line **141**. A radio-frequency signal is supplied from the SiP module **105** to the radiating elements **122** via a feeder line **142**.

[0075] Two projecting portions **196** are formed in the planar section **135**B of the antenna module **100**B. Two radiating elements **125** are provided to correspond to each of the projecting portions **196**. Each of the radiating elements **125** of the planar section **135**B is disposed to at least partially overlap the associated projecting portion **196**. A radio-frequency signal is supplied from the SiP module **105** to the radiating elements **125** via a feeder line **145**. A radio-frequency signal is supplied to radiating elements **126** disposed in an external dielectric substrate **150**, such as that discussed with reference to FIG. **3**, via a feeder line **146** and connectors **171** and **173**.

[0076] The feeder lines **145** and **146** and a ground electrode GND extend from the planar section **131**B, passes through the connecting section **195**B, and reaches the planar section **135**B.

[0077] The connector **171** is disposed on the main surface of the planar section **135**B in the negative direction of the Y axis. As viewed from the X-axis direction, which is perpendicular to a normal direction to the planar section **131**B and also to a normal direction to the planar section **135**B, the connector **171** is disposed at a position that overlaps the bending portion of the connecting section **195**B. Disposing the connector **171** at such a position can effectively use a dead space produced in the connecting section **195**B between the planar sections **131**B and **135**B, thereby contributing to reducing the size of the antenna module **100**B.

[0078] As shown in FIG. **8**, as viewed in the normal direction (Y-axis direction) to the planar section **135**B, the connector **171** is disposed at a position at which it at least partially overlaps the radiating elements **125**, e.g., the connector **171** may partially overlap, e.g., cover less than half, two adjacent radiating elements **125**. As shown in FIG. **8**, when the shortest distance L**2** from the center of the radiating element **125** to the end portion of the planar section **135**B in the polarization direction (Z-axis direction) of the radiating elements **125** is smaller than the length L**1** of one side of the substantially square radiating element **125** (L**1**>L**2**), the ground electrode GND is not large enough for the radiating elements **125**. This may lower the antenna gain. However, disposing the connector **171** to overlap the radiating elements **125** can strengthen the grounding function, thereby making it possible to suppress the degradation of the antenna gain.

[0079] The planar section **131**B and the planar section **135**B in the modified example respectively correspond to the first planar section and the second planar section in the disclosure.

Third Embodiment

[0080] In the first and second embodiments, the radiating elements disposed in the planar section **131** are used for a dual-band antenna module. In the disclosure, a radiating element disposed in the planar section **131** is also applicable to a single-band antenna module that radiates a radio wave of a single frequency band.

[0081] FIG. **9** is a transparent side view of an antenna module **100**C according to a third embodiment. The antenna module **100**C includes neither of the radiating element **121** on the higher frequency side nor the feeder line **141** in the planar section **131**, which are provided in the antenna module **100** in FIG. **3**. The configurations of the other elements in the antenna module **100**C in FIG. **9** are the same as those of the antenna module **100** in FIG. **3**, and an explanation of these elements will not be repeated.

[0082] In the configuration in FIG. **9**, too, the radiating element **126** on the lower frequency side, which corresponds to the radiating element **125** disposed in the planar section **135**, is disposed in the dielectric substrate **150** separately provided from the dielectric substrate **130**, and a radio-frequency signal is supplied to the radiating element **126** via the connector **171** of the planar section **135**. By providing the radiating element **126** externally to the dielectric substrate and separate from the radiating element **125**, the radiating element **126** can be disposed where more space is available in a communication apparatus. This can ease the limitation on the area of the ground electrode for the radiating element **126**, compared with the configuration in which the radiating element **126** is stacked on the radiating element **125**. Hence, in an antenna module that can radiate a radio wave in two different directions, the antenna gain on the lower frequency side is less likely to be lowered.

[0083] In FIG. **9**, the radiating element **122** on the lower frequency side is only disposed in the planar section **131**. Alternatively, the radiating element **122** on the lower frequency side may be removed, and only the radiating element **121** on the higher frequency side may be disposed.

