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United States Patent	12395197
Kind Code	B2
Date of Patent	August 19, 2025
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Radio frequency circuit and communication device

Abstract

A radio frequency circuit is capable of sending a transmit signal of a first communication band and a transmit signal of a second communication band simultaneously and includes a transmit input terminal, a power amplifier capable of amplifying a transmit signal of the first communication band, and a filter connected between the transmit input terminal and an input terminal of the power amplifier. In the filter, a pass band is a band including a transmit band of the first communication band, and an attenuation band is a band including a transmit band of the second communication band.

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Appl. No.:	17/224162
Filed:	April 07, 2021

Prior Publication Data

Document Identifier	Publication Date
US 20210336640 A1	Oct. 28, 2021

Foreign Application Priority Data

JP	2020-077682	Apr. 24, 2020
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Publication Classification

Int. Cl.: H04B1/04 (20060101); **H03F3/24** (20060101); **H03H7/01** (20060101); **H04B1/00** (20060101); **H04B1/40** (20150101); **H04B1/56** (20060101)

U.S. Cl.:

CPC H04B1/0483 (20130101); **H03F3/245** (20130101); H03F2200/165 (20130101); H03F2200/171 (20130101); H03F2200/267 (20130101); H03F2200/294 (20130101); H03F2200/451 (20130101); H04B2001/0408 (20130101)

Field of Classification Search

USPC: None

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS

(1) This application claims the benefit of priority to Japanese Patent Application No. 2020-077682 filed on Apr. 24, 2020. The entire contents of this application are hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

(2) The present invention relates to radio frequency circuits and communication devices.

2. Description of the Related Art

(3) There is a demand for radio frequency circuits capable of sending radio frequency signals of different frequencies simultaneously.

(4) In FIG. 2B of Japanese Unexamined Patent Application Publication No. 2017-17691, a circuit configuration of an electronic system (radio frequency front-end module) including a first transmit circuit and a second transmit circuit is disclosed. Specifically, the first transmit circuit includes a first power amplifier that amplifies a radio frequency signal of one frequency region (first frequency band group), a first antenna switch, a first band selection switch arranged in a first signal path that connects the first power amplifier and the first antenna switch, and a plurality of first filters (duplexer) connected to the first band selection switch. The second transmit circuit includes a second power amplifier that amplifies a radio frequency signal of another frequency region (second frequency band group), a second antenna switch, a second band selection switch arranged in a second signal path that connects the second power amplifier and the second antenna switch, and a plurality of second filters (duplexer) connected to the second band selection switch. This enables to simultaneously send a first transmit signal output from the first transmit circuit and a second transmit signal output from the second transmit circuit.

(5) However, when the first transmit signal output from the first power amplifier and the second transmit signal output from the second power amplifier are sent simultaneously, the second transmit signal yet to be input to the second power amplifier may sometimes reach an input terminal of the first power amplifier. In this case, in the first power amplifier, intermodulation distortion caused by the first transmit signal and the second transmit signal may occur. This leads to an issue of degradation of quality of a radio frequency signal output from the first power amplifier.

SUMMARY OF THE INVENTION

(6) Preferred embodiments of the present invention provide radio frequency circuits and communication devices, in each of which the quality degradation of a transmit signal is reduced or prevented when a plurality of transmit signals is sent simultaneously.

(7) A radio frequency circuit according to a preferred embodiment of the present invention for sending a transmit signal of a first communication band and a transmit signal of a second communication band simultaneously and includes a first transmit input terminal, a first power amplifier to amplify a transmit signal of the first communication band, and a first filter connected between the first transmit input terminal and an input terminal of the first power amplifier, a pass band of the first filter includes a transmit band of the first communication band, and an attenuation band of the first filter includes a transmit band of the second communication band.

(8) The above and other elements, features, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments with reference to the attached drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) FIG. 1 is a circuit configuration diagram of a radio frequency circuit and a communication device according to a preferred embodiment of the present invention.
- (2) FIG. 2 is a diagram illustrating signal flows in a communication device according to a preferred embodiment of the present invention.
- (3) FIG. 3 is a circuit configuration diagram of a radio frequency circuit according to a modified example 1 of a preferred embodiment of the present invention.
- (4) FIG. 4 is a circuit configuration diagram of a radio frequency circuit according to a modified example 2 of a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

(5) Hereinafter, preferred embodiments of the present invention will be described in detail with reference to the drawings. Note that the preferred embodiments which will be described below illustrate comprehensive or specific examples. Numeric values, shapes, materials, elements, arrangements and connection configurations of the elements, and the like illustrated in the following preferred embodiments are mere examples, and not intended to limit the present invention. Of elements in the following preferred embodiments and modified examples, the elements that are not described in an independent claim will be described as optional elements. Further, dimensions or ratios of the dimensions of elements illustrated in the drawings are not necessarily precise. Further, in the drawings, the same reference characters denote the same or substantially the same elements, and in some cases an overlapping description is omitted or simplified.

(6) In the following section, a “transmit path”, a “receive path”, and a “bypass path” are each defined to mean a transmission line including a wiring line over which a radio frequency signal travels, an electrode directly connected to the wiring line, a terminal directly connected to the wiring line or the electrode, and the like, for example.

PREFERRED EMBODIMENT

1. Configuration of Radio Frequency Circuit and Communication Device

(7) FIG. 1 is a circuit configuration diagram of a radio frequency circuit **10** and a communication device **5** according to a preferred embodiment of the present invention. As illustrated in FIG. 1, the communication device **5** includes the radio frequency circuit **10**, a radio frequency circuit **20**, an antenna **2**, a RF signal processing circuit (RFIC) **3**, and a switch **4**.

