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RADIO-FREQUENCY CIRCUIT

Abstract

A radio-frequency circuit includes: a power amplifier to which a first signal is input; a power amplifier to which a second signal that is +90° with respect to the first signal is input; a combiner circuit that combines in phase a third signal in band A input from a fourth input end and a fourth signal in band A input from a fifth input end; a phase-shifting circuit connected to a third output end of the power amplifier; a phase-shifting circuit that is connected to a fourth output end of the power amplifier and sets a passband phase of a signal in band A to −90° with respect to the phase-shifting circuit; a filter that has a passband containing a transmission band of band A; and a filter that has a passband containing a reception band of band B that can be transmitted simultaneously with band A.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to Japanese Patent Application No. JP 2024-021873 filed on Feb. 16, 2024. The entire contents of the above-identified applications, including the specifications, drawings and claims, are incorporated herein by reference in their entirety.

BACKGROUND OF THE DISCLOSURE

1. Field of the Disclosure

[0002] The present disclosure relates to a radio-frequency circuit.

2. Description of the Related Art

[0003] Japanese Unexamined Patent Application Publication No. 2012-147352 discloses a semiconductor device (radio-frequency (RF) circuit) including: a first amplifier and a second amplifier constituting a balanced amplifier; a first phase-shifting circuit arranged in a first output path connecting an output end of the first amplifier and an output terminal; a second phase-shifting circuit arranged in a second output path connecting an output end of the second amplifier and the output terminal; a resistor connected to an output end of the first phase-shifting circuit and an output end of the second phase-shifting circuit; a first inductor connected between the output end of the first phase-shifting circuit and the output terminal; and a second inductor connected between the output end of the second phase-shifting circuit and the output terminal. Accordingly, the power combining loss in a power coupler composed of the resistor, the first inductor, and the second inductor can be reduced.

SUMMARY OF THE DISCLOSURE

[0004] In RF circuits that simultaneously transmit transmission signals and reception signals, there is a need to improve the isolation between transmission and reception, along with highly efficient power combining against load fluctuations.

[0005] Accordingly, it is an feature of the present disclosure to provide a radio-frequency circuit that achieves highly efficient power combining as well as improved isolation between transmission and reception.

[0006] To achieve the above-mentioned feature, a radio-frequency circuit according to one aspect of the present disclosure includes: a first antenna terminal; a splitter that has a first input end, a first output end, and a second output end, and is configured to separate a signal in a transmission band of a first band input to the first input end to output a first sub-band signal from the first output end and output a second sub-band signal from the second output end, the second sub-band signal having a phase relatively +90° with respect to the first sub-band signal; a first power amplifier that has a second input end and a third output end, the second input end connected to the first output end; a second power amplifier that has a third input end and a fourth output end, the third input end connected to the second output end; a combiner circuit that has a fourth input end, a fifth input end, and a fifth output end, and is configured to output, from the fifth output end, an output signal in the first band generated by combining in phase a third sub-band signal in the first band input from the fourth input end and a fourth sub-band signal in the first band input from the fifth input end; a first phase-shifting circuit connected between the third output end and the fourth input end; a second phase-shifting circuit that is connected between the fourth output end and the fifth input end, and is configured such that a passband phase of the signal in the transmission band of the first band becomes relatively −90° with respect to the first phase-shifting circuit; a first filter that is connected between the fifth output end and the first antenna terminal or between the first phase-shifting circuit and the fourth input end, and has a passband containing the transmission band of the first band; and a second filter that is connected to a path connecting the first antenna terminal and the first filter, and has a passband containing a reception band of a second band that can be transmitted simultaneously with the first band, wherein the first phase-shifting circuit and the second phase-shifting circuit are configured such that a difference between a first reflection phase in the reception band of the second band upon viewing the fifth output end from the third output end and a second reflection phase in the reception band of the second band upon viewing the fifth output end from the fourth output end becomes 180°.

[0007] Additionally, a radio-frequency circuit according to one aspect of the present disclosure includes: a first antenna terminal; a combiner that has a first output end, a first input end, and a second input end, and is configured to combine a first signal in a reception band of a first band input to the first input end and a second signal in the reception band of the first band input to the second input end, the second signal having a phase relatively +90° with respect to the first signal, and output a combined signal from the first output end; a first low-noise amplifier that has a second output end and a third input end, the second output end connected to the first input end; a second low-noise amplifier that has a third output end and a fourth input end, the third output end connected to the second input end; a splitter circuit that has a fourth output end, a fifth output end, and a fifth input end, and is configured to distribute power of a reception signal in the reception band of the first band input to the fifth input end to the fourth output end and the fifth output end; a first phase-shifting circuit connected between the third input end and the fourth output end; a second phase-shifting circuit that is connected between the fourth input end and the fifth output end, and is configured such that a passband phase in the reception band of the first band becomes relatively −90° with respect to the first phase-shifting circuit; a first filter that is connected between the fifth input end and the first antenna terminal or between the first phase-shifting circuit and the fourth output end, and has a passband containing the reception band of the first band; and a second filter that is connected to a path connecting the first antenna terminal and the first filter, and has a passband containing a transmission band of a second band that can be transmitted simultaneously with the first band, wherein the first phase-shifting circuit and the second phase-shifting circuit are configured such that a difference between a first reflection phase in the transmission band of the second band upon viewing the fifth input end from the third input end and a second reflection phase in the transmission band of the second band upon viewing the fifth input end from the fourth input end becomes 180°.

[0008] According to the present disclosure, a radio-frequency circuit that achieves highly efficient power combining as well as improved isolation between transmission and reception can be provided.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** is a circuit configuration diagram of an amplifier circuit, a radio-frequency (RF) circuit, and a communication device according to an embodiment;

[0010] FIG. **2** is a circuit state diagram illustrating the RF circuit in a first mode according to the embodiment;

[0011] FIG. **3** includes a Smith chart representing the transmission bandpass characteristics as well as the impedance in the reception band of an RF circuit according to a first embodiment and a comparative example;

[0012] FIG. **4** is a circuit state diagram illustrating the RF circuit in a second mode according to the embodiment;

[0013] FIG. **5** is a circuit state diagram illustrating the RF circuit in a third mode according to the

embodiment;
[0014] FIG. **6** is a circuit configuration diagram of an amplifier circuit, an RF circuit, and a communication device according to a first modification of the embodiment;
[0015] FIG. **7**A is a circuit state diagram illustrating an RF circuit in the first mode according to a second modification of the embodiment;
[0016] FIG. **7**B is a circuit state diagram illustrating the RF circuit in the second mode according to the second modification of the embodiment; and
[0017] FIG. **8** includes a plan view and a cross-sectional view of the RF circuit according to the second modification of the embodiment.
DESCRIPTION OF THE PREFERRED EMBODIMENTS
[0018] Hereinafter, an embodiment of the present disclosure will be described in detail using the drawings. The embodiment described hereinafter is all illustrative of comprehensive or specific examples. The numerical values, shapes, materials, components, and component arrangement and connection forms discussed in the following embodiment are merely examples and are not intended to limit the scope of the present disclosure.
[0019] Note that each of the drawings is a schematic diagram that has been appropriately emphasized, omitted, or adjusted in scale to illustrate the present disclosure. Therefore, the drawings are not necessarily depicted with strict accuracy and may differ from the actual shapes, positional relationships, and proportions. In each of the drawings, the same reference numerals are assigned to substantially identical configurations, and overlapping descriptions may be omitted or simplified.
[0020] In each of the following drawings, the x-axis and the y-axis are axes orthogonal to each other on a plane parallel to the main surface of a mounting substrate. Specifically, in the case where the mounting substrate has a rectangular shape in plan view, the x-axis is parallel to a first side of the mounting substrate, and the y-axis is parallel to a second side orthogonal to the first side of the mounting substrate. Additionally, the z-axis is an axis perpendicular to the main surface of the mounting substrate, the positive direction of which indicates an upward direction and the negative direction of which indicates a downward direction.
[0021] In the component arrangement of the present disclosure, “the component is arranged on the substrate” includes both the arrangement of the component on the main surface of the substrate and the arrangement of the component within the substrate. “The component is arranged on the main surface of the substrate” includes not only the arrangement of the component in contact with the main surface of the substrate but also the arrangement of the component above the main surface without direct contact with the main surface (for example, upon the component is laminated or stacked on top of another component arranged in contact with the main surface). Additionally, it is acceptable that “the component is arranged on the main surface of the substrate” include the arrangement of the component in a recess formed in the main surface. “The component is arranged within the substrate” includes not only the encapsulation of the component within a module substrate but also the arrangement of the entire component between two main surfaces of the substrate, with part of the component not covered by the substrate, as well as the arrangement of only part of the component within the substrate.
[0022] Furthermore, in the component arrangement of the present disclosure, “plan view of the main surface” refers to the orthogonal projection of an feature onto the xy-plane as viewed from the positive side of the z-axis. “A overlaps with B in plan view” means that at least part of the region of A projected orthogonally onto the xy-plane overlaps with at least part of the region of B projected orthogonally onto the xy-plane. In addition, “A is arranged between B and C” means that at least one of line segments connecting any point in B and any point in C passes through A.
[0023] Furthermore, in the present disclosure, terms indicating the relationship between elements, such as parallel and vertical, terms indicating the shape of elements, such as rectangular shapes, and numerical ranges do not solely represent strict meanings but also encompass substantially

equivalent ranges, including differences of a few percent, for example.
[0024] In the circuit configuration of the present disclosure, “connected” refers not only to direct connections by connection terminals and/or wiring conductors but also to cases where an electrical connection is made with another circuit element interposed therebetween. “Connected between A and B” means connected to both A and B between A and B.
[0025] Also, in the present disclosure, “path” refers to a transmission line composed of wiring through which a radio-frequency (RF) signal propagates, an electrode directly connected to the wiring, and a terminal directly connected to the wiring or the electrode.
[0026] Additionally, in the present disclosure, “component A is arranged in series in path B” means that both the signal input end and the signal output end of component A are connected to wiring, an electrode, or a terminal constituting path B.
[0027] In the present disclosure, “terminal”, “input end”, and “output end” refer to the point at which a conductor within an element ends. Note that, assuming the impedance of a conductor between elements is sufficiently low, a terminal is interpreted not only as a single point but also as any point on the conductor between the elements or as the entire conductor.
[0028] Also, terms indicating the relationship between elements, such as “parallel” and “vertical”, terms indicating the shape of elements, such as “rectangular shapes”, and numerical ranges do not solely represent strict meanings but also encompass substantially equivalent ranges, including differences of a few percent, for example.
[0029] “The passband of a filter” is a portion of the frequency spectrum transmitted by the filter, and is defined as the frequency range where the output power does not attenuate by more than 3 dB from the maximum output power. Therefore, the high and low ends of the passband of a bandpass filter are identified as the higher and lower frequencies of the two points at which the output power attenuates by 3 dB from the maximum output power.
[0030] “Transmission band” refers to the frequency band used for transmission in a communication device. “Reception band” refers to the frequency band used for reception in a communication device. For example, frequency division duplex (FDD) uses frequency bands that are different from each other as the transmission band and the reception band, and time division duplex (TDD) uses the same frequency band for the transmission band and the reception band. In particular, in FDD, upon a communication device is implemented in user equipment (UE) in a cellular network, the uplink band (uplink operation band) is used as the transmission band, while the downlink band (downlink operation band) is used as the reception band. In contrast, upon a communication device is implemented as a base station (BS) in a cellular network, the downlink band is used as the transmission band, while the uplink band is used as the reception band.
[0031] The “passband phase” between two terminals of an RF signal is obtained by applying a measuring RF probe to the two terminals and measuring the bandpass characteristics (S21) with a network analyzer. In addition, the “reflection phase” at one terminal of an RF signal is obtained by applying a measuring RF probe to the one terminal and measuring the bandpass characteristics (S11) with a network analyzer.
[0032] In the present disclosure, the numerical values of passband phase, reflection phase, and reflection phase difference do not solely represent strict meanings but also encompass substantially equivalent ranges, including differences of approximately 30%, for example.

EMBODIMENT

1 Circuit Configuration of Amplifier Circuit, Radio-Frequency Circuit, and Communication Device

[0033] The circuit configuration of an amplifier circuit **10**, a radio-frequency (RF) circuit **1**, and a communication device **4** according to the present embodiment will be described with reference to FIG. **1**. FIG. **1** is a circuit configuration diagram of the amplifier circuit **10**, the RF circuit **1**, and the communication device **4** according to the embodiment.