[0084] The radiating element **122**, radiating element **125**, and radiating element **126** in the third embodiment respectively correspond to a fifth radiating element, a sixth radiating element, and a seventh radiating element in the disclosure. In other words, the fifth radiating element corresponds to the first or second radiating element in the first embodiment, the sixth radiating element corresponds to the second radiating element in the first embodiment, and the seventh radiating element corresponds to the fourth radiating element in the first embodiment. However, regardless of the labeling herein, the numbering of the radiating element in the claims is based on an order in which they are introduced in the claims and are defined by their respective relationships recited in the claims.

Aspects

[0085] (1) An antenna module according to an aspect is configured to receive a signal from a baseband circuit and to radiate a radio wave. The antenna module includes a dielectric substrate, first and second radiating elements, and a first connector. The dielectric substrate includes first and second planar sections. The normal direction to the first planar section and that to the second planar section are different from each other. The first radiating element is disposed in or on the first planar section. The second radiating element is disposed in or on the second planar section. The antenna module is configured to transfer a radio-frequency signal to a third radiating element, which is disposed externally to the dielectric substrate, via the first connector. The size of the second radiating element is smaller than that of the third radiating element.

[0086] (2) In the antenna module according to (1), the first connector is disposed on the second planar section.

[0087] (3) The antenna module according to (2) further includes a second connector and a control circuit. The second connector receives a signal from a baseband circuit. The control circuit is configured to receive the signal from the second connector, convert the signal into a radio-frequency signal, and supply the radio-frequency signal to each of the first through third radiating elements. The first planar section has first and second surfaces facing each other. The first radiating element is disposed to radiate a radio wave from the first surface. The second connector and the control circuit are disposed on the second surface.

[0088] (4) In the antenna module according to (3), the second planar section has third and fourth surfaces facing each other. The first planar section is disposed closer to the fourth surface than to the third surface. The second radiating element is disposed to radiate a radio wave from the third surface. The first connector is disposed on the fourth surface.

[0089] (5) In the antenna module according to (4), the second planar section is disposed such that the fourth surface faces the second surface.

[0090] (6) In the antenna module according to (4), the second planar section includes a first member having a first dielectric constant and a second member having a second dielectric constant which is higher than the first dielectric constant. The second member is disposed closer to the third surface than the first member is. The second radiating element is disposed in or on the second member.

[0091] (7) In the antenna module according to one of (3) to (6), a shield is provided on a peripheral portion of the control circuit to contain an electromagnetic wave in the control circuit. When the second connector is seen from the first connector, at least part of the second connector overlaps the control circuit.
[0092] (8) The antenna module according to one of (3) to (7), as viewed from a normal direction to the first planar section, the first connector has a substantially rectangular shape having long sides and short sides and is disposed to be adjacent to the control circuit in a direction of the short sides.
[0093] (9) In the antenna module according to one of (3) to (8), as viewed from a normal direction to the second planar section, at least part of the first connector overlaps the control circuit.
[0094] (10) In the antenna module according to one of (3) to (9), the second connector is disposed on the first planar section at a position at which the second connector does not overlap the second planar section.
[0095] (11) In the antenna module according to one of (2) to (10), as viewed from a normal direction to the second planar section, the first connector has a substantially rectangular shape having long sides and short sides, and the first connector is disposed on the second planar section such that a line extending in a direction along the short sides intersects with the first planar section.
[0096] (12) In the antenna module according to one of (2) to (11), the dielectric substrate further includes a connecting section that connects the first planar section and the second planar section with each other.
[0097] (13) In the antenna module according to (12), the connecting section includes a bending portion.
[0098] (14) In the antenna module according to (13), as viewed from a direction perpendicular to a normal direction to the first planar section and to a normal direction to the second planar section, the first connector overlaps the bending portion.
[0099] (15) In the antenna module according to (14), the second radiating element has a substantially square shape. As viewed from a normal direction to the second planar section, the shortest distance from the center of the second radiating element to an end portion of the second planar section in a polarization direction of the second radiating element is smaller than a length of one side of the second radiating element, and at least part of the first connector overlaps the second radiating element.
[0100] (16) In the antenna module according to (13), the connecting section has flexibility.
[0101] (17) In the antenna module according to one of (2) to (16), a normal direction to the first planar section is perpendicular to a normal direction to the second planar section.
[0102] (18) In the antenna module according to one of (2) to (17), the antenna module includes a fourth radiating element disposed in or on the first planar section. The size of the fourth radiating element is different than that of the first radiating element.
[0103] (19) In the antenna module according to (18), the first radiating element and the fourth radiating element are stacked.
[0104] (20) A communication apparatus according to an aspect includes the antenna module according to one of (1) to (19).
[0105] The disclosed embodiments are provided only for the purposes of illustration, but are not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. It is intended that the scope of the disclosure be defined, not by the foregoing embodiments, but by the following claims. The scope of the present disclosure is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