(8) The RFIC **3** is a RF signal processing circuit that performs processing on radio frequency signals being sent or received by the antenna **2**, performs signal processing on receive signals input via receive paths of the radio frequency circuits **10** and **20** using down-converting and the like, and outputs receive signals generated by this signal processing to a base band signal processing circuit (BBIC: not illustrated). Furthermore, the RFIC **3** performs signal processing on transmit signals input from the BBIC using up-converting and the like, for example, and outputs transmit signals generated by this signal processing to transmit paths of the radio frequency circuits **10** and **20**.

(9) Particularly, the RFIC **3** is capable of simultaneously outputting transmit signals of different communication bands to the radio frequency circuits **10** and **20**.

(10) In the present preferred embodiment, the RFIC **3** includes a terminal **310** capable of sending a transmit signal of a first communication band and a transmit signal of a third communication band, a terminal **320** capable of receiving a receive signal of the first communication band and a receive signal of the third communication band, a terminal **330** capable of sending a transmit signal of a second communication band, and a terminal **340** capable of receiving a receive signal of the second communication band.

(11) Note that each of the first communication band, the second communication band, and the third communication band may be, for example, one of communication bands used in the fourth generation mobile communication system (4G) and communication bands used in the fifth

generation mobile communication system (5G).

(12) The RFIC **3** also defines and functions as a control unit that controls the connection of the switch **4** and the connections of switches **51** and **52** included in the radio frequency circuit **10** based on a communication band (frequency band) being used. Specifically, the RFIC **3** switches between the connections of the foregoing respective switches using control signals (not illustrated). Note that the control unit may be provided outside the RFIC **3**, or may be provided, for example, inside the radio frequency circuit **10** or **20** or the BBIC.

(13) The switch **4** includes a common terminal, a first selection terminal, and a second selection terminal. The common terminal is connected to the antenna **2**, the first selection terminal is connected to an input/output terminal **100** of the radio frequency circuit **10**, and the second selection terminal is connected to an input/output terminal **200** of the radio frequency circuit **20**. According to this configuration, the switch **4** switches between connecting and disconnecting the antenna **2** to/from the radio frequency circuit **10** and between connecting and disconnecting the antenna **2** to/from the radio frequency circuit **20**. That is to say, the switching operation of the switch **4** enables executing one of the following operations: (1) connecting the antenna **2** to the radio frequency circuit **10** and connecting the antenna **2** to the radio frequency circuit **20**; (2) connecting the antenna **2** to the radio frequency circuit **10** and disconnecting the antenna **2** from the radio frequency circuit **20**; and (3) disconnecting the antenna **2** from the radio frequency circuit **10** and connecting the antenna **2** to the radio frequency circuit **20**. Alternatively, the switch **4** may be omitted, and the antenna **2** may be directly connected to the radio frequency circuits **10** and **20**.

(14) The antenna **2** is connected to the common terminal of the switch **4** and radiates a transmit signal of the first communication band and a transmit signal of the second communication band or receives signals.

(15) Note that in the communication device **5** according to the present preferred embodiment, the antenna **2**, the switch **4**, and the BBIC are not necessary elements.

(16) Next, configurations of the radio frequency circuits **10** and **20** are described.

(17) As illustrated in FIG. **1**, the radio frequency circuit **10** includes the input/output terminal **100**, a transmit input terminal **110**, a receive output terminal **120**, a power amplifier **11T**, a low noise amplifier **11R**, a filter **33**, duplexers **31** and **32**, and the switches **51** and **52**.

(18) The transmit input terminal **110** is an example of a first transmit input terminal and is connected to the terminal **310** of the RFIC **3**. The receive output terminal **120** is connected to the terminal **320** of the RFIC **3**. The input/output terminal **100** is connected to a common terminal of the duplexer **31** and a common terminal of the duplexer **32**.

(19) The power amplifier **11T** is an example of a first power amplifier and is capable of amplifying transmit signals of the first communication band and the third communication band.

(20) The filter **33** is an example of a first filter and is connected to the transmit input terminal **110** at one end portion and to an input terminal of the power amplifier **11T** at the other end portion. The filter **33** has a bandpass characteristic in which a pass band is a band including a transmit band of the first communication band and an attenuation band is a band including a transmit band of the second communication band. Note that the filter **33** may be any one of a band pass filter, a low pass filter, a high pass filter, and a band stop filter, provided that the filter has a bandpass characteristic that satisfies the foregoing bandpass characteristic. The filter **33** may be, for example, a LC filter including one or more inductors and one or more capacitors. This enables, for example, at least one of the inductor and the capacitor of the LC filter to also define and function as an inductor or a capacitor of the power amplifier **11T**.

(21) The low noise amplifier **11R** is an example of a first low noise amplifier and is capable of amplifying a receive signal of the first communication band and a receive signal of the third communication band. An output terminal of the low noise amplifier **11R** is connected to the receive output terminal **120**.

(22) Note that the power amplifier **11T** and the low noise amplifier **11R** each include, for example,

a field-effect transistor (FET), a heterojunction bipolar transistor (HBT), or the like, which preferably includes, for example, Si-based complementary metal oxide semiconductor (CMOS) or GaAs as a material.

(23) The duplexer **31** is a multiplexer including a transmit filter **31T** and a receive filter **31R**. A pass band of the transmit filter **31T** is a transmit band of the first communication band, and a pass band of the receive filter **31R** is a receive band of the first communication band.

