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(54) **TRANSMISSION/RECEPTION BASEBAND-PROCESSING DEVICE, COMMUNICATION SYSTEM, CORRECTION METHOD, AND PROGRAM**

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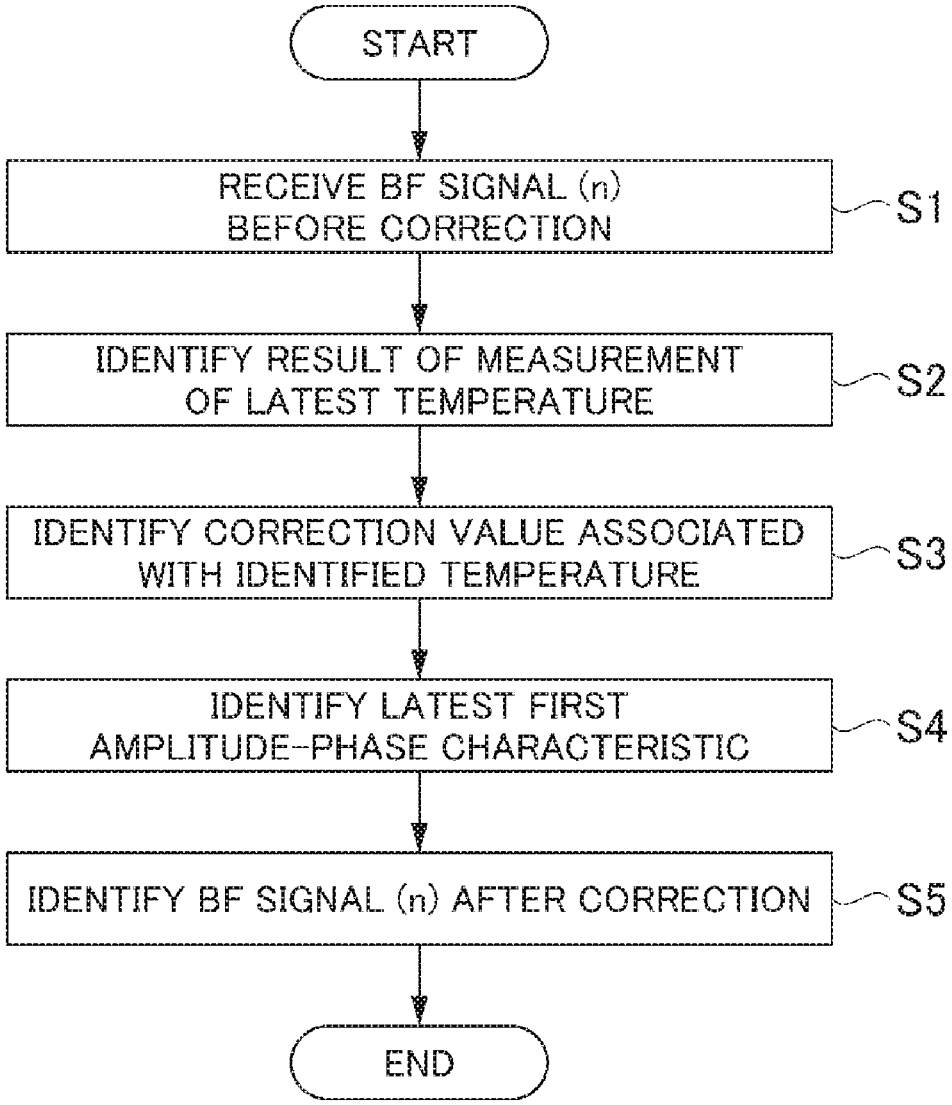
(57) **ABSTRACT**

A transmission/reception baseband-processing device includes a calibration-processing unit configured to correct an input signal input to a transmission unit on the basis of a first characteristic according to characteristics of the transmission unit of a transmission/reception front end-processing unit and a calibration reception unit that is a reception unit of a calibration transmission/reception unit and a second characteristic according to a characteristic of the calibration reception unit.