1.1 Circuit Configuration of Communication Device **4**

[0034] First, the circuit configuration of the communication device **4** will be described. As

illustrated in FIG. **1**, the communication device **4** according to the present embodiment includes the RF circuit **1**, an antenna **2**, and an RF signal processing circuit (RFIC: Radio Frequency Integrated Circuit) **3**.
[0035] The RF circuit **1** transmits RF signals between the antenna **2** and the RFIC **3**. The detailed circuit configuration of the RF circuit **1** will be described later.
[0036] The antenna **2** is connected to an antenna connection terminal **100** (first antenna terminal) of the RF circuit **1**. The antenna **2** transmits an RF signal output from the RF circuit **1**. The antenna **2** also receives an RF signal from the outside and outputs it to the RF circuit **1**.
[0037] The RFIC **3** is an example of a signal processing circuit that processes RF signals. Specifically, the RFIC **3** applies signal processing, such as upconverting or the like, to a transmission signal input from a baseband signal processing circuit (BBIC, not illustrated), and outputs the transmission signal generated by the signal processing to a transmission path of the RF circuit **1**. In addition, the RFIC **3** applies signal processing, such as downconverting or the like, to a reception signal input via a reception path of the RF circuit **1**, and outputs the reception signal generated by the signal processing to the BBIC. The RFIC **3** also has a control unit that controls the RF circuit **1**. Note that the function of the RFIC **3** as the control unit, either partially or entirely, may be implemented outside of the RFIC **3**, such as in the BBIC or in the RF circuit **1**.
[0038] The RFIC **3** also has the function as a control unit that controls a power supply voltage Vcc and bias current supplied to each amplifier included in the amplifier circuit **10**. Specifically, the RFIC **3** outputs a control signal to a power supply circuit (not illustrated) and a bias circuit (not illustrated). Note that the power supply circuit and the bias circuit may be arranged in the RF circuit **1** or the amplifier circuit **10**. Each amplifier in the amplifier circuit **10** is supplied with the power supply voltage Vcc controlled by the above-mentioned control signal from the power supply circuit, and is also supplied with a bias current controlled by the above-mentioned control signal from the bias circuit.
[0039] The RFIC **3** also has the function as a control unit that controls the connection of switch circuits **41** and **42** included in the RF circuit **1** based on the frequency band used or the like.
[0040] Note that the antenna **2** is not an essential element in the communication device **4** according to the present embodiment.
1.2 Circuit Configuration of RF Circuit **1**
[0041] Next, the circuit configuration of the RF circuit **1** will be described. As illustrated in FIG. **1**, the RF circuit **1** includes the amplifier circuit **10**, filters **61**, **62**, **63**, **64**, **65** and **66**, the switch circuit **42**, inductors **71** to **78**, and the antenna connection terminal **100**.
[0042] The amplifier circuit **10** is a circuit that amplifies transmission signals in band A and band B, input from an RF input terminal **110**, and amplifies reception signals in band A and band B, input from the antenna connection terminal **100**.
[0043] Note that, in the present embodiment, each of band A and band B refers to a frequency band predefined by a standardization organization (such as 3GPP (3rd Generation Partnership Project, registered trademark), IEEE (Institute of Electrical and Electronics Engineers), etc.) for communication systems built using radio access technology (RAT). In the present embodiment, the communication systems can be, for example, 4G (4th Generation)-LTE (Long Term Evolution) systems, 5G (5th Generation)-NR (New Radio) systems, WLAN (Wireless Local Area Network) systems, and the like, but are not limited to these.
[0044] The filter **61**, which is an example of a first filter, is connected between the switch circuit **41** and the antenna connection terminal **100** and has a passband containing the transmission band of band A (first band). Specifically, one end of the filter **61** is connected to a terminal **41***a* of the switch circuit **41**, and the other end of the filter **61** is connected to the antenna connection terminal **100** with the inductors **71** and **77** and the switch circuit **42** interposed therebetween.
[0045] The filter **62**, which is an example of a fifth filter, is connected between a phase-shifting circuit **22** and the switch circuit **42** and has a passband containing the transmission band of band A

(first band). Specifically, one end of the filter **62** is connected to a terminal **41***b* of the switch circuit **41**, and the other end of the filter **62** is connected to a terminal **42***c* of the switch circuit **42** with the inductor **72** interposed therebetween.

[0046] The filter **63**, which is an example of a third filter, is connected between the switch circuit **41** and the antenna connection terminal **100** and has a passband containing the transmission band of band B (second band). Specifically, one end of the filter **63** is connected to a terminal **41***c* of the switch circuit **41**, and the other end of the filter **63** is connected to the antenna connection terminal **100** with the inductors **73** and **77** and the switch circuit **42** interposed therebetween.

[0047] The filter **64**, which is an example of a second filter, has a passband containing the reception band of band B (second band). One end of the filter **64** is connected to the path connecting the antenna connection terminal **100** and the filter **61**, and the other end is connected to an input end of a low-noise amplifier **14**.

[0048] The filter **65**, which is an example of a fourth filter, has a passband containing the reception band of band A (first band). One end of the filter **65** is connected to the path connecting the antenna connection terminal **100** and the filter **63**, and the other end is connected to an input end of a low-noise amplifier **15**.

[0049] The filter **66** has a passband containing the reception band of band C. One end of the filter **66** is connected to a terminal **42***e* of the switch circuit **42**, and the other end is connected to an input end of a low-noise amplifier **16**.

[0050] Note that the low-noise amplifiers connected to the filters **64** to **66** may be included in the amplifier circuit **10**.

[0051] Band A (first band) and band B (second band) are a combination of bands allowing simultaneous transmission. Note that each of band A (first band) and band B (second band) may be a band using time-division duplexing (TDD). In this case, the filters **61** to **65** may have the same passband.

[0052] Band A is, for example, band B41 for 4G-LTE or band n41 for 5G-NR, while band B is, for example, band B40 for 4G-LTE or band n40 for 5G-NR.

[0053] The switch circuit **42**, which is an example of an antenna switch, has terminals **42***a*, **42***b*, **42***c*, **42***d*, and **42***e*. The terminal **42***a* is connected to the antenna connection terminal **100** with the inductor **77** interposed therebetween; the terminal **42***b* is connected to the filters **61** and **64** with the inductor **71** interposed therebetween; the terminal **42***c* is connected to the filter **62** with the inductor **72** interposed therebetween; the terminal **42***d* is connected to the filters **63** and **65** with the inductor **73** interposed therebetween; and the terminal **42***e* is connected to the filter **66**.

[0054] Note that, in the case where the RF circuit **1** operates in a later-described third mode (see FIG. **5**), the switch circuit **42** corresponds to a combiner circuit. In the case of the third mode, the terminal **42***b* corresponds to a fourth input end, the terminal **42***c* corresponds to a fifth input end, and the terminal **42***a* corresponds to a fifth output end.

[0055] With the above-mentioned configuration, the switch circuit **42** switches between the connection and disconnection between the antenna connection terminal **100** and the filters **61** and **64**, switches between the connection and disconnection between the antenna connection terminal **100** and the filter **62**, switches between the connection and disconnection between the antenna connection terminal **100** and the filters **63** and **65**, and switches between the connection and disconnection between the antenna connection terminal **100** and the filter **66**.

[0056] The inductor **71** is arranged in series in the path connecting the terminal **42***b* and the filters **61** and **64**. The inductor **74** is connected between the above-mentioned path and ground. The inductors **71** and **74** perform impedance matching between the switch circuit **42** and the filters **61** and **64**. The inductor **72** is arranged in series in the path connecting the terminal **42***c* and the filter **62**. The inductor **75** is connected between the above-mentioned path and ground. The inductors **72** and **75** perform impedance matching between the switch circuit **42** and the filter **62**. The inductor **73** is arranged in series in the path connecting the terminal **42***d* and the filters **63** and **65**. The inductor **76** is connected between the above-mentioned path and ground. The inductors **73** and **76** perform impedance matching between the switch circuit **42** and the filters **63** and **65**. The inductor **77** is arranged in series in the path connecting the terminal **42***a* and the antenna connection terminal **100**. The inductor **78** is connected between the above-mentioned path and ground. The inductors **77** and **78** perform impedance matching between the switch circuit **42** and the antenna **2**. Note that at least one of the inductors **71** to **78** may be omitted.

[0057] According to the above-mentioned circuit configuration, the RF circuit **1** can perform simultaneous transmission of the transmission signal in band A and the reception signal in band B, as well as simultaneous transmission of the transmission signal in band B and the reception signal in band A.

[0058] Note that it is only necessary for the RF circuit **1** according to the present disclosure to have at least the amplifier circuit **10** and the filters **61** and **64** in the circuit configuration illustrated in FIG. **1**.

1.3 Circuit Configuration of Amplifier Circuit **10**

[0059] Next, the circuit configuration of the amplifier circuit **10** will be described in detail.

[0060] As illustrated in FIG. **1**, the amplifier circuit **10** includes power amplifiers **11** and **12**, phase-shifting circuits **21** and **22**, the switch circuit **41**, a 90° hybrid **50**, phase-shifting lines **51** and **52**, a capacitor **53**, the RF input terminal **110**, and the low-noise amplifiers **14**, **15** and **16**.

[0061] The RF input terminal **110** is connected to the RFIC **3**. Note that the RF input terminal **110** and the antenna connection terminal **100** each may be a metal conductor such as a metal electrode and a metal bump, or may be a single point (node) on the metal wiring.

[0062] The 90° hybrid **50**, which is an example of a splitter, has a first input end, a first output end, and a second output end, the first input end connected to the RF input terminal **110**, the first output end connected to a second input end of the power amplifier **11**, and the second output end connected to a third input end of the power amplifier **12**. The 90° hybrid **50** is configured to separate the fundamental wave signal in the transmission band of band A or band B, which is input to the first input end, to output a first sub-band signal RF**1** from the first output end, and to output a second sub-band signal RF**2** from the second output end, the second sub-band signal having a phase relatively +90° with respect to the first sub-band signal RF**1**.

[0063] Note that, instead of the 90° hybrid **50**, a phase-shifting circuit having other circuit configuration may be arranged.

[0064] The power amplifier **11**, which is an example of a first power amplifier, has the second input end and a third output end, the second input end connected to the first output end of the 90° hybrid **50**. The power amplifier **12**, which is an example of a second power amplifier, has the third input end and a fourth output end, the third input end connected to the second output end of the 90° hybrid **50**. The power amplifiers **11** and **12** can amplify RF signals in band A or band B output from the 90° hybrid **50**.

[0065] The power amplifiers **11** and **12** each have an amplifier transistor. The amplifier transistors are, for example, bipolar transistors such as heterojunction bipolar transistors (HBTs) or field-effect transistors such as MOSFETs (Metal-Oxide-Semiconductor Field Effect Transistors). Note that, in the case where the above-mentioned amplifier transistors are bipolar transistors, the input ends of the power amplifiers **11** and **12** are, for example, the base ends of the bipolar transistors, and the output ends of the power amplifiers **11** and **12** are, for example, the collector ends of the bipolar transistors. Note that, in the case where the above-mentioned amplifier transistors are field-effect transistors, the input ends of the power amplifiers **11** and **12** are, for example, the gate ends of the field-effect transistors, and the output ends of the power amplifiers **11** and **12** are, for example, the drain ends of the field-effect transistors.

[0066] The phase-shifting circuit **21**, which is an example of a first phase-shifting circuit, is connected between the third output end of the power amplifier **11** and a terminal **41***d* of the switch circuit **41**. The phase-shifting circuit **21** includes, for example, capacitors **211** and **212** and an inductor **213**. The capacitor **211**, which is an example of a first capacitor, is connected between the third output end and the terminal **41***d*. The inductor **213**, which is an example of a first inductor, is connected between the path connecting the capacitor **211** and the terminal **41***d* and ground. The capacitor **212** is arranged in series in the path connecting the capacitor **211** and the terminal **41***d*. The phase-shifting circuit **21** has the configuration of a so-called high-pass filter, and sets the passband phase of the transmission signals in bands A and B to, for example, +45° (45° forward). Note that the capacitor **212** is a capacitor for DC cutting and does not contribute to phase shifting, and it is not necessary for the capacitor **212** to be included in the phase-shifting circuit **21**.

[0067] The phase-shifting circuit **22**, which is an example of a second phase-shifting circuit, is connected between the fourth output end of the power amplifier **12** and a terminal **41***e* of the switch circuit **41**, and is configured to set the passband phase of the transmission signals in bands A and B to be relatively −90° (90° delayed) with respect to the phase-shifting circuit **21**. The phase-shifting circuit **22** includes, for example, an inductor **221** and capacitors **222** and **223**. The inductor **221**, which is an example of a second inductor, is connected between the fourth output end and the terminal **41***e*. The capacitor **223**, which is an example of a second capacitor, is connected between the path connecting the inductor **221** and the terminal **41***e* and ground. The capacitor **222** is arranged in series in the path connecting the inductor **221** and the terminal **41***e*. The phase-shifting circuit **22** has the configuration of a so-called low-pass filter, and sets the passband phase of the transmission signals in bands A and B to, for example −45° (−45° delayed). Note that the capacitor **222** is a capacitor for DC cutting and does not contribute to phase shifting, and it is not necessary for the capacitor **222** to be included in the phase-shifting circuit **22**.