(24) The duplexer **32** is a multiplexer including a transmit filter **32T** and a receive filter **32R**. A pass band of the transmit filter **32T** is a transmit band of the third communication band, and a pass band of the receive filter **32R** is a receive band of the third communication band.

(25) Note that each of the duplexers **31** and **32** may not necessarily be a duplexer and may alternatively be a single filter that performs transmission using a time division duplex (TDD) system. In this case, the single filter is preceded and/or followed by a switch that switches between sending and receiving.

(26) The switch **51** includes a common terminal **51a** and selection terminals **51b** and **51c**. The common terminal **51a** is connected to an output terminal of the power amplifier **11T**, the selection terminal **51b** is connected to an input terminal of the transmit filter **31T**, and the selection terminal **51c** is connected to an input terminal of the transmit filter **32T**. The connection configuration enables the switch **51** to switch between connecting the power amplifier **11T** to the transmit filter **31T** and connecting the power amplifier **11T** to the transmit filter **32T**. The switch **51** preferably includes, for example, a single pole double throw (SPDT) switch circuit.

(27) The switch **52** includes a common terminal **52a** and selection terminals **52b** and **52c**. The common terminal **52a** is connected to an input terminal of the low noise amplifier **11R**, the selection terminal **52b** is connected to an output terminal of the receive filter **31R**, and the selection terminal **52c** is connected to an output terminal of the receive filter **32R**. The connection configuration enables the switch **52** to switch between connecting the low noise amplifier **11R** to the receive filter **31R** and connecting the low noise amplifier **11R** to the receive filter **32R**. The switch **52** preferably includes, for example, a SPDT switch circuit.

(28) Note that the low noise amplifier **11R** and at least one of the switches **51** and **52** may be defined by a single semiconductor IC. The semiconductor IC is preferably, for example, made of CMOS. Specifically, the semiconductor IC is preferably formed by a silicon-on-insulator (SOI) process, for example. This enables fabrication of the semiconductor IC inexpensively. Note that the semiconductor IC may be made of at least one of GaAs, SiGe, and GaN, for example. This enables output of a radio frequency signal with high quality amplification performance and noise performance.

(29) The foregoing configuration enables the radio frequency circuit **10** to selectively perform the sending and receiving of a radio frequency signal of the first communication band and the sending and receiving of a radio frequency signal of the third communication band.

(30) Note that it is only necessary for the radio frequency circuit **10** to at least send a radio frequency signal of the first communication band. In this case, the radio frequency circuit **10** only needs to include the power amplifier **11T** and the transmit filter **31T**, and other circuit elements are not necessary elements.

(31) As illustrated in FIG. **1**, the radio frequency circuit **20** includes the input/output terminal **200**, a transmit input terminal **210**, a receive output terminal **220**, a power amplifier **21T**, a low noise amplifier **21R**, and a duplexer **41**.

(32) The transmit input terminal **210** is an example of a second transmit input terminal and is connected to the terminal **330** of the RFIC **3**. The receive output terminal **220** is connected to the terminal **340** of the RFIC **3**. The input/output terminal **200** is connected to the common terminal of the duplexer **41**.

(33) The power amplifier **21T** is an example of a second power amplifier and is capable of amplifying a transmit signal of the second communication band. An input terminal of the power

amplifier **21T** is connected to the transmit input terminal **210**.

(34) The low noise amplifier **21R** is capable of amplifying a receive signal of the second communication band. An output terminal of the low noise amplifier **21R** is connected to the receive output terminal **220**.

(35) Note that the power amplifier **21T** and the low noise amplifier **21R** each preferably include, for example, a field effect transistor (FET), a heterojunction bipolar transistor (HBT), or the like, which uses Si-based CMOS or GaAs as a material.

(36) The duplexer **41** is a multiplexer including a transmit filter **41T** and a receive filter **41R**. A pass band of the transmit filter **41T** is a transmit band of the second communication band, and a pass band of the receive filter **41R** is a receive band of the second communication band. An input terminal of the transmit filter **41T** is connected to an output terminal of the power amplifier **21T**, and an output terminal of the receive filter **41R** is connected to an input terminal of the low noise amplifier **21R**.

(37) The foregoing configuration enables the radio frequency circuit **20** to perform the sending and receiving of a radio frequency signal of the second communication band.

(38) According to the foregoing configuration of the communication device **5**, it becomes possible to simultaneously send a transmit signal of the first communication band and a transmit signal of the second communication band or to simultaneously send a transmit signal of the third communication band and a transmit signal of the second communication band.

(39) FIG. **2** is a diagram illustrating signal flows in the communication device **5** according to the present preferred embodiment. FIG. **2** illustrates a state where simultaneous transmission of a transmit signal and a receive signal of the first communication band and a transmit signal and a receive signal of the second communication band is being performed.

(40) In the radio frequency circuit **10**, a transmit signal of the first communication band is output from the terminal **310** of the RFIC **3**, transmitted via the transmit input terminal **110**, the filter **33**, the power amplifier **11T**, the switch **51**, the transmit filter **31T**, the input/output terminal **100**, and the switch **4** in this order, and sent from the antenna **2**. At the same time, a receive signal of the first communication band is received by the antenna **2**, transmitted via the switch **4**, the input/output terminal **100**, the receive filter **31R**, the switch **52**, the low noise amplifier **11R**, and the receive output terminal **120** in this order, and received at the terminal **320** of the RFIC **3**.