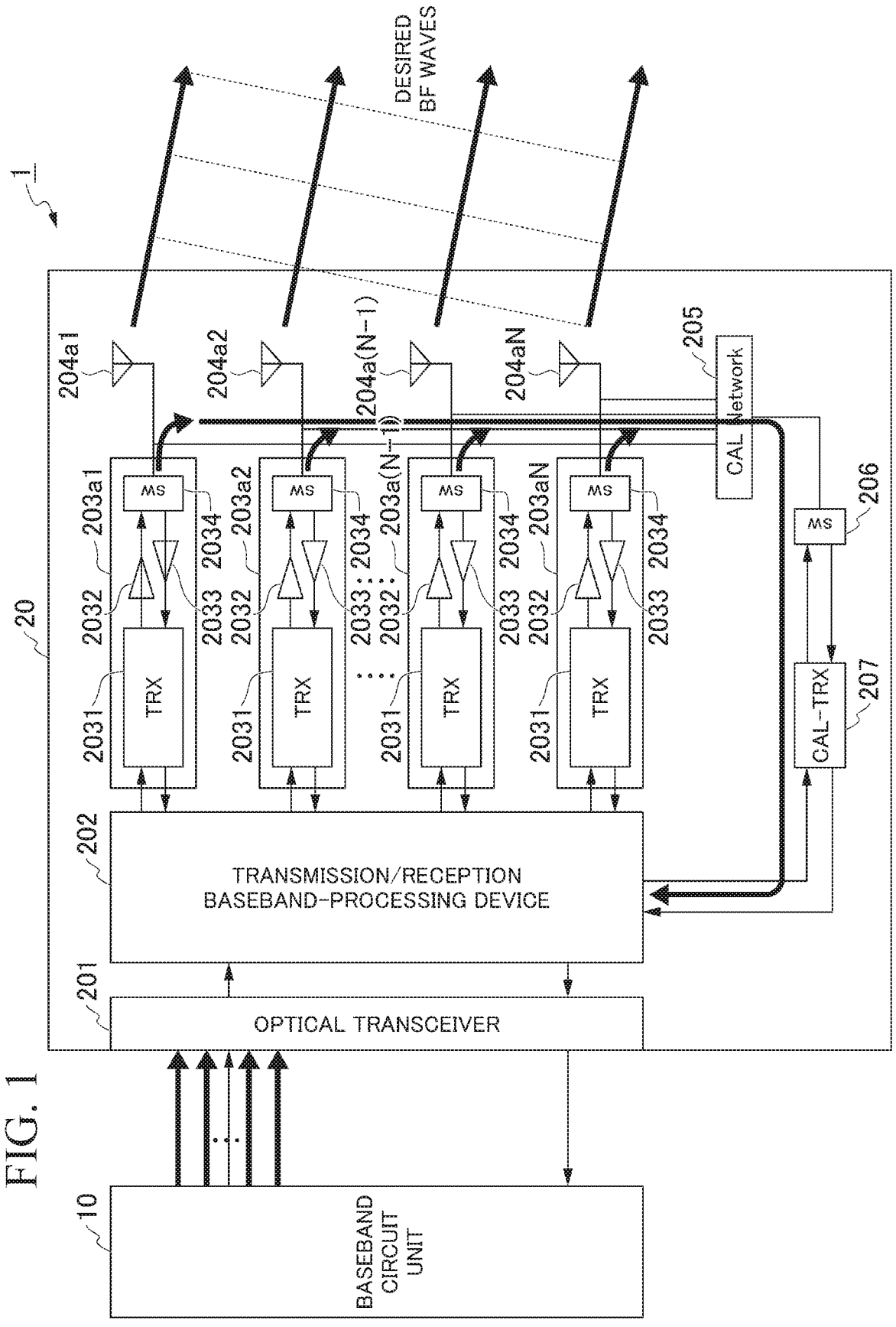

DESIRED BF WAVES
1
20
204a1
204a2
204a(N-1)
204aN
205
CAL network
206
MS
203a1
203a2
203a(N-1)
203aN
2034
2032
2033
2033 : 2034
2032 : 2033
2031
TRX
207
CAL-TRX
202
TRANSMISSION/RECEPTION BASEBAND-PROCESSING DEVICE
201
OPTICAL TRANSCEIVER
10
BASEBAND CIRCUIT UNIT