[0068] The switch circuit **41** is an example of a combiner circuit and has the terminals **41***a*, **41***b*, **41***c*, **41***d*. and **41***e*. The switch circuit **41** switches between (1) the connection between the terminal **41***d* and the terminal **41***a* and the connection between the terminal **41***e* and the terminal **41***a* (first mode), (2) the connection between the terminal **41***d* and the terminal **41***c* and the connection between the terminal **41***e* and the terminal **41***c* (second mode), and (3) the connection between the terminal **41***d* and the terminal **41***a* and the connection between the terminal **41***e* and the terminal **41***b* (third mode).

[0069] Accordingly, the switch circuit **41** (1) outputs from the terminal **41***a* an output signal generated by combining in phase the transmission signal in band A input from the terminal **41***d* and the transmission signal in band A input from the terminal **41***e* at the terminal **41***a* (first mode). Additionally, the switch circuit **41** (2) outputs from the terminal **41***c* an output signal generated by combining in phase the transmission signal in band B input from the terminal **41***d* and the transmission signal in band B input from the terminal **41***e* at the terminal **41***c* (second mode). Furthermore, the switch circuit **41** (3) outputs from the terminal **41***a* the transmission signal in band A input from the terminal **41***d*, and outputs from the terminal **41***b* the transmission signal in band B input from the terminal **41***e* (third mode).

[0070] The first mode is a mode for simultaneously transmitting the transmission signal in band A and the reception signal in band B combined in phase at the terminal **41***a*. The second mode is a mode for simultaneously transmitting the transmission signal in band B and the reception signal in band A combined in phase at the terminal **41***c*. The third mode is a mode for simultaneously transmitting the transmission signal in band A and the reception signal in band B combined in phase at the terminal **42***a* of the switch circuit **42**.

[0071] Note that, in the case where the RF circuit **1** operates in the first mode (see FIG. **2**) or the second mode (see FIG. **4**), the switch circuit **41** corresponds to a combiner circuit. In the case of the first mode or the second mode, the terminal **41***d* corresponds to a fourth input end, the terminal **41***e* corresponds to a fifth input end, the terminal **41***a* corresponds to a fifth output end, and the terminal **41***c* corresponds to a sixth output end. In the case of the first mode or the second mode, the terminal **41***a* is a signal combining point where a third sub-band signal in band A and a fourth sub-band signal in band A are combined in phase, while the terminal **41***c* is a signal combining point where a third sub-band signal in band B and a fourth sub-band signal in band B are combined in phase.

[0072] The phase-shifting line **51** is arranged in series between the third output end of the power amplifier **11** and the power supply voltage (Vcc) terminal, and suppresses leakage of a first RF signal, output from the power amplifier **11**, to the Vcc terminal. The phase-shifting line **52** is arranged in series between the fourth output end of the power amplifier **12** and the power supply voltage (Vcc) terminal, and suppresses leakage of a second RF signal, output from the power amplifier **12**, to the Vcc terminal. The capacitor **53** is connected between the Vcc terminal and ground, suppresses leakage components of the first RF signal and the second RF signal from entering the Vcc terminal, and prevents the power supply voltage from dropping to ground.

[0073] In the amplifier circuit **10** having the above-described configuration, the phase-shifting circuits **21** and **22** are configured such that the difference between a first reflection phase in the reception band of band B upon viewing the fifth output end from the third output end and a second reflection phase in the reception band of band B upon viewing the fifth output end from the fourth output end becomes 180°.

[0074] Note that the first reflection phase in the reception band of band B upon viewing the fifth output end from the third output end is defined, in the case of the first mode, as the phase change amount of the reflected signal that has been reflected at the terminal **41***a* and returned to the third output end, with respect to the phase of the signal in the reception band of band B output from the third output end, in the state where the terminal **41***d* and the terminal **41***a* are connected. Additionally, the second reflection phase in the reception band of band B upon viewing the fifth output end from the fourth output end is defined, in the case of the first mode, as the phase change amount of the reflected signal that has been reflected at the terminal **41***a* and returned to the fourth output end, with respect to the phase of the signal in the reception band of band B output from the fourth output end, in the state where the terminal **41***e* and the terminal **41***a* are connected.

[0075] Furthermore, the first reflection phase in the reception band of band B upon viewing the fifth output end from the third output end is defined, in the case of the third mode, as the phase change amount of the reflected signal that has been reflected at the terminal **42***a* and returned to the third output end, with respect to the phase of the signal in the reception band of band B output from the third output end, in the state where the terminal **41***d* and the terminal **41***a* are connected and the terminal **42***b* and the terminal **42***a* are connected. In addition, the second reflection phase in the reception band of band B upon viewing the fifth output end from the fourth output end is defined, in the case of the third mode, as the phase change amount of the reflected signal that has been reflected at the terminal **42***a* and returned to the fourth output end, with respect to the phase of the signal in the reception band of band B output from the fourth output end, in the state where the terminal **41***e* and the terminal **41***b* are connected and the terminal **42***c* and the terminal **42***a* are connected.

[0076] Accordingly, in the case of simultaneously transmitting the transmission signal in band A and the reception signal in band B, the reflection phase difference in the reception band of band B as viewed from the output ends of the two balanced power amplifiers **11** and **12** becomes 180°. This allows the reflection coefficient (P) of band B (attenuation band) in the filter **61**, which has the transmission band of band A as its passband, to be increased. Therefore, this can suppress the leakage of the reception signal in band B to the two power amplifiers **11** and **12** through the filter **61**, thereby improving the isolation between the transmission signal in band A and the reception signal in band B, which are transmitted simultaneously. Therefore, it is possible to provide the RF circuit **1**, which is equipped with the balanced power amplifiers **11** and **12** and achieves highly efficient power combining as well as improved isolation between transmission and reception.

[0077] Note that the first reflection phase in the reception band of band B upon viewing the fifth output end from the third output end is obtained by, in the case of the first mode, measuring the reflection phase in the reception band of band B at the terminal **41***a* in the state where the terminal

41*a* and the terminal **41***d* are connected, the terminal **41***a* and the terminal **41***e* are disconnected, and the terminal **41***a* and the filter **61** are disconnected.
[0078] Additionally, the second reflection phase in the reception band of band B upon viewing the fifth output end from the fourth output end is obtained by, in the case of the first mode, measuring the reflection phase in the reception band of band B at the terminal **41***a* in the state where the terminal **41***a* and the terminal **41***e* are connected, the terminal **41***a* and the terminal **41***d* are disconnected, and the terminal **41***a* and the filter **61** are disconnected.
[0079] Furthermore, the first reflection phase in the reception band of band B upon viewing the fifth output end from the third output end is obtained by, in the case of the third mode, measuring the reflection phase in the reception band of band B at the terminal **42***a* in the state where the terminal **41***a* and the terminal **41***d* are connected, the terminal **41***a* and the terminal **41***e* are disconnected, the terminal **42***b* and the terminal **42***a* are connected, the terminals **42***c*, **42***d*, and **42***e* and the terminal **42***a* are disconnected, and the antenna connection terminal **100** and the antenna **2** are disconnected.
[0080] In addition, the second reflection phase in the reception band of band B upon viewing the fifth output end from the fourth output end is obtained by, in the case of the third mode, measuring the reflection phase in the reception band of band B at the terminal **42***a* in the state where the terminal **41***b* and the terminal **41***e* are connected, the terminal **41***b* and the terminal **41***d* are disconnected, the terminal **42***c* and the terminal **42***a* are connected, the terminals **42***b*, **42***d*, and **42***e* and the terminal **42***a* are disconnected, and the antenna connection terminal **100** and the antenna **2** are disconnected.
[0081] Furthermore, in the amplifier circuit **10** having the above-described configuration, the phase-shifting circuits **21** and **22** may be configured such that the difference between a third reflection phase in the reception band of band A upon viewing the sixth output end from the third output end and a fourth reflection phase in the reception band of band A upon viewing the sixth output end from the fourth output end becomes 180°.
[0082] Note that the third reflection phase in the reception band of band A upon viewing the sixth output end from the third output end is defined, in the case of the second mode, as the phase change amount of the reflected signal that has been reflected at the terminal **41***c* and returned to the third output end, with respect to the phase of the signal in the reception band of band A output from the third output end, in the state where the terminal **41***d* and the terminal **41***c* are connected. Additionally, the fourth reflection phase in the reception band of band A upon viewing the sixth output end from the fourth output end is defined, in the case of the second mode, as the phase change amount of the reflected signal that has been reflected at the terminal **41***c* and returned to the fourth output end, with respect to the phase of the signal in the reception band of band A output from the fourth output end, in the state where the terminal **41***e* and the terminal **41***c* are connected.
[0083] Accordingly, in the case of simultaneously transmitting the transmission signal in band B and the reception signal in band A, the reflection phase difference in the reception band of band A as viewed from the output ends of the two balanced power amplifiers **11** and **12** becomes 180°. This allows the reflection coefficient (Γ) of band A (attenuation band) in the filter **63**, which has the transmission band of band B as its passband, to be increased. Therefore, this can suppress the leakage of the reception signal in band A to the two power amplifiers **11** and **12** through the filter **63**, thereby improving the isolation between the transmission signal in band B and the reception signal in band A, which are transmitted simultaneously. Therefore, it is possible to provide the RF circuit **1**, which is equipped with the balanced power amplifiers **11** and **12** and achieves highly efficient power combining as well as improved isolation between transmission and reception.
[0084] Note that the third reflection phase in the reception band of band B upon viewing the sixth output end from the third output end is obtained by, in the case of the second mode, measuring the reflection phase in the reception band of band A at the terminal **41***c* in the state where the terminal **41***c* and the terminal **41***d* are connected, the terminal **41***c* and the terminal **41***e* are disconnected,

and the terminal **41***c* and the filter **63** are disconnected.
[0085] Additionally, the fourth reflection phase in the reception band of band A upon viewing the sixth output end from the fourth output end is obtained by, in the case of the second mode, measuring the reflection phase in the reception band of band A at the terminal **41***c* in the state where the terminal **41***c* and the terminal **41***e* are connected, the terminal **41***c* and the terminal **41***d* are disconnected, and the terminal **41***c* and the filter **63** are disconnected.
1.4 Transmission and Reception Characteristics of RF Circuit **1**
[0086] FIG. **2** is a circuit state diagram illustrating the RF circuit **1** in the first mode according to the embodiment. As illustrated in the diagram, in the case of the first mode for simultaneously transmitting the transmission signal in band A and the reception signal in band B, in the switch circuit **41**, the terminal **41***a* and the terminal **41***d* are connected, and the terminal **41***a* and the terminal **41***e* are connected. Additionally, in the switch circuit **42**, the terminal **42***a* and the terminal **42***b* are connected.
[0087] The transmission signal in band A is separated into a first sub-band signal RF**1** and a second sub-band signal RF**2** by the 90° hybrid **50**. These signals are then respectively input to and amplified by the power amplifiers **11** and **12** to become a first signal and a second signal. At the third output end of the power amplifier **11**, the phase of the first signal is 0°, and at the fourth output end of the power amplifier **12**, the phase of the second signal is 90°.
[0088] The phase of the first signal at the terminal **41***a* that has passed through the phase-shifting circuit **21** (the passband phase of the transmission signal in band A is +45°) is +45°, and the phase of the second signal at the terminal **41***a* that has passed through the phase-shifting circuit **22** (the passband phase of the transmission signal in band A is −45°) is +45°. Accordingly, the first signal and the second signal in band A are combined in phase at the terminal **41***a*, enabling highly efficient power combining against load fluctuations.
[0089] Furthermore, due to the phase-shifting circuits **21** and **22**, the difference between the first reflection phase (+45°×2=90°) in the reception band of band B upon viewing the terminal **41***a* from the third output end and the second reflection phase (−45°×2=−90°) in the reception band of band B upon viewing the terminal **41***a* from the fourth output end is 180°.
[0090] FIG. **3** includes a Smith chart representing the transmission bandpass characteristics as well as the impedance in the reception band of an RF circuit according to a first embodiment and a comparative example. The RF circuit according to the first embodiment has the same configuration and characteristics as the RF circuit **1** according to the embodiment, with band A being band B41 for 4G-LTE (TDD: 2496-2690 MHz) and band B being band B40 for 4G-LTE (TDD: 2300-2400 MHz). In addition, the RF circuit according to the comparative example has the same circuit configuration as the RF circuit **1** according to the embodiment, but the phase-shifting circuits **21** and **22** do not have the characteristic that they are “configured such that the difference between the first reflection phase in the reception band of band B upon viewing the fifth output end from the third output end and the second reflection phase in the reception band of band B upon viewing the fifth output end from the fourth output end becomes 1800”.
[0091] The difference between the first reflection phase in the band B40 range at the third output end of the power amplifier **11** (PA**11**) and the second reflection phase in the band B40 range at the fourth output end of the power amplifier **12** (PA**12**) is 180°. Thus, as illustrated in part (b) of FIG. **3**, the reflection coefficient (P) of the band B40 range (2300-2400 MHz) increases, causing the output impedance of the power amplifier **11** (PA**11**) and the output impedance of the power amplifier **12** (PA**12**) to undergo a phase inversion. The band B40 range moves away from the gain matching point, allowing for reduced gain across the entire B40 range.
[0092] This greatly improves the attenuation of band B40 (reception band Rx) in the bandpass characteristics of the circuit where the power amplifiers **11** and **12** are combined with the filter **61**, as illustrated in part (a) of FIG. **3**. Therefore, this can suppress the leakage of the reception signal in band B to the two power amplifiers **11** and **12** through the filter **61**, thereby improving the isolation

between the transmission signal in band A and the reception signal in band B, which are transmitted simultaneously. Therefore, it is possible to provide the RF circuit **1**, which is equipped with the balanced power amplifiers **11** and **12** and achieves highly efficient power combining as well as improved isolation between transmission and reception.