(41) On the other hand, in the radio frequency circuit **20**, at the same time as when sending and receiving in the first communication band are performed in the radio frequency circuit **10**, a transmit signal of the second communication band is output from the terminal **330** of the RFIC **3**, transmitted via the transmit input terminal **210**, the power amplifier **21T**, the transmit filter **41T**, the input/output terminal **200**, and the switch **4** in this order, and sent from the antenna **2**. At the same time, a receive signal of the second communication band is received by the antenna **2**, transmitted via the switch **4**, the input/output terminal **200**, the receive filter **41R**, the low noise amplifier **21R**, and the receive output terminal **220** in this order, and received at the terminal **340** of the RFIC **3**.

(42) Here, as described above, when a transmit signal of the first communication band and a transmit signal of the second communication band are being sent simultaneously, the transmit signal of the second communication band output from the terminal **330** may sometimes enter the radio frequency circuit **10** through the transmit input terminal **110** via the terminal **310** of the RFIC **3**. In this case, it is envisaged that intermodulation distortion caused by the transmit signal of the first communication band and the transmit signal of the second communication band may occur in the power amplifier **11T**. In the case where an unwanted wave of this intermodulation distortion overlaps the transmit signal of the first communication band, there is an issue that a transmit signal output from the radio frequency circuit **10** may not be able to satisfy preset standards (spurious emission standards and the like, for example).

(43) Whereas, according to the radio frequency circuit **10** of the present preferred embodiment, the power amplifier **11T** is preceded by the filter **33** whose attenuation band is a band including a

transmit band of the second communication band, and thus it becomes possible to reduce or prevent the transmit signal of the second communication band from entering the power amplifier **11T**. This enables a reduction or prevention of the occurrence of the intermodulation distortion caused by the transmit signal of the first communication band and the transmit signal of the second communication band in the power amplifier **11T**. Accordingly, the degradation of signal quality of a transmit signal sent from the radio frequency circuit **10** is reduced or prevented.

(44) Note that the filter **33** may have a variable pass band. This enables, for example, varying of the pass band of the filter **33** depending on the frequency of the transmit signal of the second communication band entering through the transmit input terminal **110**. Accordingly, it becomes possible to reduce or prevent the degradation of signal quality of a transmit signal sent from the radio frequency circuit **10** with a high degree of accuracy.

(45) Furthermore, there is a concern that an unwanted wave of the intermodulation distortion caused by the transmit signal of the first communication band and the transmit signal of the second communication band and occurring in the power amplifier **11T** may enter the receive path via the switch **51**, the transmit filter **31T**, the receive filter **31R**, the switch **52**, and the low noise amplifier **11R**.

(46) Whereas, according to the radio frequency circuit **10** of the present preferred embodiment, the power amplifier **11T** is preceded by the filter **33** whose attenuation band is a band including a transmit band of the second communication band, and thus it becomes possible to reduce or prevent the intermodulation distortion from entering the receive path. Accordingly, the degradation of the receiving sensitivity of the radio frequency circuit **10** is reduced or prevented.

(47) Note that the radio frequency circuit **10** according to the present preferred embodiment may include the radio frequency circuit **20**. In this case, for example, circuit elements of the radio frequency circuit **10** and circuit elements of the radio frequency circuit **20** may be provided on the same mounting board. Alternatively, circuit elements of the radio frequency circuit **10** and circuit elements of the radio frequency circuit **20** may be included in the same package. In this case, the low noise amplifiers **11R** and **21R** and the switches **51** and **52** may be defined by a single semiconductor IC. Furthermore, the power amplifiers **11T** and **21T** may be defined by a single semiconductor IC.

(48) In this case, downsizing of the radio frequency circuit is facilitated. Although there is a concern that the transmit signal of the second communication band may enter the power amplifier **11T** via the transmit input terminal **110** more easily, the power amplifier **11T** is preceded by the filter **33**. Accordingly, it becomes possible to reduce or prevent the degradation of quality of a transmit signal of the first communication band while downsizing the radio frequency circuit **10**.

(49) In the radio frequency circuits **10** and **20** according to the present preferred embodiment, the circuit elements of the radio frequency circuit **10** and the circuit elements of the radio frequency circuit **20** may be provided on different mounting boards.

(50) In the radio frequency circuits **10** and **20** according to the present preferred embodiment, preferably, for example, Band 5 (transmit band: 824-849 MHz, receive band: about 869-894 MHz) of 4G-Long Term Evolution (LTE) is used as the first communication band. Furthermore, Band 66 (transmit band: about 1710-1780 MHz, receive band: about 2110-2200 MHz) of 4G-LTE is used as the second communication band. At this time, the frequency of a second order intermodulation distortion (IMD2: $f_{\text{sub.T2}} - f_{\text{sub.T1}}$) caused by a transmit signal of the first communication band ($f_{\text{sub.T1}}$: about 835 MHz) and a transmit signal of the second communication band ($f_{\text{sub.T2}}$: about 1715 MHz) is about 880 MHz and is included in the receive band of Band 5.

(51) Whereas, according to the radio frequency circuit **10** of the present preferred embodiment, the power amplifier **11T** is preceded by the filter **33** whose attenuation band is a band including the transmit band of Band 66 of 4G-LTE, and thus it becomes possible to reduce or prevent the intermodulation distortion IMD2 from entering a receive path of Band 5 of 4G-LTE. Accordingly, the degradation of the receiving sensitivity of the radio frequency circuit **10** is reduced or

prevented.