FIG. 1

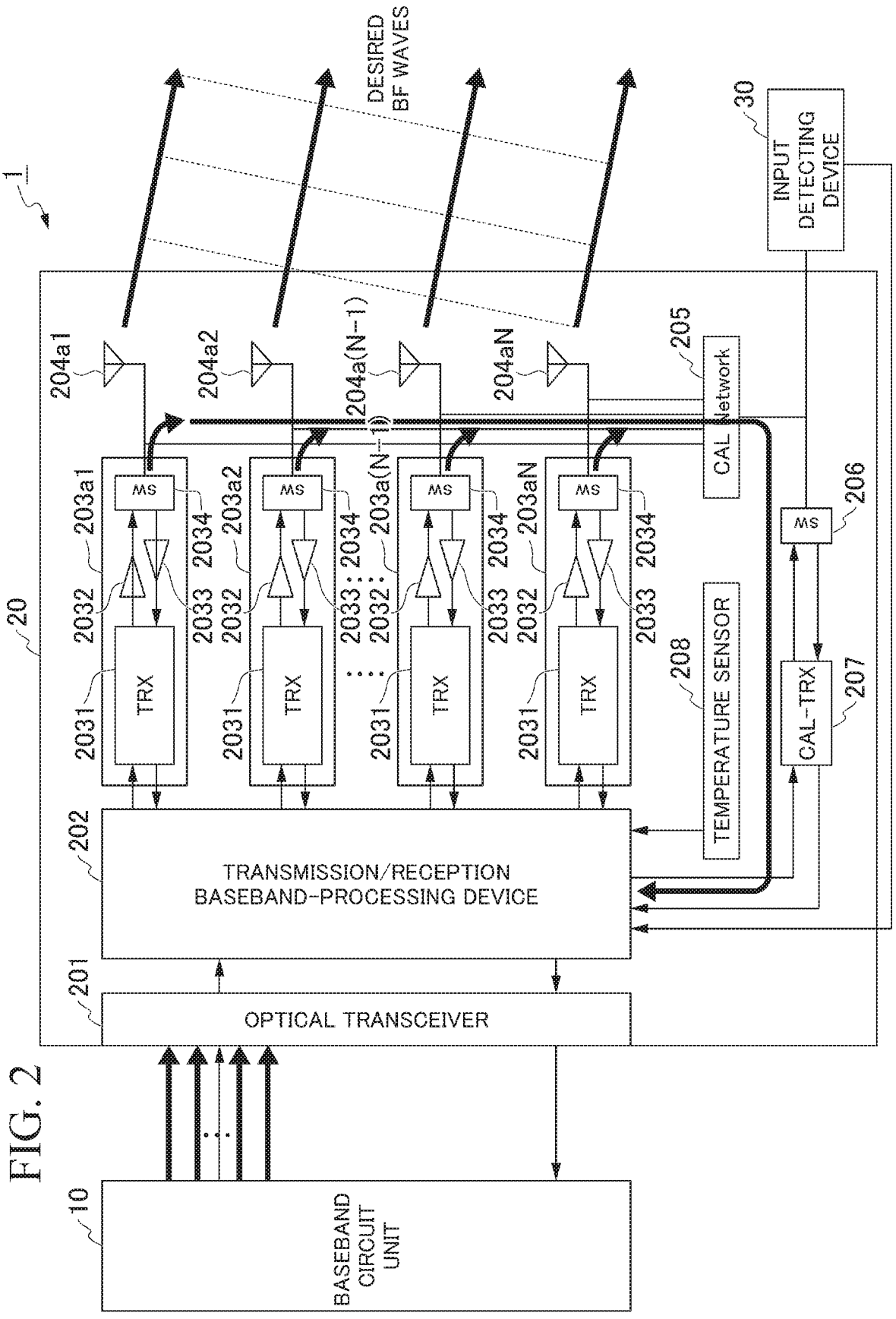

DESIRED BF WAVES
1
30
INPUT DETECTING DEVICE
204a1
204a2
204a(N-1)
204aN
205
CAL Network
206
MS
203a1
203a2
203a(N-1)
203aN
2034
2032
2033
2031
TRX
20
208
TEMPERATURE SENSOR