[0093] FIG. **4** is a circuit state diagram illustrating the RF circuit **1** in the second mode according to the embodiment. As illustrated in the diagram, in the case of the second mode for simultaneously transmitting the transmission signal in band B and the reception signal in band A, in the switch circuit **41**, the terminal **41***c* and the terminal **41***d* are connected, and the terminal **41***c* and the terminal **41***e* are connected. Additionally, in the switch circuit **42**, the terminal **42***a* and the terminal **42***d* are connected.

[0094] The transmission signal in band B is separated into a first sub-band signal RF**1** and a second sub-band signal RF**2** by the 90° hybrid **50**. These signals are then respectively input to and amplified by the power amplifiers **11** and **12** to become a first signal and a second signal. At the third output end of the power amplifier **11**, the phase of the first signal is 0°, and at the fourth output end of the power amplifier **12**, the phase of the second signal is 90°.

[0095] The phase of the first signal at the terminal **41***c* that has passed through the phase-shifting circuit **21** (the passband phase of the transmission signal in band B is +45°) is +45°, and the phase of the second signal at the terminal **41***c* that has passed through the phase-shifting circuit **22** (the passband phase of the transmission signal in band B is −45°) is +45°. Accordingly, the first signal and the second signal in band B are combined in phase at the terminal **41***c*, enabling highly efficient power combining against load fluctuations.

[0096] Furthermore, due to the phase-shifting circuits **21** and **22**, the difference between the third reflection phase (+45°×2=90°) in the reception band of band A upon viewing the terminal **41***c* from the third output end and the fourth reflection phase (−45°×2=−90°) in the reception band of band A upon viewing the terminal **41***c* from the fourth output end is 180°.

[0097] Accordingly, the reflection coefficient (F) of the reception band of band A increases, causing the output impedance of the power amplifier **11** and the output impedance of the power amplifier **12** to undergo a phase inversion. The reception band of band A moves away from the gain matching point, allowing for reduced gain across the entire reception band of band A.

[0098] This greatly improves the attenuation in the reception band of band A in the bandpass characteristics of the circuit where the power amplifiers **11** and **12** are combined with the filter **63**. Therefore, this can suppress the leakage of the reception signal in band A to the two power amplifiers **11** and **12** through the filter **63**, thereby improving the isolation between the transmission signal in band B and the reception signal in band A, which are transmitted simultaneously. Therefore, it is possible to provide the RF circuit **1**, which is equipped with the balanced power amplifiers **11** and **12** and achieves highly efficient power combining as well as improved isolation between transmission and reception.

[0099] FIG. **5** is a circuit state diagram illustrating the RF circuit **1** in the third mode according to the embodiment. As illustrated in the diagram, in the case of the third mode for simultaneously transmitting the transmission signal in band A and the reception signal in band B, in the switch circuit **41**, the terminal **41***a* and the terminal **41***d* are connected, and the terminal **41***b* and the terminal **41***e* are connected. Additionally, in the switch circuit **42**, the terminal **42***a* and the terminal **42***b* are connected, and the terminal **42***a* and the terminal **42***c* are connected.

[0100] The transmission signal in band A is separated into a first sub-band signal RF**1** and a second sub-band signal RF**2** by the 90° hybrid **50**. These signals are then respectively input to and amplified by the power amplifiers **11** and **12** to become a first signal and a second signal. At the third output end of the power amplifier **11**, the phase of the first signal is 0°, and at the fourth output end of the power amplifier **12**, the phase of the second signal is 90°.

[0101] The phase of the first signal at the terminal **41***a* that has passed through the phase-shifting circuit **21** (the passband phase of the transmission signal in band A is +45°) is +45°, and the phase of the second signal at the terminal **41***b* that has passed through the phase-shifting circuit **22** (the passband phase of the transmission signal in band A is −45°) is +45°. In addition, because the filter **61** through which the first signal passes and the filter **62** through which the second signal passes have the same passband and characteristics, the passband phases of the filter **61** and the filter **62** are equal. Accordingly, the first signal and the second signal in band A are combined in phase at the terminal **42***a*, enabling highly efficient power combining against load fluctuations.

[0102] Furthermore, due to the phase-shifting circuits **21** and **22**, the difference between the first reflection phase (+45°×2=90°) in the reception band of band B upon viewing the terminal **42***a* from the third output end and the second reflection phase (−45°×2=−90°) in the reception band of band B upon viewing the terminal **42***a* from the fourth output end is 180°.

[0103] Accordingly, the reflection coefficient (F) of the reception band of band B increases, causing the output impedance of the power amplifier **11** and the output impedance of the power amplifier **12** to undergo a phase inversion. The reception band of band B moves away from the gain matching point, allowing for reduced gain across the entire reception band of band B.

[0104] This greatly improves the attenuation in the reception band of band B in the bandpass characteristics of the circuit where the power amplifiers **11** and **12** are combined with the filters **61** and **62**. Therefore, this can suppress the leakage of the reception signal in band B to the two power amplifiers **11** and **12** through the filter **61** or **62**, thereby improving the isolation between the transmission signal in band A and the reception signal in band B, which are transmitted simultaneously. Therefore, it is possible to provide the RF circuit **1**, which is equipped with the balanced power amplifiers **11** and **12** and achieves highly efficient power combining as well as improved isolation between transmission and reception.

[0105] Note that, in the first mode, the transmission signal in band A passes through the filter **61**, whereas, in the third mode, the transmission signal in band A passes through the filters **61** and **62**. Accordingly, in the case of simultaneous transmission of transmission in band A and reception in band B, the first mode can reduce the number of filters used, while the third mode can ease the electric power handling capability of the filters, allowing for miniaturization of a single filter.

[0106] Furthermore, in the third mode, the switch circuit **42** uses a combiner circuit that combines balanced signals also as an antenna switch circuit, allowing for the miniaturization of the RF circuit **1**.

2 Configuration of Amplifier Circuit, RF Circuit, and Communication Device According to First Modification

[0107] While the amplifier circuit **10** according to the embodiment has the function of adjusting the reflection phase of the transmission path, an amplifier circuit **10**A according to a first modification has the function of adjusting the reflection phase of the reception path. FIG. **6** is a circuit configuration diagram of the amplifier circuit **10**A, an RF circuit **1**A, and a communication device **4**A according to the first modification of the embodiment. As illustrated in the diagram, the communication device **4**A according to the present modification includes the RF circuit **1**A, the antenna **2**, and the RFIC **3**. The communication device **4**A according to the present modification differs from the communication device **4** according to the embodiment in the configuration of the RF circuit **1**A. Therefore, the configuration of the RF circuit **1**A according to the present modification will be described below.

[0108] The RF circuit **1**A includes the amplifier circuit **10**A, the filters **61** to **66**, the switch circuit **42**, the inductors **71** to **78**, and the antenna connection terminal **100**. The RF circuit **1**A according to the present modification mainly differs from the RF circuit **1** according to the embodiment in the configuration of the amplifier circuit **10**A. Hereinafter, the RF circuit **1**A according to the present modification will be described, mainly focusing on different configurations while omitting the description of the same configurations as the RF circuit **1** according to the embodiment.

[0109] The amplifier circuit **10**A is a circuit that amplifies transmission signals in band A and band B, input from the RF input terminal **110**, amplifies reception signals in band A and band B, input from the antenna connection terminal **100**, and outputs them from an RF output terminal **120**.

[0110] The filter **61**, which is an example of a second filter, is connected between the switch circuit **41** and the antenna connection terminal **100** and has a passband containing the transmission band of band A (second band). One end of the filter **61** is connected to the path connecting the antenna connection terminal **100** and the filter **64**, and the other end is connected to the switch circuit **41**.

[0111] The filter **62** is connected between the phase-shifting circuit **22** and the switch circuit **42** and has a passband containing the transmission band of band A (second band).

[0112] The filter **63** is connected between the switch circuit **41** and the antenna connection terminal **100** and has a passband containing the transmission band of band B (first band). One end of the filter **63** is connected to the path connecting the antenna connection terminal **100** and the filter **65**, and the other end is connected to the switch circuit **41**.

[0113] The filter **64**, which is an example of a first filter, is connected between a switch circuit **43** and the antenna connection terminal **100** and has a passband containing the reception band of band B (first band). Specifically, one end of the filter **64** is connected to a terminal **43***a* of the switch circuit **43**, and the other end of the filter **64** is connected to the antenna connection terminal **100** with the inductors **71** and **77** and the switch circuit **42** interposed therebetween.

[0114] The filter **65**, which is an example of a third filter, is connected between the switch circuit **43** and the antenna connection terminal **100** and has a passband containing the reception band of band A (second band). Specifically, one end of the filter **65** is connected to a terminal **43***b* of the switch circuit **43**, and the other end of the filter **65** is connected to the antenna connection terminal **100** with the inductors **73** and **77** and the switch circuit **42** interposed therebetween.

[0115] The filter **66** has a passband containing the reception band of band C. One end of the filter **66** is connected to the terminal **42***e* of the switch circuit **42**, and the other end is connected to a terminal **43***c* of the switch circuit **43**.

[0116] Band A (second band) and band B (first band) are a combination of bands allowing simultaneous transmission. Note that each of band A (second band) and band B (first band) may be a band using time-division duplexing (TDD). In this case, the filters **61** to **65** may have the same passband.

[0117] Band A is, for example, band B41 for 4G-LTE or band n41 for 5G-NR, while band B is, for example, band B40 for 4G-LTE or band n40 for 5G-NR.

[0118] The switch circuit **42**, which is an example of an antenna switch, has the terminals **42***a*, **42***b*, **42***c*, **42***d*, and **42***e*. The terminal **42***a* is connected to the antenna connection terminal **100** with the inductor **77** interposed therebetween; the terminal **42***b* is connected to the filters **61** and **64** with the inductor **71** interposed therebetween; the terminal **42***c* is connected to the filter **62** with the inductor **72** interposed therebetween; the terminal **42***d* is connected to the filters **63** and **65** with the inductor **73** interposed therebetween; and the terminal **42***e* is connected to the filter **66**.

[0119] According to the above-mentioned circuit configuration, the RF circuit **1**A can perform simultaneous transmission of the transmission signal in band A and the reception signal in band B, as well as simultaneous transmission of the transmission signal in band B and the reception signal in band A.

[0120] Note that the RF circuit **1**A according to the present modification may have at least the amplifier circuit **10**A and the filters **61** and **64** in the circuit configuration illustrated in FIG. **6**.

[0121] Next, the circuit configuration of the amplifier circuit **10**A will be described in detail.

[0122] As illustrated in FIG. **6**, the amplifier circuit **10**A includes the power amplifiers **11** and **12**, low-noise amplifiers **14** and **15**, phase-shifting circuits **21**, **22**, **23**, and **24**, switch circuits **41** and **43**, 90° hybrids **50** and **54**, phase-shifting lines **51** and **52**, capacitor **53**, RF input terminal **110**, and RF output terminal **120**. The amplifier circuit **10**A according to the present modification differs from the amplifier circuit **10** according to the embodiment in the configuration of the reception circuit. Hereinafter, the amplifier circuit **10**A according to the present modification will be described, mainly focusing on the reception circuit, which is a different configuration, while omitting the description of the transmission circuit, which is the same configuration as the amplifier circuit **10** according to the embodiment.

[0123] The RF output terminal **120** is connected to the RFIC **3**. Note that the RF output terminal **120** may be a metal conductor such as a metal electrode and a metal bump, or may be a single point (node) on the metal wiring.

[0124] The 90° hybrid **54**, which is an example of a combiner, has a first output end, a first input end, and a second input end, the first output end connected to the RF output terminal **120**, the first input end connected to a second output end of the low-noise amplifier **14**, and the second input end connected to a third output end of the low-noise amplifier **15**. The 90° hybrid **54** is configured to combine a first signal in the reception band of band A or band B, input to the first input end, and a second signal in the reception band of band A or band B, input to the second input end, where the second signal is relatively +90° with respect to the first signal, and output the combined signal from the first output end.