(52) Note that typically, frequencies of the intermodulation distortion caused by two transmit signals (T1 and T2) include $3f_{\text{sub.T1}} - 2f_{\text{sub.T2}}$, $2f_{\text{sub.T2}} - 2f_{\text{sub.T1}}$, $2f_{\text{sub.T1}} - f_{\text{sub.T2}}$, $2f_{\text{sub.T2}} - f_{\text{sub.T1}}$, $f_{\text{sub.T1}} - f_{\text{sub.T2}}$, and $f_{\text{sub.T2}} - f_{\text{sub.T1}}$, but are not limited thereto and include ones defined by $mf_{\text{sub.T1}} \pm nf_{\text{sub.T2}}$ and $mf_{\text{sub.T2}} \pm nf_{\text{sub.T1}}$ (m and n are natural numbers).

(53) In the present preferred embodiment, for example, a radio frequency signal transmitted in the radio frequency circuit **10** may be used in 4G, a radio frequency signal transmitted in the radio frequency circuit **20** may be used in 5G, and a radio frequency signal transmitted in the radio frequency circuit **10** and a radio frequency signal transmitted in the radio frequency circuit **20** may be sent simultaneously using Dual Connectivity (DC).

(54) In recent years, for example, as a preparation step for making a transition from 4G to 5G, a technology called NSA has been developed to perform 5G communication using a 4G-LTE communication network. In NSA, in order to increase the communication data volume, a DC technology is being developed to allow simultaneous sending and receiving of two radio frequency signals used in different communication systems (4G-LTE and 5G-NR (New Radio)) within the same communication band.

(55) With regard to this, the radio frequency circuits **10** and **20** according to the present preferred embodiment enable a reduction or prevention of quality degradation of transmit signals and a reduction or prevention of degradation of the receiving sensitivity without limiting the combination of two communication bands to be sent simultaneously even in the case where simultaneous sending is performed using the DC technology of 4G and 5G.

2. Configuration of Radio Frequency Circuit According to Modified Example 1

(56) FIG. **3** is a circuit configuration diagram of a radio frequency circuit **10A** according to a modified example 1 of a preferred embodiment of the present invention. As illustrated in FIG. **3**, the radio frequency circuit **10A** according to the present modified example includes the input/output terminal **100**, the transmit input terminal **110**, the receive output terminal **120**, the power amplifier **11T**, the low noise amplifier **11R**, the filter **33**, the duplexers **31** and **32**, the switches **51** and **52**, and a switch **53**. The radio frequency circuit **10A** according to the present modified example is different from the radio frequency circuit **10** according to the present preferred embodiment in that the switch **53** is added. Hereinafter, the radio frequency circuit **10A** according to the present modified example is described with the emphasis on elements different from the radio frequency module **10** according to the present preferred embodiment while omitting the descriptions regarding the same or corresponding elements.

(57) The switch **53** is an example of a first switch, is connected to an input terminal and an output terminal of the filter **33**, and switches between bypassing and non-bypassing the filter **33**.

Specifically, by being set to the conductive state, the switch **53** provides electrical continuity of a bypass path connecting the input terminal and the output terminal of the filter **33**. On the other hand, the switch **53** makes the foregoing bypass path electrically discontinuous by being set to a non-conductive state. The switch **53** preferably includes, for example, a single pole single throw (SPST) switch circuit.

(58) The foregoing configuration enables selection of whether a transmit signal of the second communication band entering through the transmit input terminal **110** is allowed to pass or bypass the filter **33** depending on the frequency of this transmit signal.

(59) Suppose the following case: when a transmit signal of the first communication band and a transmit signal of the second communication band are transmitted simultaneously, there is a possibility that an unwanted wave of the intermodulation distortion caused by these two transmit signals may degrade the signal quality of the transmit signal of the first communication band output from the radio frequency circuit **10A** or may degrade the receiving sensitivity of the radio frequency circuit **10A**; and when a transmit signal of the third communication band and a transmit

signal of the second communication band are transmitted simultaneously, an unwanted wave of the intermodulation distortion caused by these two transmit signals does not degrade the signal quality of the transmit signal of the third communication band output from the radio frequency circuit **10A** and does not degrade the receiving sensitivity of the radio frequency circuit **10A**. In this supposed case, when a transmit signal of the first communication band and a transmit signal of the second communication band are transmitted simultaneously, the switch **53** is set to the non-conductive state, and a transmit signal traveling from the transmit input terminal **110** to the power amplifier **11T** is allowed to pass the filter **33**. Whereas, when a transmit signal of the third communication band and a transmit signal of the second communication band are transmitted simultaneously, the switch **53** is set to the conductive state, and a transmit signal traveling from the transmit input terminal **110** to the power amplifier **11T** is allowed to bypass the filter **33**.

(60) According to this, when a transmit signal of the first communication band and a transmit signal of the second communication band are transmitted simultaneously, it becomes possible to reduce or prevent the degradation of signal quality of a transmit signal sent from the radio frequency circuit **10A**, and when a transmit signal of the third communication band and a transmit signal of the second communication band are transmitted simultaneously, it becomes possible to reduce or prevent the transmission loss of a transmit signal of the third communication band because this transmit signal is not allowed to pass the filter **33**.