207
CAL-TRX
202
TRANSMISSION/RECEPTION BASEBAND-PROCESSING DEVICE
201
OPTICAL TRANSCEIVER
10
BASEBAND CIRCUIT UNIT

FIG. 2

FIG. 3

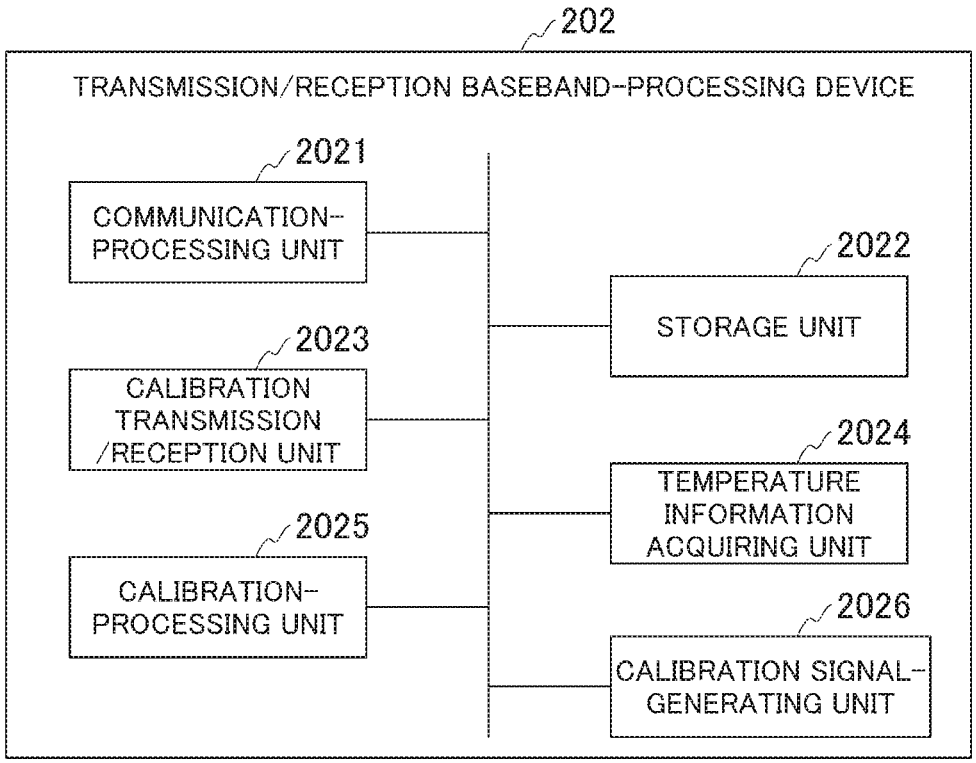
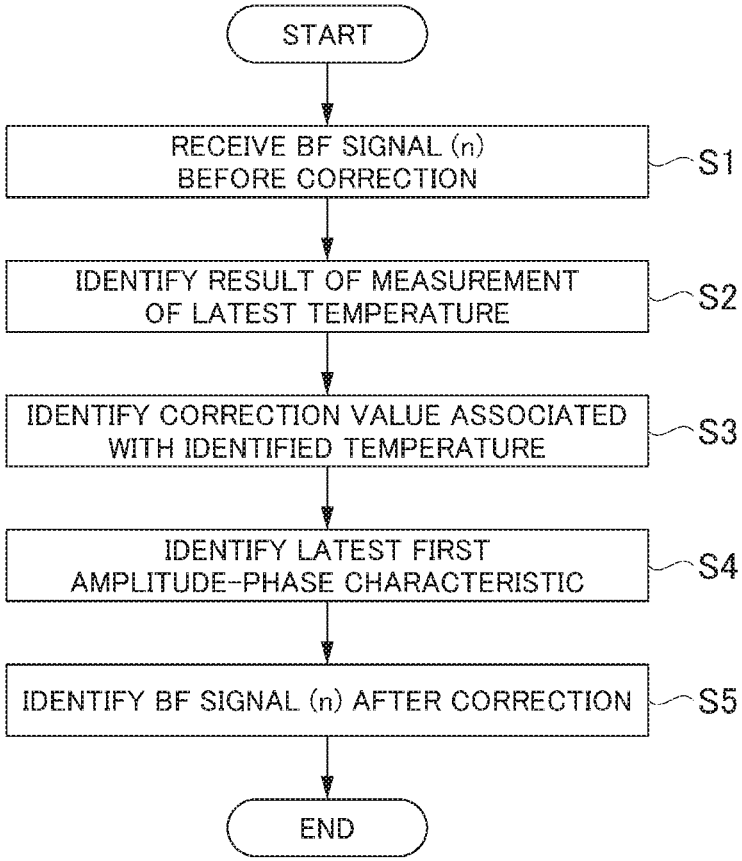