[0125] Note that, instead of the 90° hybrid **54**, a phase-shifting circuit having other circuit configuration may be arranged.

[0126] The low-noise amplifier **14**, which is an example of a first low-noise amplifier, has a second output end and a third input end, the second output end connected to the first input end of the 90° hybrid **54**. The low-noise amplifier **15**, which is an example of a second low-noise amplifier, has a third output end and a fourth input end, the third output end connected to the second input end of the 90° hybrid **54**.

[0127] The low-noise amplifiers **14** and **15** each have an amplifier transistor. The amplifier transistors are, for example, bipolar transistors such as HBTs or field-effect transistors such as MOSFETs. Note that, in the case where the amplifier transistors are bipolar transistors, the input ends of the low-noise amplifiers **14** and **15** are, for example, the base ends of the bipolar transistors, and the output ends of the low-noise amplifiers **14** and **15** are, for example, the collector ends of the bipolar transistors. Note that, in the case where the amplifier transistors are field-effect transistors, the input ends of the low-noise amplifiers **14** and **15** are, for example, the gate ends of the field-effect transistors, and the output ends of the low-noise amplifiers **14** and **15** are, for example, the drain ends of the field-effect transistors.

[0128] The phase-shifting circuit **23**, which is an example of a first phase-shifting circuit, is connected between the third input end of the low-noise amplifier **14** and a terminal **43***d* of the switch circuit **43**. The phase-shifting circuit **23** includes, for example, capacitors **231** and **232** and an inductor **233**. The capacitor **231** is connected between the third input end and the terminal **43***d*. The inductor **233** is connected between the path connecting the capacitor **231** and the terminal **43***d* and ground. The capacitor **232** is arranged in series in the path connecting the capacitor **231** and the terminal **43***d*. The phase-shifting circuit **23** has the configuration of a so-called high-pass filter, and sets the passband phase of the reception signals in bands A and B to, for example, +45° (45° forward). Note that the capacitor **232** is a capacitor for DC cutting and does not contribute to phase shifting, and it is not necessary for the capacitor **232** to be included in the phase-shifting circuit **23**.

[0129] The phase-shifting circuit **24**, which is an example of a second phase-shifting circuit, is connected between the fourth input end of the low-noise amplifier **15** and a terminal **43***e* of the switch circuit **43**, and is configured to set the passband phase of the reception signals in bands A and B to be relatively −90° (90° delayed) with respect to the phase-shifting circuit **23**. The phase-shifting circuit **24** includes, for example, an inductor **241** and capacitors **242** and **243**. The inductor **241** is connected between the fourth input end and the terminal **43***e*. The capacitor **243** is connected between the path connecting the inductor **241** and the terminal **43***e* and ground. The capacitor **242** is arranged in series in the path connecting the inductor **241** and the terminal **43***e*. The phase-shifting circuit **24** has the configuration of a so-called low-pass filter, and sets the passband phase of the reception signals in bands A and B to, for example −45° (−45° delayed). Note that the capacitor **242** is a capacitor for DC cutting and does not contribute to phase shifting, and it is not

necessary for the capacitor **242** to be included in the phase-shifting circuit **24**.
[0130] The switch circuit **43**, which is an example of a splitter circuit, has the terminals **43***a*, **43***b*, **43***c*, **43***d*, and **43***e*, and switches between (1) the connection between the terminal **43***d* and the terminal **43***a* and the connection between the terminal **43***e* and the terminal **43***a* (first mode), and (2) the connection between the terminal **43***d* and the terminal **43***b* and the connection between the terminal **43***e* and the terminal **43***b* (second mode).
[0131] Accordingly, the switch circuit **43** (1) distributes the power of the reception signal in band B, which is input to the terminal **43***a*, to the terminal **43***d* and the terminal **43***e* (first mode). Additionally, the switch circuit **43** (2) distributes the power of the reception signal in band A, which is input to the terminal **43***b*, to the terminal **43***d* and the terminal **43***e* (second mode).
[0132] The first mode is a mode for simultaneously transmitting the transmission signal in band A, combined in-phase at the terminal **41***a*, and the reception signal in band B, power-distributed at the terminal **43***a*. The second mode is a mode for simultaneously transmitting the transmission signal in band B, combined in-phase at the terminal **41***c*, and the reception signal in band A, power-distributed at the terminal **43***b*.
[0133] Note that, in the case where the RF circuit **1**A operates in the first mode or the second mode, the switch circuit **41** corresponds to a combiner circuit, and the switch circuit **43** corresponds to a splitter circuit. In the case of the first mode or the second mode, the terminal **43***d* corresponds to a fourth output end, the terminal **43***e* corresponds to a fifth output end, the terminal **43***a* corresponds to a fifth input end, and the terminal **43***b* corresponds to a sixth input end. In the case of the first mode or the second mode, the terminal **43***a* is a signal distribution point at which the power of the reception signal in band B is distributed to a first signal in band B and a second signal in band B, and the terminal **43***b* is a signal distribution point at which the power of the reception signal in band A is distributed to a first signal in band A and a second signal in band A.
[0134] In the amplifier circuit **10**A having the above-described configuration, the phase-shifting circuits **23** and **24** are configured such that the difference between a first reflection phase in the transmission band of band A upon viewing the fifth input end from the third input end and a second reflection phase in the transmission band of band A upon viewing the fifth input end from the fourth input end becomes 180°.
[0135] Accordingly, in the case of simultaneously transmitting the reception signal in band B and the transmission signal in band A, the reflection phase difference in the transmission band of band A as viewed from the input ends of the two balanced low-noise amplifiers **14** and **15** becomes 180°. This allows the reflection coefficient (P) of band A (attenuation band) in the filter **64**, which has the reception band of band B as its passband, to be increased. Therefore, this can suppress the leakage of the transmission signal in band A to the two low-noise amplifiers **14** and **15** through the filter **64**, thereby improving the isolation between the transmission signal in band A and the reception signal in band B, which are transmitted simultaneously, as well as suppressing the degradation of the reception sensitivity of band B. Therefore, it is possible to provide the RF circuit **1**A, which is equipped with the balanced low-noise amplifiers **14** and **15** and achieves highly efficient power combining as well as improved isolation between transmission and reception.
[0136] Note that the first reflection phase in the transmission band of band A upon viewing the fifth input end from the third input end is obtained by, in the case of the first mode, measuring the reflection phase in the transmission band of band A at the terminal **43***a* in the state where the terminal **43***a* and the terminal **43***d* are connected, the terminal **43***a* and the terminal **43***e* are disconnected, and the terminal **43***a* and the filter **64** are disconnected.
[0137] Additionally, the second reflection phase in the transmission band of band A upon viewing the fifth input end from the fourth input end is obtained by, in the case of the first mode, measuring the reflection phase in the transmission band of band A at the terminal **43***a* in the state where the terminal **43***a* and the terminal **43***e* are connected, the terminal **43***a* and the terminal **43***d* are disconnected, and the terminal **43***a* and the filter **64** are disconnected.

[0138] Furthermore, in the amplifier circuit **10**A having the above-described configuration, the phase-shifting circuits **23** and **24** may be configured such that the difference between a third reflection phase in the transmission band of band B upon viewing the sixth input end from the third input end and a fourth reflection phase in the transmission band of band B upon viewing the sixth input end from the fourth input end becomes 180°.
[0139] Accordingly, in the case of simultaneously transmitting the reception signal in band A and the transmission signal in band B, the reflection phase difference in the transmission band of band B as viewed from the input ends of the two balanced low-noise amplifiers **14** and **15** becomes 180°. This allows the reflection coefficient (F) of band B (attenuation band) in the filter **65**, which has the reception band of band A as its passband, to be increased. Therefore, this can suppress the leakage of the transmission signal in band B to the two low-noise amplifiers **14** and **15** through the filter **65**, thereby improving the isolation between the reception signal in band A and the transmission signal in band B, which are transmitted simultaneously, as well as suppressing the degradation of the reception sensitivity of band A. Therefore, it is possible to provide the RF circuit **1**A, which is equipped with the balanced low-noise amplifiers **14** and **15** and achieves highly efficient power combining as well as improved isolation between transmission and reception.
[0140] Note that the third reflection phase in the transmission band of band B upon viewing the sixth input end from the third input end is obtained by, in the case of the second mode, measuring the reflection phase in the transmission band of band B at the terminal **43***b* in the state where the terminal **43***b* and the terminal **43***d* are connected, the terminal **43***b* and the terminal **43***e* are disconnected, and the terminal **43***b* and the filter **65** are disconnected.
[0141] Additionally, the fourth reflection phase in the transmission band of band B upon viewing the sixth input end from the fourth input end is obtained by, in the case of the second mode, measuring the reflection phase in the transmission band of band B at the terminal **43***b* in the state where the terminal **43***b* and the terminal **43***e* are connected, the terminal **43***b* and the terminal **43***d* are disconnected, and the terminal **43***b* and the filter **65** are disconnected.
3 Configuration of Amplifier Circuit and RF Circuit According to Second Modification
[0142] In a second modification, the configuration has fewer filters compared to the RF circuit **1**A according to the first modification. FIG. **7**A is a circuit state diagram illustrating an RF circuit **1**B in the first mode according to the second modification of the embodiment. FIG. **7**B is a circuit state diagram illustrating the RF circuit **1**B in the second mode according to the second modification of the embodiment.
[0143] As illustrated in FIGS. **7**A and **7**B, the RF circuit **1**B according to the present modification includes an amplifier circuit **10**B, the filters **61** to **63** and **66**, the switch circuit **42**, the inductors **71** to **78**, and the antenna connection terminal **100**. The RF circuit **1**B according to the present modification mainly differs from the RF circuit **1**A according to the first modification in that the filters **61** and **63** are used for both transmission and reception. Hereinafter, the RF circuit **1**B according to the present modification will be described, mainly focusing on different configurations while omitting the description of the same configurations as the RF circuit **1**A according to the first modification.
[0144] Band A (second band) and band B (first band) are a combination of bands allowing simultaneous transmission. Each of band A (second band) and band B (first band) is a band using time-division duplexing (TDD). Therefore, the transmission band and the reception band of band A are the same, and the transmission band and the reception band of band B are the same.
[0145] The filter **61**, which is an example of a second filter, is connected between a terminal **44***a* of a switch circuit **44** and the antenna connection terminal **100** and has a passband containing band A (second band).
[0146] The filter **62** is connected between the phase-shifting circuit **22** and the switch circuit **42** and has a passband containing band A (second band).
[0147] The filter **63**, which is an example of a first filter, is connected between a terminal **44***c* of

the switch circuit **44** and the antenna connection terminal **100** and has a passband containing band B (first band).

[0148] The filter **66** has a passband containing the reception band of band C. One end of the filter **66** is connected to the terminal **42***e* of the switch circuit **42**, and the other end is connected to a terminal **44***h* of the switch circuit **44**.

[0149] The switch circuit **42**, which is an example of an antenna switch, has the terminals **42***a*, **42***b*, **42***c*, **42***d*, and **42***e*. The terminal **42***a* is connected to the antenna connection terminal **100** with the inductor **77** interposed therebetween; the terminal **42***b* is connected to the filter **61** with the inductor **71** interposed therebetween; the terminal **42***c* is connected to the filter **62** with the inductor **72** interposed therebetween; the terminal **42***d* is connected to the filter **63** with the inductor **73** interposed therebetween; and the terminal **42***e* is connected to the filter **66**.

[0150] As illustrated in FIGS. **7**A and **7**B, the amplifier circuit **10**B includes the power amplifiers **11** and **12**, low-noise amplifiers **14** and **15**, phase-shifting circuits **21**, **22**, **23** and **24**, switch circuit **44**, 90° hybrids **50** and **54**, phase-shifting lines **51** and **52**, capacitor **53**, RF input terminal **110**, and RF output terminal **120**. The amplifier circuit **10**B according to the present modification mainly differs from the amplifier circuit **10**A according to the first modification in the configuration of the switch circuit **44**. Hereinafter, the amplifier circuit **10**B according to the present modification will be described, mainly focusing on different configurations while omitting the description of the same configurations as the amplifier circuit **10**A according to the first modification.

[0151] The switch circuit **44**, which is an example of a combiner circuit and a splitter circuit, has terminals **44***a*, **44***b*, **44***c*, **44***d*, **44***e*, **44***f*, **44***g*, and **44***h* and switches between (1) the connection between the terminal **44***a* and the terminal **44***d*, the connection between the terminal **44***a* and the terminal **44***e*, the connection between the terminal **44***c* and the terminal **44***f*, and the connection between the terminal **44***c* and the terminal **44***g* (first mode), and (2) the connection between the terminal **44***c* and the terminal **44***d*, the connection between the terminal **44***c* and the terminal **44***e*, the connection between the terminal **44***a* and the terminal **44***f*, and the connection between the terminal **44***a* and the terminal **44***g* (second mode).