Claims

1. An antenna module comprising: a dielectric substrate including first and second planar sections, a normal direction to the first planar section and a normal direction to the second planar section being different from each other; a first radiating element disposed in or on the first planar section; a second radiating element disposed in or on the second planar section; and a first connector, wherein the antenna module is configured to transfer a radio-frequency signal to a third radiating element via the first connector, the third radiating element being disposed externally to the dielectric substrate, a size of the second radiating element is smaller than a size of the third radiating element, and the third radiating element is attachable to and detachable from the dielectric substrate by the first connector.

2. The antenna module according to claim 1, wherein the first connector is disposed on the second planar section.

3. The antenna module according to claim 2, further comprising: a baseband circuit; a second connector that receives a signal from the baseband circuit; and a control circuit configured to receive the signal from the second connector, convert the signal into a radio-frequency signal and supply the radio-frequency signal to each of the first through third radiating elements, wherein the first planar section has first and second surfaces facing each other, the first radiating element is disposed to radiate a radio wave from the first surface, and the second connector and the control circuit are disposed on the second surface.

4. The antenna module according to claim 3, wherein: the second planar section has third and fourth surfaces facing each other; the first planar section is closer to the fourth surface than to the third surface, the second radiating element is disposed to radiate a radio wave from the third surface, and the first connector is disposed on the fourth surface.

5. The antenna module according to claim 4, wherein the second planar section is disposed such that the fourth surface faces the second surface.

6. The antenna module according to claim 4, wherein: the second planar section includes a first member having a first dielectric constant, and a second member that is disposed closer to the third surface than the first member is and that has a second dielectric constant which is higher than the first dielectric constant; and the third radiating element is disposed in or on the second member.

7. The antenna module according to claim 3, further comprising: a shield on a peripheral portion of the control circuit to contain an electromagnetic wave in the control circuit; and when the second connector is seen from the first connector, at least part of the second connector overlaps the control circuit.

8. The antenna module according to claim 3, wherein, as viewed from a normal direction to the first planar section, the first planar section has a substantially rectangular shape having long sides and short sides, and the first connector is disposed to be adjacent to the control circuit in a direction of the short sides.

9. The antenna module according to claim 3, wherein, as viewed from a normal direction to the second planar section, at least part of the first connector overlaps the control circuit.

10. The antenna module according to claim 3, wherein, as viewed from a normal direction to the second planar section, the second connector is disposed on the first planar section at a position at which the second connector does not overlap the second planar section.

11. The antenna module according to claim 2, wherein, as viewed from a normal direction to the second planar section, the first connector has a substantially rectangular shape having long sides and short sides, and the first connector is disposed on the second planar section such that a line extending in a direction along the short sides intersects with the first planar section.

12. The antenna module according to claim 2, wherein the dielectric substrate further includes a connecting section that connects the first planar section and the second planar section with each other.

13. The antenna module according to claim 12, wherein the connecting section includes a bending portion.

14. The antenna module according to claim 13, wherein, as viewed from a direction perpendicular to a normal line to the first planar section and to a normal line to the second planar section, the first

connector overlaps the bending portion.
15. The antenna module according to claim 14, wherein: the second radiating element has a substantially square shape; and as viewed from a normal direction to the second planar section, a shortest distance from a center of the second radiating element to an end portion of the second planar section in a polarization direction of the second radiating element is smaller than a length of one side of the second radiating element, and at least part of the first connector overlaps the third radiating element.
16. The antenna module according to claim 13, wherein the connecting section has flexibility.
17. The antenna module according to claim 2, wherein a normal direction to the first planar section is perpendicular to a normal direction to the second planar section.
18. The antenna module according to claim 1, further comprising a fourth radiating element disposed in or on the first planar section; wherein a size of the fourth radiating element is different than a size of the first radiating element.
19. The antenna module according to claim 18, wherein the fourth radiating element and the first radiating element are stacked.
20. A communication apparatus comprising: the antenna module according to one of claim 1.