FIG. 4

TBL1

TEMPERATURE	CORRECTION VALUE
-30°C	AAAA
0°C	BBBB
+25°C	CCCC
+50°C	DDDD

FIG. 5


START
RECEIVE BF SIGNAL (n) BEFORE CORRECTION
S1
IDENTIFY RESULT OF MEASUREMENT OF LATEST TEMPERATURE
S2
IDENTIFY CORRECTION VALUE ASSOCIATED WITH IDENTIFIED TEMPERATURE
S3
IDENTIFY LATEST FIRST AMPLITUDE-PHASE CHARACTERISTIC
S4
IDENTIFY BF SIGNAL (n) AFTER CORRECTION
S5
END

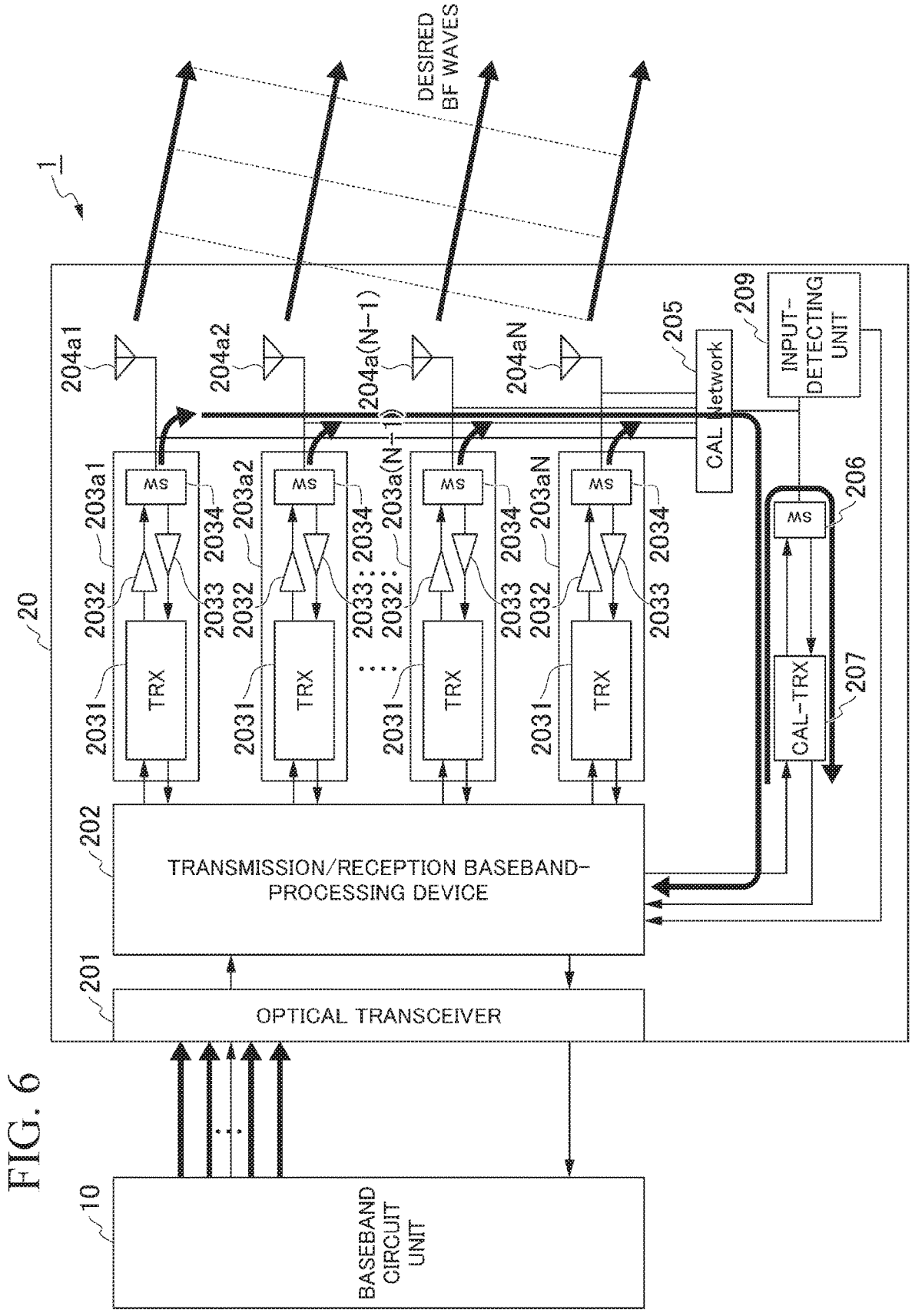

DESIRED BF WAVES
1
20
204a1
204a2
204a(N-1)
204aN
205
CAL network
209
INPUT-DETECTING UNIT
206
MS
203a1
203a2
203a(N-1)
203aN
2034
2033
2032
2031
TRX
CAL-TRX
207
202
TRANSMISSION/RECEPTION BASEBAND-PROCESSING DEVICE
201
OPTICAL TRANSCEIVER
10
BASEBAND CIRCUIT UNIT