[0152] The terminal **44***a* is connected to the filter **61**; the terminal **44***b* is connected to the filter **62**; the terminal **44***c* is connected to the filter **63**; the terminal **44***d* is connected to the phase-shifting circuit **21**; the terminal **44***e* is connected to the phase-shifting circuit **22**; the terminal **44***f* is connected to the phase-shifting circuit **23**; the terminal **44***g* is connected to the phase-shifting circuit **24**; and the terminal **44***h* is connected to the filter **66**.

[0153] Accordingly, the switch circuit **44**, as illustrated in FIG. **7**A, (1) outputs from the terminal **44***a* an output signal generated by combining in phase the transmission signal in band A input from the terminal **44***d* and the transmission signal in band A input from the terminal **44***e* at the terminal **44***a*; and, at the same time, distributes the power of the reception signal in band B input to the terminal **44***c* and outputs them from the terminal **44***f* and terminal **44***g*. Additionally, the switch circuit **44**, as illustrated in FIG. **7**B, (2) outputs from the terminal **44***c* an output signal generated by combining in phase the transmission signal in band A input from the terminal **44***d* and the transmission signal in band B input from the terminal **44***e* at the terminal **44***c*; and, at the same time, distributes the power of the reception signal in band A input to the terminal **44***a* and outputs them from the terminal **44***f* and terminal **44***g*.

[0154] Accordingly, in the case of simultaneously transmitting the transmission signal in band A and the reception signal in band B, the reflection phase difference of band B as viewed from the output ends of the two balanced power amplifiers **11** and **12** becomes 180°. This allows the reflection coefficient (P) of band B (attenuation band) in the filter **61**, which has band A as its passband, to be increased. Therefore, this can suppress the leakage of the reception signal in band B to the two power amplifiers **11** and **12** through the filter **61**. Additionally, the reflection phase difference of band A as viewed from the input ends of the two balanced low-noise amplifiers **14** and **15** becomes 180°. This allows the reflection coefficient (P) of band A (attenuation band) in the filter **63**, which has band B as its passband, to be increased. Therefore, this can suppress the leakage of the transmission signal in band A to the two low-noise amplifiers **14** and **15** through the filter **63**. This can improve the isolation between the transmission signal in band A and the reception signal in band B, which are transmitted simultaneously.

[0155] Additionally, in the case of simultaneously transmitting the transmission signal in band B and the reception signal in band A, the reflection phase difference of band A as viewed from the output ends of the two balanced power amplifiers **11** and **12** becomes 180°. This allows the reflection coefficient (P) of band A (attenuation band) in the filter **63**, which has band B as its passband, to be increased. Therefore, this can suppress the leakage of the reception signal in band A to the two power amplifiers **11** and **12** through the filter **63**. Additionally, the reflection phase difference of band A as viewed from the input ends of the two balanced low-noise amplifiers **14** and **15** becomes 180°. This allows the reflection coefficient (F) of band B (attenuation band) in the filter **61**, which has band A as its passband, to be increased. Therefore, this can suppress the leakage of the transmission signal in band B to the two low-noise amplifiers **14** and **15** through the filter **61**. This can improve the isolation between the transmission signal in band B and the reception signal in band A, which are transmitted simultaneously. Therefore, it is possible to achieve highly efficient power combining and distribution, as well as improved isolation between transmission and reception, by having the balanced power amplifiers **11** and **12**, as well as the balanced low-noise amplifiers **14** and **15**.

[0156] Furthermore, the transmission signal and the reception signal in band A pass through the same filter **61**, and the transmission signal and the reception signal in band B pass through the same filter **63**. Therefore, the RF circuit **1**B can be miniaturized.

4 Arrangement of Components of RF Circuit According to Second Modification

[0157] Next, the arrangement of components of the RF circuit **1**B according to the second modification will be described. FIG. **8** includes a plan view and a cross-sectional view of the RF circuit **1**B according to the second modification of the embodiment. Part (a) of FIG. **8** illustrates the arrangement of circuit components (depicted by solid lines) in the case where a main surface **90***a* of a mounting substrate **90** is viewed from the positive side of the z-axis, and the arrangement of circuit components (depicted by dashed lines) in the case where a main surface **90***b* of the mounting substrate **90** is seen in a transparent view from the positive side of the Z-axis. Additionally, part (b) of FIG. **8** illustrates a cross-sectional view taken along the VIII-VIII line in part (a) of FIG. **8**. Note that, in FIG. **8**, the illustration of the mounting substrate **90** and the wiring that connects each circuit component is partially omitted.

[0158] The RF circuit **1**B illustrated in FIG. **8** has the mounting substrate **90**, a resin member **91**, and a shield electrode layer **95** in addition to the RF circuit **1**B illustrated in FIGS. **7**A and **7**B.

[0159] The mounting substrate **90** is a substrate that has the main surfaces **90***a* and **90***b* facing each other, and that mounts circuit components constituting the RF circuit **1**B. As the mounting substrate **90**, for example, a low temperature co-fired ceramics (LTCC) substrate, a high temperature co-fired ceramics (HTCC) substrate, a substrate with built-in components, a substrate having a redistribution layer (RDL), or a printed substrate, which has a multilayer structure of multiple dielectric layers, is used.

[0160] The resin member **91** is arranged on the main surface **90***a* and covers part of the circuit components and the main surface **90***a*. The resin member **91** has the function of ensuring the reliability, such as mechanical strength and moisture resistance, of the circuit components.

[0161] The shield electrode layer **95** covers the front and lateral sides of the resin member **91** and is set to a ground potential. This improves the electromagnetic field shielding function against the external circuit.

[0162] Note that the resin member **91** and the shield electrode layer **95** are not essential components of the RF circuit **1**B.

[0163] As illustrated in FIG. **8**, the main surface **90***a* is provided with the power amplifiers **11** and

12, phase-shifting circuits **21** and **22**, 90° hybrid **50**, filters **61** to **63** and **66**, RF input terminal **110**, and antenna connection terminal **100**. Additionally, the main surface **90***b* is provided with the low-noise amplifiers **14** and **15**, phase-shifting circuits **23** and **24**, switch circuits **42** and **44**, and 90° hybrid **54**.

[0164] Accordingly, the circuit components constituting the RF circuit **1**B are arranged separately on the main surfaces **90***a* and **90***b* of the mounting substrate **90**, thereby miniaturizing the RF circuit **1**B.

[0165] The power amplifiers **11** and **12** and the 90° hybrid **50** are included in a semiconductor integrated circuit (IC) **81**. The low-noise amplifiers **14** and **15**, the 90° hybrid **54**, and the phase-shifting circuits **23** and **24** are included in a semiconductor IC **83**. The switch circuit **44** is included in a semiconductor IC **82**. The switch circuit **42** is included in a semiconductor IC **84**. The semiconductor IC **81** is arranged on the main surface **90***a*, and the semiconductor ICs **82** to **84** are arranged on the main surface **90***b*. Note that the semiconductor IC **83** may be formed within the semiconductor IC **82**.

[0166] The semiconductor ICs **81** to **84** are configured, for example, using CMOS (Complementary Metal Oxide Semiconductor), and specifically may be manufactured using a SOI (Silicon on Insulator) process. Furthermore, the semiconductor ICs **81** to **84** may be made of at least one of GaAs, SiGe, and GaN. Note that the semiconductor materials of the semiconductor ICs **81** to **84** are not limited to the materials described above.

[0167] Accordingly, the RF circuit **1**B can be miniaturized.

[0168] Each of the filters **61** to **63** overlaps with the semiconductor IC **84** upon the mounting substrate **90** is viewed in plan. Accordingly, the wiring connecting the filters **61** to **63** and the switch circuit **42** can be shortened, thereby reducing the signal transmission losses in bands A and B.

[0169] Note that at least one of the phase-shifting circuit **21** (capacitors **211** and **212** and inductor **213**) and the phase-shifting circuit **22** (inductor **221** and capacitors **222** and **223**) may be included in the semiconductor IC **82**. Accordingly, part of the phase-shifting circuits **21** and **22** can be included in the semiconductor IC **82** in which the switch circuit **44** is formed, thereby miniaturizing the RF circuit **1**B.

[0170] Note that the arrangement of components of the RF circuit **1**B according to the present modification is also applicable to the arrangement of components of the RF circuit **1** according to the embodiment. That is, the RF circuit **1** has the mounting substrate **90**, and the power amplifiers **11** and **12**, phase-shifting circuits **21** and **22**, 90° hybrid **50**, filters **61** to **66**, RF input terminal **110**, and antenna connection terminal **100** are arranged on the main surface **90***a*. Additionally, the low-noise amplifiers **14** to **16** and the switch circuits **41** and **42** are arranged on the main surface **90***b*.

[0171] The power amplifiers **11** and **12** and the 90° hybrid **50** are included in the semiconductor IC **81**; the low-noise amplifiers **14** to **16** are included in the semiconductor IC **83**; the switch circuit **41** is included in the semiconductor IC **82**; and the switch circuit **42** is included in the semiconductor IC **84**. At least one of the phase-shifting circuit **21** (capacitors **211** and **212** and inductor **213**) and the phase-shifting circuit **22** (inductor **221** and capacitors **222** and **223**) may be included in the semiconductor IC **82**. Accordingly, part of the phase-shifting circuits **21** and **22** can be included in the semiconductor IC **82** in which the switch circuit **41** is formed, thereby miniaturizing the RF circuit **1**.

5 Effects, Etc.

[0172] As described above, the RF circuit **1** according to the present embodiment includes: the antenna connection terminal **100**; the 90° hybrid **50** having a first input end, a first output end, and a second output end, and configured to separate a signal in a transmission band of band A input to the first input end to output a first sub-band signal from the first output end and output a second sub-band signal from the second output end, the second sub-band signal having a phase relatively +90° with respect to the first sub-band signal; the power amplifier **11** having a second input end and a third output end, the second input end connected to the first output end; the power amplifier **12** having a third input end and a fourth output end, the third input end connected to the second output end; a combiner circuit that has a fourth input end, a fifth input end, and a fifth output end, and is configured to output, from the fifth output end, an output signal in band A generated by combining in phase a third sub-band signal in band A input from the fourth input end and a fourth sub-band signal in band A input from the fifth input end; the phase-shifting circuit **21** connected between the third output end and the fourth input end; the phase-shifting circuit **22** connected between the fourth output end and the fifth input end, and configured to set a passband phase of the signal in the transmission band of band A to be relatively −90° with respect to the phase-shifting circuit **21**; the filter **61** connected between the fifth output end and the antenna connection terminal **100** or between the phase-shifting circuit **21** and the fourth input end, and having a passband containing the transmission band of band A; and the filter **64** connected to a path connecting the antenna connection terminal **100** and the filter **61**, and having a passband containing a reception band of band B that can be transmitted simultaneously with band A, wherein the phase-shifting circuits **21** and **22** are configured such that a difference between a first reflection phase in the reception band of band B upon viewing the fifth output end from the third output end and a second reflection phase in the reception band of band B upon viewing the fifth output end from the fourth output end becomes 180°.

[0173] Accordingly, in the case of simultaneously transmitting the transmission signal in band A and the reception signal in band B, the reflection phase difference in the reception band of band B as viewed from the output ends of the two balanced power amplifiers **11** and **12** becomes 180°. This allows the reflection coefficient (F) of band B (attenuation band) in the filter **61**, which has the transmission band of band A as its passband, to be increased. Therefore, this can suppress the leakage of the reception signal in band B to the two power amplifiers **11** and **12** through the filter **61**, thereby improving the isolation between the transmission signal in band A and the reception signal in band B, which are transmitted simultaneously. Therefore, it is possible to provide the RF circuit **1**, which is equipped with the balanced power amplifiers **11** and **12** and achieves highly efficient power combining as well as improved isolation between transmission and reception.

[0174] Additionally, for example, in the RF circuit **1**, the phase-shifting circuit **21** is configured such that the passband phase in the transmission band of band A becomes +45°, and the phase-shifting circuit **22** is configured such that the passband phase in the transmission band of band A becomes −45°.

[0175] Accordingly, the first signal and the second signal, which are the two RF signals in band A, are combined in phase at the fifth output end, enabling high-efficiency fundamental wave power combining against load fluctuations.

[0176] Furthermore, for example, in the RF circuit **1**, the phase-shifting circuit **21** includes the capacitor **211** connected between the third output end and the fourth input end, and the inductor **213** connected between the path connecting the capacitor **211** and the fourth input end and ground. The phase-shifting circuit **22** includes the inductor **221** connected between the fourth output end and the fifth input end, and the capacitor **223** connected between the path connecting the inductor **221** and the fifth input end and ground.

[0177] This allows the phase-shifting circuit **21** to have a configuration of a high-pass filter and to set the passband phase in the transmission band of band A to +45°. This also allows the phase-shifting circuit **22** to have a configuration of a low-pass filter and to set the passband phase in the transmission band of band A to −45°.