3. Configuration of Radio Frequency Circuit According to Modified Example 2

(61) FIG. **4** is a circuit configuration diagram of a radio frequency circuit **10B** according to a modified example 2 of a preferred embodiment of the present invention. As illustrated in FIG. **4**, the radio frequency circuit **10B** according to the present modified example includes the input/output terminal **100**, the transmit input terminal **110**, the receive output terminal **120**, the power amplifier **11T**, the low noise amplifier **11R**, filters **34** and **35**, a bypass path **36**, the duplexers **31** and **32**, the switches **51** and **52**, and switches **54** and **55**. The radio frequency circuit **10B** according to the present modified example is different from the radio frequency circuit **10** according to the present preferred embodiment in that, instead of the filter **33**, the filters **34** and **35**, the bypass path **36**, and the switch **55** are added. Hereinafter, the radio frequency circuit **10B** according to the present modified example is described with emphasis on elements different from the radio frequency module **10** according to the present preferred embodiment, while omitting the descriptions regarding the same or corresponding elements.

(62) The filter **34** is an example of the first filter and is connected to the switch **54** at one end portion and to the switch **55** at the other end portion. The filter **34** has a bandpass characteristic in which a pass band is a band including a transmit band of the first communication band and an attenuation band is a band including a transmit band of the second communication band.

(63) The filter **35** is an example of a second filter and is connected to the switch **54** at one end portion and to the switch **55** at the other end portion. The filter **35** has a bandpass characteristic in which an attenuation band is a band including a transmit band of the second communication band. Note that in the present modified example, the filter **35** has a bandpass characteristic in which a pass band is a band including a transmit band of the third communication band and an attenuation band is a band including a transmit band of the second communication band.

(64) The switch **55** is an example of the second switch, is arranged between the transmit input terminal **110** and the filters and **35**, and includes a common terminal, a first selection terminal, a second selection terminal, and a third selection terminal. The common terminal is connected to the transmit input terminal **110**, the first selection terminal is connected to one end portion of the bypass path **36**, the second selection terminal is connected to one end portion of the filter **34**, and the third selection terminal is connected to one end portion of the filter **35**. The switch **55** preferably includes, for example, a single pole 3 throw (SP3T) switch circuit. The switch **55** switches between connecting the transmit input terminal **110** to the bypass path **36**, connecting the transmit input terminal **110** to the filter **34**, and connecting the transmit input terminal **110** to the

filter 35.

(65) The switch **54** is arranged between the power amplifier **11T** and the filters **34** and **35**, and includes a common terminal, a first selection terminal, a second selection terminal, and a third selection terminal. The common terminal is connected to an input terminal of the power amplifier **11T**, the first selection terminal is connected to the other end portion of the bypass path **36**, the second selection terminal is connected to the other end portion of the filter **34**, and the third selection terminal is connected to the other end portion of the filter **35**. The switch **55** preferably includes, for example, a SP3T switch circuit. The switch **54** switches between connecting the power amplifier **11T** to the bypass path **36**, connecting the power amplifier **11T** to the filter **34**, and connecting the power amplifier **11T** to the filter **35**. Note that the switch **54** may be omitted.

(66) The foregoing configuration enables selection of one from among the filters **34** and **35** and the bypass path **36** depending on the frequency and the signal strength of a transmit signal of the second communication band that enters through the transmit input terminal **110** and depending on which one of the first communication band and the third communication band is used for sending.

(67) For example, when a transmit signal of the first communication band and a transmit signal of the second communication band are transmitted simultaneously, a transmit signal traveling from the transmit input terminal **110** to the power amplifier **11T** is allowed to pass the filter **34**. When a transmit signal of the third communication band and a transmit signal of the second communication band are transmitted simultaneously, a transmit signal traveling from the transmit input terminal **110** to the power amplifier **11T** is allowed to pass the filter **35**. When there is no need to suppress the occurrence of intermodulation distortion in the power amplifier **11T**, a transmit signal traveling from the transmit input terminal **110** to the power amplifier **11T** is allowed to pass the bypass path **36**.

(68) This enables a reduction or prevention of degradation of signal quality of a transmit signal sent from the radio frequency circuit **10B** by allowing this transmit signal to pass the filter **34** or **35** and enables a reduction in the transmission loss of a transmit signal sent from the radio frequency circuit **10B** by allowing this transmit signal to pass the bypass path **36**.

(69) As described above, the radio frequency circuit **10** according to the present preferred embodiment is capable of simultaneously sending a transmit signal of the first communication band and a transmit signal of the second communication band and includes the transmit input terminal **110**, the power amplifier **11T** capable of amplifying the transmit signal of the first communication band, and the filter **33** connected between the transmit input terminal **110** and the input terminal of the power amplifier **11T** wherein a pass band of the filter **33** is a band including a transmit band of the first communication band and an attenuation band of the filter **33** is a band including a transmit band of the second communication band.

(70) According to this, the power amplifier **11T** is preceded by the filter **33** whose attenuation band is a band including a transmit band of the second communication band, and thus it becomes possible to reduce or prevent the transmit signal of the second communication band from entering the power amplifier **11T**. This enables a reduction or prevention of the occurrence of the intermodulation distortion caused by the transmit signal of the first communication band and the transmit signal of the second communication band in the power amplifier **11T**. Accordingly, the degradation of signal quality of a transmit signal sent from the radio frequency circuit **10** is reduced or prevented.

(71) The radio frequency circuit **10** may further include the low noise amplifier **11R** capable of amplifying a receive signal of the first communication band.

(72) This enables a reduction or prevention the intermodulation distortion caused by a transmit signal of the first communication band and a transmit signal of the second communication band from entering the receive path. Accordingly, the degradation of the receiving sensitivity of the radio frequency circuit **10** is reduced or prevented.