[0178] In addition, for example, the RF circuit **1** further includes the filter **63**. The filter **61** is connected between the fifth output end and the antenna connection terminal **100**. The combiner circuit includes the switch circuit **41**, which has the terminal **41***d* (fourth input end), the terminal **41***e* (fifth input end), the terminal **41***a* (fifth output end), and, the terminal **41***c* (sixth output end), and which switches between the connection between the terminal **41***d* and the terminal **41***a* and the connection between the terminal **41***e* and the terminal **41***a*, and the connection between the terminal **41***d* and the terminal **41***c* and the connection between the terminal **41***e* and the terminal **41***c*. The filter **63** is connected to the terminal **41***c*.

[0179] Accordingly, the transmission signal in band A output from the power amplifier **11** and the transmission signal in band A output from the power amplifier **12** are combined in phase at the terminal **41***a* of the switch circuit **41**, which switches between the filter **61** and the filter **63**. Therefore, the switch circuit **41** uses the combiner circuit that combines balanced signals also as the switch circuit that switches between the filter connections, allowing for the miniaturization of the RF circuit **1**.

[0180] Additionally, for example, in the RF circuit **1**, the switch circuit **41** is included in the semiconductor IC **82**, and at least part of the phase-shifting circuits **21** and **22** is included in the semiconductor IC **82**.

[0181] Accordingly, part of the phase-shifting circuits can be included in the semiconductor IC **82** in which the switch circuit **41** is formed, thereby miniaturizing the RF circuit **1**.

[0182] Also, for example, in the RF circuit **1**, the filter **63** has a passband containing the transmission band of band B.

[0183] Accordingly, the transmission signal in band A output from the power amplifier **11** and the transmission signal in band A output from the power amplifier **12** are combined in phase at the terminal **41***a* of the switch circuit **41**, which switches between the transmission signal in band A and the transmission signal in band B. Therefore, the switch circuit **41** uses the combiner circuit that combines balanced signals also as the switch circuit that switches between band A and band B, allowing for the miniaturization of the RF circuit **1**.

[0184] Furthermore, for example, the RF circuit **1** further includes the filter **65** which is connected to a path connecting the antenna connection terminal **100** and the filter **63** and which has a passband containing the reception band of band A, and each of band A and band B is a band using time-division duplexing (TDD).

[0185] Accordingly, simultaneous transmission of the transmission signal in band A and the reception signal in band B and simultaneous transmission of the transmission signal in band B and the reception signal in band A can be realized.

[0186] Also, for example, in the RF circuit **1**, the phase-shifting circuits **21** and **22** are configured such that a difference between a first reflection phase in the reception band of band B upon viewing the fifth output end from the third output end and a second reflection phase in the reception band of the band B upon viewing the fifth output end from the fourth output end becomes 180°. Furthermore, the phase-shifting circuits **21** and **22** are configured such that a difference between a third reflection phase in the reception band of band A upon viewing the sixth output end from the third output end and a fourth reflection phase in the reception band of band A upon viewing the sixth output end from the fourth output end becomes 180°.

[0187] Accordingly, the isolation between the transmission signal and the reception signal can be improved in both of the case of simultaneously transmitting and receiving the transmission signal in band A and the reception signal in band B, and the case of simultaneously transmitting and receiving the transmission signal in band B and the reception signal in band A.

[0188] In addition, for example, in the RF circuit **1**, band A is band B41 for 4G-LTE or band n41 for 5G-NR, and band B is band B40 for 4G-LTE or band n40 for 5G-NR.

[0189] Additionally, for example, the RF circuit **1** further includes the low-noise amplifier **14** connected to the filter **64**.

[0190] This can suppress the leakage of the reception signal in band B to the two power amplifiers **11** and **12** through the filter **61**, thereby improving the isolation between the transmission signal in band A and the reception signal in band B, which are transmitted simultaneously. Therefore, the degradation of the reception sensitivity of the reception signal in band B output from the low-noise amplifier **14** can be suppressed.

[0191] Additionally, for example, the RF circuit **1** further includes the filter **62** having a passband containing the transmission band of band A. The filter **61** is connected between the phase-shifting circuit **21** and the terminal **42***b* of the switch circuit **42**. The combiner circuit includes the switch circuit **42**, which has the terminal **42***b* (fourth input end), the terminal **42***c* (fifth input end), and the terminal **42***a* (fifth output end), and which can connect the terminal **42***b* and the terminal **42***a* and connect the terminal **42***c* and the terminal **42***a*. The terminal **42***a* is connected to the antenna connection terminal **100**, and the filter **62** is connected between the phase-shifting circuit **22** and the terminal **42***c*.
[0192] Accordingly, the transmission signal in band A output from the power amplifier **11** and the transmission signal in band A output from the power amplifier **12** are combined in phase at the terminal **42***a* of the switch circuit **42** connected to the antenna connection terminal **100** (third mode). Therefore, the switch circuit **42** uses the combiner circuit that combines balanced signals also as the antenna switch circuit, allowing for the miniaturization of the RF circuit **1**.
[0193] Furthermore, the RF circuit **1**A according to the first modification and the RF circuit **1**B according to the second modification include: the antenna connection terminal **100**; the 90° hybrid **54** having a first output end, a first input end, and a second input end, and configured to combine a first signal in a reception band of band B input to the first input end and a second signal in the reception band of band B input to the second input end, the second signal having a phase relatively +90° with respect to the first signal, and output a combined signal from the first output end; the low-noise amplifier **14** having a second output end and a third input end, the second output end connected to the first input end; the low-noise amplifier **15** having a third output end and a fourth input end, the third output end connected to the second input end; a splitter circuit that has a fourth output end, a fifth output end, and a fifth input end, and is configured to distribute power of a reception signal in band B input to the fifth input end to the fourth output end and the fifth output end; the phase-shifting circuit **23** connected between the third input end and the fourth output end; the phase-shifting circuit **24** connected between the fourth input end and the fifth output end, and configured to set a passband phase in the reception band of band B to be relatively −90° with respect to the phase-shifting circuit **23**; the filter **64** connected between the fifth input end and the antenna connection terminal **100** or between the phase-shifting circuit **23** and the fourth output end, and having a passband containing the reception band of band B; and the filter **61** connected to a path connecting the antenna connection terminal **100** and the filter **64**, and having a passband containing a transmission band of band A that can be transmitted simultaneously with band B, wherein the phase-shifting circuits **23** and **24** are configured such that a difference between a first reflection phase in the transmission band of band A upon viewing the fifth input end from the third input end and a second reflection phase in the transmission band of band A upon viewing the fifth input end from the fourth input end becomes 180°.
[0194] Accordingly, in the case of simultaneously transmitting the reception signal in band B and the transmission signal in band A, the reflection phase difference in the transmission band of band A as viewed from the input ends of the two balanced low-noise amplifiers **14** and **15** becomes 180°. This allows the reflection coefficient (F) of band A (attenuation band) in the filter **64**, which has the reception band of band B as its passband, to be increased. Therefore, this can suppress the leakage of the transmission signal in band A to the two low-noise amplifiers **14** and **15** through the filter **64**, thereby improving the isolation between the transmission signal in band A and the reception signal in band B, which are transmitted simultaneously, as well as suppressing the degradation of the reception sensitivity of band B. Therefore, it is possible to provide the RF circuits **1**A and **1**B, which are equipped with the balanced low-noise amplifiers **14** and **15** and achieves highly efficient power combining as well as improved isolation between transmission and reception.
[0195] In addition, for example, the RF circuit **1**A further includes the filter **65**. The filter **64** is connected between the terminal **43***a* and the antenna connection terminal **100**. The splitter circuit includes the switch circuit **43**, which has the terminal **43***d* (fourth output end), the terminal **43***e*

(fifth output end), the terminal **43***a* (fifth input end), and the terminal **43***b* (sixth input end), and which switches between the connection between the terminal **43***d* and the terminal **43***a* and the connection between the terminal **43***e* and the terminal **43***a*, and the connection between the terminal **43***d* and the terminal **43***b* and the connection between the terminal **43***e* and the terminal **43***b*. The filter **65** is connected to the terminal **43***b*.

[0196] Accordingly, the reception signal in band B input to the low-noise amplifier **14** and the reception signal in band B input to the low-noise amplifier **15** are power-distributed at the terminal **43***a* of the switch circuit **43**, which switches between the filter **64** and the filter **65**. Therefore, the switch circuit **43** uses the splitter circuit that separates balanced signals also as the switch circuit that switches between the filter connections, allowing for the miniaturization of the RF circuit **1**A.

[0197] Furthermore, for example, the RF circuits **1**A and **1**B further include the power amplifier **11** connected to the filter **61**.

[0198] This can suppress the leakage of the transmission signal in band A output from the power amplifier **11** to the two low-noise amplifiers **14** and **15** through the filter **64**, thereby improving the isolation between the transmission signal in band A and the reception signal in band B, which are transmitted simultaneously.

Other Embodiments, Etc.

[0199] The RF circuit according to the embodiment of the present disclosure has been described above with reference to the embodiment and modifications, but the RF circuit according to the present disclosure is not limited to the embodiment and modifications described above. Another embodiment realized by combining any components from the above embodiment and modifications, as well as modifications obtained by applying various changes conceived by those skilled in the art without departing from the spirit of the present disclosure to the above embodiment and modifications, and various devices incorporating the above-mentioned RF circuit are also included in the present disclosure.

[0200] For example, in the amplifier circuit, RF circuit, and communication device according to the above embodiment and modifications, other circuit elements and wiring may be inserted between the circuit elements and the paths connecting the signal paths disclosed in the drawings.

[0201] Hereinafter, the characteristics of the RF circuits described based on the above embodiment will be described.

[0202] <1>

[0203] A radio-frequency circuit comprising: [0204] a first antenna terminal; [0205] a splitter that has a first input end, a first output end, and a second output end, and is configured to separate a signal in a transmission band of a first band input to the first input end to output a first sub-band signal from the first output end and output a second sub-band signal from the second output end, the second sub-band signal having a phase relatively +90° with respect to the first sub-band signal; [0206] a first power amplifier that has a second input end and a third output end, the second input end connected to the first output end; [0207] a second power amplifier that has a third input end and a fourth output end, the third input end connected to the second output end; [0208] a combiner circuit that has a fourth input end, a fifth input end, and a fifth output end, and is configured to output, from the fifth output end, an output signal in the first band generated by combining in phase a third sub-band signal in the first band input from the fourth input end and a fourth sub-band signal in the first band input from the fifth input end; [0209] a first phase-shifting circuit connected between the third output end and the fourth input end; [0210] a second phase-shifting circuit that is connected between the fourth output end and the fifth input end, and is configured such that a passband phase of the signal in the transmission band of the first band becomes relatively −90° with respect to the first phase-shifting circuit; [0211] a first filter that is connected between the fifth output end and the first antenna terminal or between the first phase-shifting circuit and the fourth input end, and has a passband containing the transmission band of the first band; and [0212] a second filter that is connected to a path connecting the first antenna terminal and the first filter, and has a passband containing a reception band of a second band that can be transmitted simultaneously with the first band, [0213] wherein the first phase-shifting circuit and the second phase-shifting circuit are configured such that [0214] a difference between a first reflection phase in the reception band of the second band upon viewing the fifth output end from the third output end and a second reflection phase in the reception band of the second band upon viewing the fifth output end from the fourth output end becomes 1800.

<2>

[0215] The radio-frequency circuit according to <1>, wherein: [0216] the first phase-shifting circuit is configured such that a passband phase in the transmission band of the first band becomes +45°; and [0217] the second phase-shifting circuit is configured such that a passband phase in the transmission band of the first band becomes −45°.

<3>

[0218] The radio-frequency circuit according to <2>, wherein: [0219] the first phase-shifting circuit includes [0220] a first capacitor connected between the third output end and the fourth input end, and [0221] a first inductor connected between a path connecting the first capacitor and the fourth input end and ground; and [0222] the second phase-shifting circuit includes [0223] a second inductor connected between the fourth output end and the fifth input end, and [0224] a second capacitor connected between a path connecting the second inductor and the fifth input end and ground.

<4>

[0225] The radio-frequency circuit according to any of <1> to <3> further comprising: [0226] a third filter, [0227] wherein the first filter is connected between the fifth output end and the first antenna terminal, [0228] the combiner circuit includes [0229] a switch circuit that has the fourth input end, the fifth input end, the fifth output end, and a sixth output end, and switches between a connection between the fourth input end and the fifth output end and a connection between the fifth input end and the fifth output end, and a connection between the fourth input end and the sixth output end and a connection between the fifth input end and the sixth output end, and [0230] the third filter is connected to the sixth output end.

<5>

[0231] The radio-frequency circuit according to <4>, wherein: [0232] the switch circuit is included in a semiconductor IC; and [0233] at least part of the first phase-shifting circuit and the second phase-shifting circuit is included in the semiconductor IC.

<6>

[0234] The radio-frequency circuit according to <4> or <5>, wherein the third filter has a passband containing a transmission band of the second band.