(73) The radio frequency circuit **10** may further include the transmit input terminal **210** and the

power amplifier **21T** that is connected to the transmit input terminal **210** and capable of amplifying a transmit signal of the second communication band.

(74) This leads to a concern that the transmit signal of the second communication band may enter the power amplifier **11T** from the transmit input terminal **210** via the transmit input terminal **110**. However, because of the arrangement of the filter **33**, it becomes possible to reduce or prevent the transmit signal of the second communication band from entering the power amplifier **11T**.

(75) The radio frequency circuit **10A** may further include the switch **53** that is connected to the input terminal and the output terminal of the filter **33** and switches between bypassing and non-bypassing the filter **33**.

(76) This enables selection whether a transmit signal of the second communication band entering through the transmit input terminal **110** is allowed to pass or bypass the filter **33** depending on the frequency of this transmit signal, and thus it becomes possible to reduce the transmission loss of a transmit signal output from the radio frequency circuit **10A** when the foregoing intermodulation distortion does not occur.

(77) In the radio frequency circuit **10**, the filter **33** may be a filter having a variable pass band.

(78) This causes the pass band of the filter **33** to vary depending on the frequency of the transmit signal of the second communication band entering through the transmit input terminal **110**, and thus it becomes possible to reduce or prevent the degradation of signal quality of a transmit signal sent from the radio frequency circuit **10** with a high degree of accuracy.

(79) The radio frequency circuit **10B** may include the filter **34** connected between the transmit input terminal **110** and the input terminal of the power amplifier **11T**, wherein a pass band of the filter **34** is a band including a transmit band of the first communication band and an attenuation band of the filter **34** is a band including a transmit band of the second communication band, the filter **35** connected between the transmit input terminal **110** and the input terminal of the power amplifier **11T**, wherein an attenuation band of the filter **35** is a band including the transmit band of the second communication band, and the switch **55** arranged between the transmit input terminal **110** and the filters **34** and **35**, wherein the switch **55** switches between connecting the transmit input terminal **110** to the filter **34** and connecting the transmit input terminal **110** to the filter **35**.

(80) This enables selection of one of the filters **34** and **35** depending on the frequency and the signal strength of a transmit signal of the second communication band entering through the transmit input terminal **110** or depending on a similar variable, and thus it becomes possible to reduce or prevent the degradation of signal quality of a transmit signal sent from the radio frequency circuit **10B** with a high degree of accuracy.

(81) In the radio frequency circuit **10**, the filter **33** may preferably be, for example, a LC filter including one or more inductors and one or more capacitors.

(82) This enables, for example, at least one of the inductor and the capacitor of the LC filter to also define and function as an inductor or a capacitor of the power amplifier **11T**.

(83) The communication device **5** includes the radio frequency circuit **10** and the RFIC **3** capable of simultaneously sending a transmit signal of the first communication band and a transmit signal of the second communication band to the radio frequency circuits **10** and **20**.

(84) This reduces or prevents the degradation of signal quality of a transmit signal sent from the communication device **5**.

OTHER PREFERRED EMBODIMENTS

(85) The radio frequency circuit and the communication device according to the present preferred embodiment are described using the above-described preferred embodiment and the modified examples thereof. However, the radio frequency circuits and the communication devices of the present invention are not limited to the above-described preferred embodiment and the modified examples thereof. Other preferred embodiments obtained by combining arbitrary elements of the above-described preferred embodiment and the modified examples thereof, modified examples obtained by applying various modifications apparent to those skilled in the art to the above-

described preferred embodiment and the modified examples thereof without departing the scope of the present invention, and various devices incorporating the radio frequency circuits and the communication devices according to preferred embodiments of the present invention may also be included in the present invention.

(86) In the above-described preferred embodiment and the modified examples thereof, the cases where transmit signals of two different communication bands are transmitted simultaneously are exemplified. Alternatively, the configurations of the radio frequency circuits and the communication devices according to referred embodiments of the present invention may be applied to cases where transmit signals of three or more different communication bands are transmitted simultaneously. That is to say, preferred embodiments of the present invention include radio frequency circuits and communication devices each having a configuration that simultaneously transmits transmit signals of three or more different communication bands and include the configuration of the radio frequency circuits or the communication devices according to preferred embodiments or modified examples thereof.

(87) Note that the combination of the first communication band and the second communication band is not limited to the combination of Band 5 of 4G-LTE and Band 66 of 4G-LTE. The combination in which the simultaneous sending of the first communication band and the second communication band would cause a second-order intermodulation distortion or a third-order intermodulation distortion in the first communication band or the second communication band is also applicable to combinations of the first communication band and the second communication band illustrated in the following Table 1. Note that in Table 1, in the case where the band with which IMD overlaps is the second communication band, the combination is applied for the case where the radio frequency circuit 10 sends a transmit signal of the second communication band and the radio frequency circuit 20 sends a transmit signal of the first communication band.

(88) TABLE-US-00001
TABLE 1
FIRST SECOND IMD2 IMD3 BAND COMMUNICATION
COMMUNICATION Tx2-Tx1 2Tx2-Tx1 WHERE IMD BAND (Tx1, Rx1) BAND (Tx2, Rx2)
(MHz) (MHz) OVERLAPS
EXAMPLE 1 B1 n77 ○ B1-Tx
EXAMPLE 2 B2 B(n)66 ○ B(n)66-Tx
EXAMPLE 3 B2 n78 ○ B2-Tx
EXAMPLE 4 B3 n77 ○ B3-Tx
EXAMPLE 5 B3 n78 ○ B3-Tx
EXAMPLE 6 B8 n78 ○ n78
EXAMPLE 7 B18 n77 ○ n77
EXAMPLE 8 B19 n77 ○ n77
EXAMPLE 9 B20 n8 ○ B20-Tx n8-Tx
EXAMPLE 10 B20 n77 ○ n77
EXAMPLE 11 B26 n77 ○ n77
EXAMPLE 12 B28 n51 ○ B28-Tx
EXAMPLE 13 B28 n77 ○ n77
EXAMPLE 14 B39 n78 ○ B39
EXAMPLE 15 B41 n79 ○ B41
EXAMPLE 16 B66 n78 ○ B66-Tx

(89) In above-described preferred embodiment, the communication system is defined to mean a communication system constructed using the radio access technology (RAT) defined by a standards body or the like (for example, 3GPP or Institute of Electrical and Electronics Engineers (IEEE)). As the communication system, for example, a 5G-NR system, a 4G-LTE system, a wireless local area network (WLAN) system, or the like may be used, but the communication system is not limited thereto.

(90) The communication band is defined to mean a frequency band defined in advance by a standards body or the like for the communication system. As the communication band, for example, a 5G-NR frequency band, a 4G-LTE frequency band, or the like may be used, but the communication band is not limited thereto.

(91) In the radio frequency circuits and the communication devices according to preferred embodiments of the present invention and modified examples, a matching element, such as an inductor, a capacitor, or the like, for example, and a switch circuit may be connected between circuit elements. Note that the inductor may include a wiring line inductor defined by a wiring line connecting circuit elements.

(92) In the radio frequency circuits and the communication devices according to preferred embodiments of the present invention and modified examples, the term “A and B are connected” refers to not only a mode of connection in which A and B are directly connected without any other

circuit element interposed therebetween but also a mode of connection in which A and B are indirectly connected with a passive circuit including, for example, an inductor, a capacitor, and the like, a switch circuit, or the like interposed therebetween.

(93) The LC filter is defined to mean a filter in which a pass band of the LC filter includes one or more inductors and one or more capacitors. Accordingly, the LC filter may include, for example, an acoustic wave resonator providing an attenuation pole outside the pass band.

(94) The control unit according to preferred embodiments of the present invention may be provided by large scale integration (LSI), which is an integrated circuit (IC). A dedicated circuit or a general-purpose processor may be used for an integrated circuit. After fabricating the LSI, a field programmable gate array (FPGA), which is programmable, or a reconfigurable processor, in which connection or setting of circuit cells in the LSI are reconfigurable, may be used. In addition, when a technology of circuit integration that can replace the LSI emerges due to development of semiconductor technology or another technology derived therefrom, for example, the integration of the functional blocks may be performed by using such technology.

(95) Preferred embodiments of the present invention can be widely used in communication equipment, such as mobile phones and the like, for example, as a multiband/multimode front-end module that includes a carrier aggregation system or a dual connectivity system.

(96) While preferred embodiments of the invention have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art without departing from the scope and spirit of the invention. The scope of the invention, therefore, is to be determined solely by the following claims.

Claims

1. A radio frequency circuit for sending a transmit signal of a first communication band and a transmit signal of a second communication band simultaneously, the radio frequency circuit comprising: a first transmit input terminal; a first power amplifier to amplify a transmit signal of the first communication band; a first filter connected between the first transmit input terminal and an input terminal of the first power amplifier, a pass band of the first filter being a band including a transmit band of the first communication band, an attenuation band of the first filter being a band including a transmit band of the second communication band; a second transmit input terminal; a second power amplifier connected to the second transmit input terminal to amplify a transmit signal of the second communication band; and an antenna switch including a first select terminal connected to the first power amplifier, a second select terminal connected to the second power amplifier, and a common terminal connectable to the first select terminal and the second select terminal; wherein the first filter is directly connected the input terminal of the first power amplifier.
2. The radio frequency circuit according to claim 1, further comprising a first low noise amplifier to amplify a receive signal of the first communication band.
3. The radio frequency circuit according to claim 1, further comprising a first switch connected to an input terminal and an output terminal of the first filter to switch between bypassing and not bypassing the first filter.
4. The radio frequency circuit according to claim 3, wherein the first switch includes a single pole single throw switch circuit.
5. The radio frequency circuit according to claim 1, wherein the first filter has a variable pass band.
6. The radio frequency circuit according to claim 1, wherein the first filter is a LC filter including one or more inductors and one or more capacitors.
7. A communication device comprising: the radio frequency circuit according to claim 1; and a RF signal processing circuit to send a transmit signal of the first communication band and a transmit signal of the second communication band simultaneously to the radio frequency circuit.
8. The communication device according to claim 7, further comprising a first low noise amplifier to

amplify a receive signal of the first communication band.

9. The communication device according to claim 7, further comprising a first switch connected to an input terminal and an output terminal of the first filter to switch between bypassing and not bypassing the first filter.

10. The communication device according to claim 9, wherein the first switch includes a single pole single throw switch circuit.

11. The communication device according to claim 7, wherein the first filter has a variable pass band.

12. The communication device according to claim 7, wherein the first filter is a LC filter including one or more inductors and one or more capacitors.

13. The communication device according to claim 7, wherein the first power amplifier includes a field effect transistor or a heterojunction bipolar transistor.

14. The radio frequency circuit according to claim 1, wherein the first power amplifier includes a field effect transistor or a heterojunction bipolar transistor.