<7>

[0235] The radio-frequency circuit according to <6>, further comprising: [0236] a fourth filter that is connected to a path connecting the first antenna terminal and the third filter, and has a passband containing a reception band of the first band, [0237] wherein each of the first band and the second band is a band using time-division duplexing (TDD).

<8>

[0238] The radio-frequency circuit according to <7>, wherein: [0239] the first phase-shifting circuit and the second phase-shifting circuit are configured such that [0240] a difference between the first reflection phase in the reception band of the second band upon viewing the fifth output end from the third output end and the second reflection phase in the reception band of the second band upon viewing the fifth output end from the fourth output end becomes 180°, and a difference between a third reflection phase in a reception band of the first band upon viewing the sixth output end from the third output end and a fourth reflection phase in the reception band of the first band upon viewing the sixth output end from the fourth output end becomes 180°.

<9>

[0241] The radio-frequency circuit according to any of <1> to <8>, wherein: [0242] the first band is band B41 for 4G-LTE or band n41 for 5G-NR; and [0243] the second band is band B40 for 4G-LTE or band n40 for 5G-NR.

<10>

[0244] The radio-frequency circuit according to any one of <1> to <9>, further comprising a low-noise amplifier connected to the second filter.

<11>

[0245] The radio-frequency circuit according to any of <1> to <3> further comprising: [0246] a fifth filter that has a passband containing the transmission band of the first band, [0247] wherein the first filter is connected between the first phase-shifting circuit and the fourth input end, [0248] the combiner circuit includes [0249] a switch circuit that has the fourth input end, the fifth input end, and the fifth output end, and is capable of connecting the fourth input end and the fifth output end, and connecting the fifth input end and the fifth output end, [0250] the fifth output end is connected to the first antenna terminal, and [0251] the fifth filter is connected between the second phase-shifting circuit and the fifth input end.

<12>

[0252] A radio-frequency circuit comprising: [0253] a first antenna terminal; [0254] a combiner that has a first output end, a first input end, and a second input end, and is configured to combine a first signal in a reception band of a first band input to the first input end and a second signal in the reception band of the first band input to the second input end, the second signal having a phase relatively +90° with respect to the first signal, and output a combined signal from the first output end; [0255] a first low-noise amplifier that has a second output end and a third input end, the second output end connected to the first input end; [0256] a second low-noise amplifier that has a third output end and a fourth input end, the third output end connected to the second input end; [0257] a splitter circuit that has a fourth output end, a fifth output end, and a fifth input end, and is configured to distribute power of a reception signal in the first band input to the fifth input end to the fourth output end and the fifth output end; [0258] a first phase-shifting circuit connected between the third input end and the fourth output end; [0259] a second phase-shifting circuit that is connected between the fourth input end and the fifth output end, and is configured such that a passband phase in the reception band of the first band becomes relatively −90° with respect to the first phase-shifting circuit; [0260] a first filter that is connected between the fifth input end and the first antenna terminal or between the first phase-shifting circuit and the fourth output end, and has a passband containing the reception band of the first band; and [0261] a second filter that is connected to a path connecting the first antenna terminal and the first filter, and has a passband containing a transmission band of a second band that can be transmitted simultaneously with the first band, [0262] wherein the first phase-shifting circuit and the second phase-shifting circuit are configured such that [0263] a difference between a first reflection phase in the transmission band of the second band upon viewing the fifth input end from the third input end and a second reflection phase in the transmission band of the second band upon viewing the fifth input end from the fourth input end becomes 180°.

<13>

[0264] The radio-frequency circuit according to <12>, further comprising: [0265] a third filter, [0266] wherein the first filter is connected between the fifth input end and the first antenna terminal, [0267] the splitter circuit includes [0268] a switch circuit that has the fourth output end, the fifth output end, the fifth input end, and a sixth input end, and switches between a connection between the fourth output end and the fifth input end and a connection between the fifth output end and the fifth input end, and a connection between the fourth output end and the sixth input end and a connection between the fifth output end and the sixth input end, and [0269] the third filter is connected to the sixth input end.

<14>

[0270] The radio-frequency circuit according to <12> or <13>, further comprising a power amplifier connected to the second filter.
[0271] The present disclosure can be widely used in communication equipment such as mobile phones, as an amplifying circuit, a radio-frequency circuit, or a communication device arranged in the front-end portion.

Claims

1. A radio-frequency circuit comprising: a first antenna terminal; a splitter that has a first input end, a first output end, and a second output end, and is configured to separate a signal in a transmission band of a first band input to the first input end to output a first sub-band signal from the first output end and output a second sub-band signal from the second output end, the second sub-band signal having a phase relatively +90° with respect to the first sub-band signal; a first power amplifier that has a second input end and a third output end, the second input end connected to the first output end; a second power amplifier that has a third input end and a fourth output end, the third input end connected to the second output end; a combiner circuit that has a fourth input end, a fifth input end, and a fifth output end, and is configured to output, from the fifth output end, an output signal in the first band generated by combining in phase a third sub-band signal in the first band input from the fourth input end and a fourth sub-band signal in the first band input from the fifth input end; a first phase-shifting circuit connected between the third output end and the fourth input end; a second phase-shifting circuit that is connected between the fourth output end and the fifth input end, and is configured such that a passband phase of the signal in the transmission band of the first band becomes relatively −90° with respect to the first phase-shifting circuit; a first filter that is connected between the fifth output end and the first antenna terminal or between the first phase-shifting circuit and the fourth input end, and has a passband containing the transmission band of the first band; and a second filter that is connected to a path connecting the first antenna terminal and the first filter, and has a passband containing a reception band of a second band that can be transmitted simultaneously with the first band, wherein the first phase-shifting circuit and the second phase-shifting circuit are configured such that a difference between a first reflection phase in the reception band of the second band upon viewing the fifth output end from the third output end and a second reflection phase in the reception band of the second band upon viewing the fifth output end from the fourth output end becomes 180°.
2. The radio-frequency circuit according to claim 1, wherein: the first phase-shifting circuit is configured such that a passband phase in the transmission band of the first band becomes +45°; and the second phase-shifting circuit is configured such that a passband phase in the transmission band of the first band becomes −45°.
3. The radio-frequency circuit according to claim 2, wherein: the first phase-shifting circuit includes a first capacitor connected between the third output end and the fourth input end, and a first inductor connected between a path connecting the first capacitor and the fourth input end and ground; and the second phase-shifting circuit includes a second inductor connected between the fourth output end and the fifth input end, and a second capacitor connected between a path connecting the second inductor and the fifth input end and ground.
4. The radio-frequency circuit according to claim 3, further comprising: a third filter, wherein the first filter is connected between the fifth output end and the first antenna terminal, the combiner circuit includes a switch circuit that has the fourth input end, the fifth input end, the fifth output end, and a sixth output end, and switches between a connection between the fourth input end and the fifth output end and a connection between the fifth input end and the fifth output end, and a connection between the fourth input end and the sixth output end and a connection between the fifth input end and the sixth output end, and the third filter is connected to the sixth output end.
5. The radio-frequency circuit according to claim 4, wherein: the switch circuit is included in a

semiconductor IC; and at least part of the first phase-shifting circuit and the second phase-shifting circuit is included in the semiconductor IC.

6. The radio-frequency circuit according to claim 4, wherein: the third filter has a passband containing a transmission band of the second band.

7. The radio-frequency circuit according to claim 6, further comprising: a fourth filter that is connected to a path connecting the first antenna terminal and the third filter, and has a passband containing a reception band of the first band, wherein each of the first band and the second band is a band using time-division duplexing (TDD).

8. The radio-frequency circuit according to claim 7, wherein: the first phase-shifting circuit and the second phase-shifting circuit are configured such that a difference between the first reflection phase in the reception band of the second band upon viewing the fifth output end from the third output end and the second reflection phase in the reception band of the second band upon viewing the fifth output end from the fourth output end becomes 180°, and a difference between a third reflection phase in a reception band of the first band upon viewing the sixth output end from the third output end and a fourth reflection phase in the reception band of the first band upon viewing the sixth output end from the fourth output end becomes 180°.

9. The radio-frequency circuit according to claim 3, wherein: the first band is band B41 for 4G-LTE or band n41 for 5G-NR, and the second band is band B40 for 4G-LTE or band n40 for 5G-NR.

10. The radio-frequency circuit according to claim 3, further comprising: a low-noise amplifier connected to the second filter.

11. The radio-frequency circuit according to claim 3, further comprising: a fifth filter that has a passband containing the transmission band of the first band, wherein the first filter is connected between the first phase-shifting circuit and the fourth input end, the combiner circuit includes a switch circuit that has the fourth input end, the fifth input end, and the fifth output end, and is capable of connecting the fourth input end and the fifth output end, and connecting the fifth input end and the fifth output end, the fifth output end is connected to the first antenna terminal, and the fifth filter is connected between the second phase-shifting circuit and the fifth input end.

12. A radio-frequency circuit comprising: a first antenna terminal; a combiner that has a first output end, a first input end, and a second input end, and is configured to combine a first signal in a reception band of a first band input to the first input end and a second signal in the reception band of the first band input to the second input end, the second signal having a phase relatively +90° with respect to the first signal, and output a combined signal from the first output end; a first low-noise amplifier that has a second output end and a third input end, the second output end connected to the first input end; a second low-noise amplifier that has a third output end and a fourth input end, the third output end connected to the second input end; a splitter circuit that has a fourth output end, a fifth output end, and a fifth input end, and is configured to distribute power of a reception signal in the first band input to the fifth input end to the fourth output end and the fifth output end; a first phase-shifting circuit connected between the third input end and the fourth output end; a second phase-shifting circuit that is connected between the fourth input end and the fifth output end, and is configured such that a passband phase in the reception band of the first band becomes relatively −90° with respect to the first phase-shifting circuit; a first filter that is connected between the fifth input end and the first antenna terminal or between the first phase-shifting circuit and the fourth output end, and has a passband containing the reception band of the first band; and a second filter that is connected to a path connecting the first antenna terminal and the first filter, and has a passband containing a transmission band of a second band that can be transmitted simultaneously with the first band, wherein the first phase-shifting circuit and the second phase-shifting circuit are configured such that a difference between a first reflection phase in the transmission band of the second band upon viewing the fifth input end from the third input end and a second reflection phase in the transmission band of the second band upon viewing the fifth input end from the fourth input end becomes 180°.

13. The radio-frequency circuit according to claim 12, further comprising: a third filter, wherein the first filter is connected between the fifth input end and the first antenna terminal, the splitter circuit includes a switch circuit that has the fourth output end, the fifth output end, the fifth input end, and a sixth input end, and switches between a connection between the fourth output end and the fifth input end and a connection between the fifth output end and the fifth input end, and a connection between the fourth output end and the sixth input end and a connection between the fifth output end and the sixth input end, and the third filter is connected to the sixth input end.
14. The radio-frequency circuit according to claim 13, further comprising: a power amplifier connected to the second filter.
15. The radio-frequency circuit according to claim 12, further comprising: a power amplifier connected to the second filter.
16. The radio-frequency circuit according to claim 1, further comprising: a third filter, wherein the first filter is connected between the fifth output end and the first antenna terminal, the combiner circuit includes a switch circuit that has the fourth input end, the fifth input end, the fifth output end, and a sixth output end, and switches between a connection between the fourth input end and the fifth output end and a connection between the fifth input end and the fifth output end, and a connection between the fourth input end and the sixth output end and a connection between the fifth input end and the sixth output end, and the third filter is connected to the sixth output end.
17. The radio-frequency circuit according to claim 16, wherein: the switch circuit is included in a semiconductor IC; and at least part of the first phase-shifting circuit and the second phase-shifting circuit is included in the semiconductor IC.
18. The radio-frequency circuit according to claim 2, further comprising: a third filter, wherein the first filter is connected between the fifth output end and the first antenna terminal, the combiner circuit includes a switch circuit that has the fourth input end, the fifth input end, the fifth output end, and a sixth output end, and switches between a connection between the fourth input end and the fifth output end and a connection between the fifth input end and the fifth output end, and a connection between the fourth input end and the sixth output end and a connection between the fifth input end and the sixth output end, and the third filter is connected to the sixth output end.
19. The radio-frequency circuit according to claim 18, wherein: the switch circuit is included in a semiconductor IC; and at least part of the first phase-shifting circuit and the second phase-shifting circuit is included in the semiconductor IC.
20. The radio-frequency circuit according to claim 1, further comprising: a fifth filter that has a passband containing the transmission band of the first band, wherein the first filter is connected between the first phase-shifting circuit and the fourth input end, the combiner circuit includes a switch circuit that has the fourth input end, the fifth input end, and the fifth output end, and is capable of connecting the fourth input end and the fifth output end, and connecting the fifth input end and the fifth output end, the fifth output end is connected to the first antenna terminal, and the fifth filter is connected between the second phase-shifting circuit and the fifth input end.