FIG. 6

FIG. 7

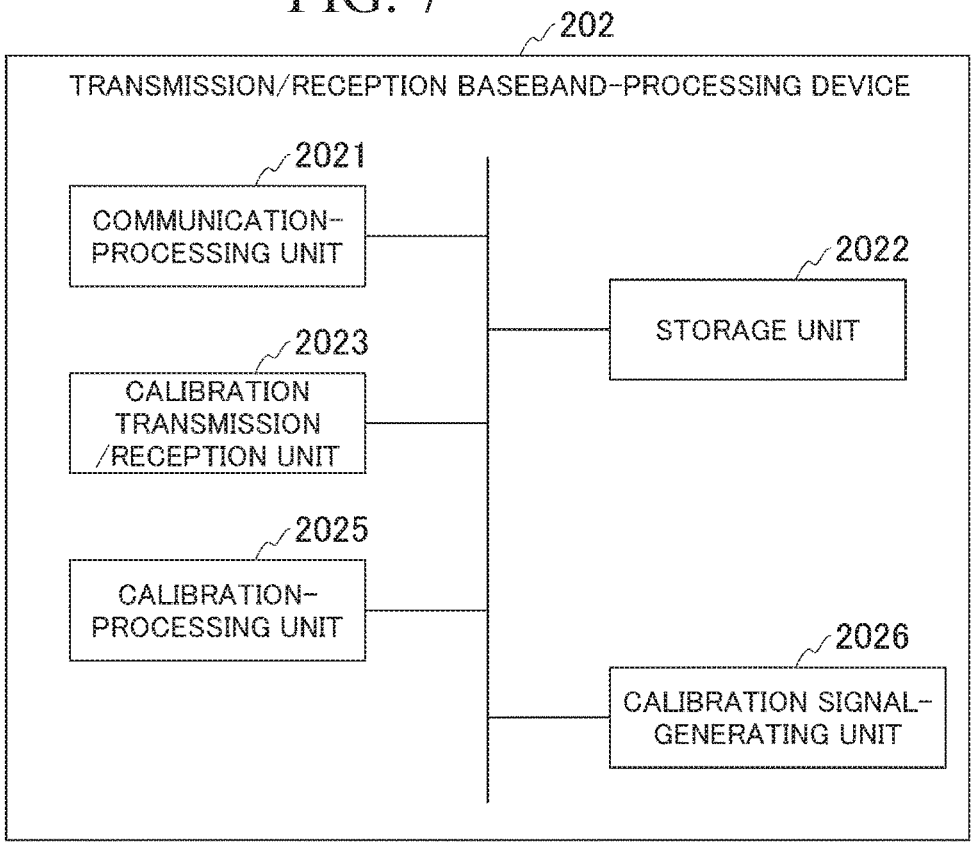
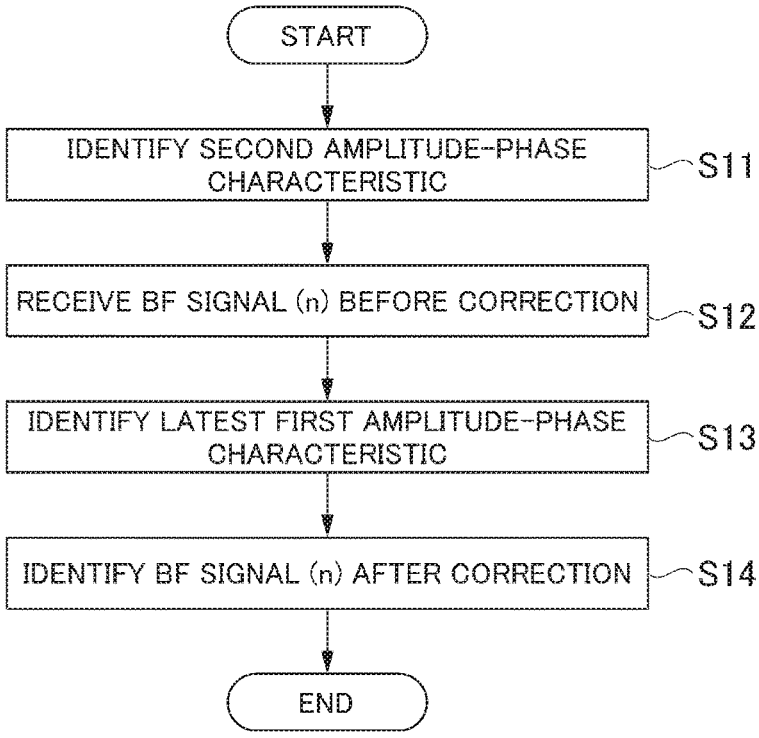

202
TRANSMISSION/RECEPTION BASEBAND-PROCESSING DEVICE
2021
COMMUNICATION-PROCESSING UNIT
2022
STORAGE UNIT
2023
CALIBRATION TRANSMISSION /RECEPTION UNIT
2025
CALIBRATION-PROCESSING UNIT
2026
CALIBRATION SIGNAL-GENERATING UNIT

FIG. 8


START
IDENTIFY SECOND AMPLITUDE-PHASE CHARACTERISTIC
S11
RECEIVE BF SIGNAL (n) BEFORE CORRECTION
S12
IDENTIFY LATEST FIRST AMPLITUDE-PHASE CHARACTERISTIC
S13
IDENTIFY BF SIGNAL (n) AFTER CORRECTION
S14
END

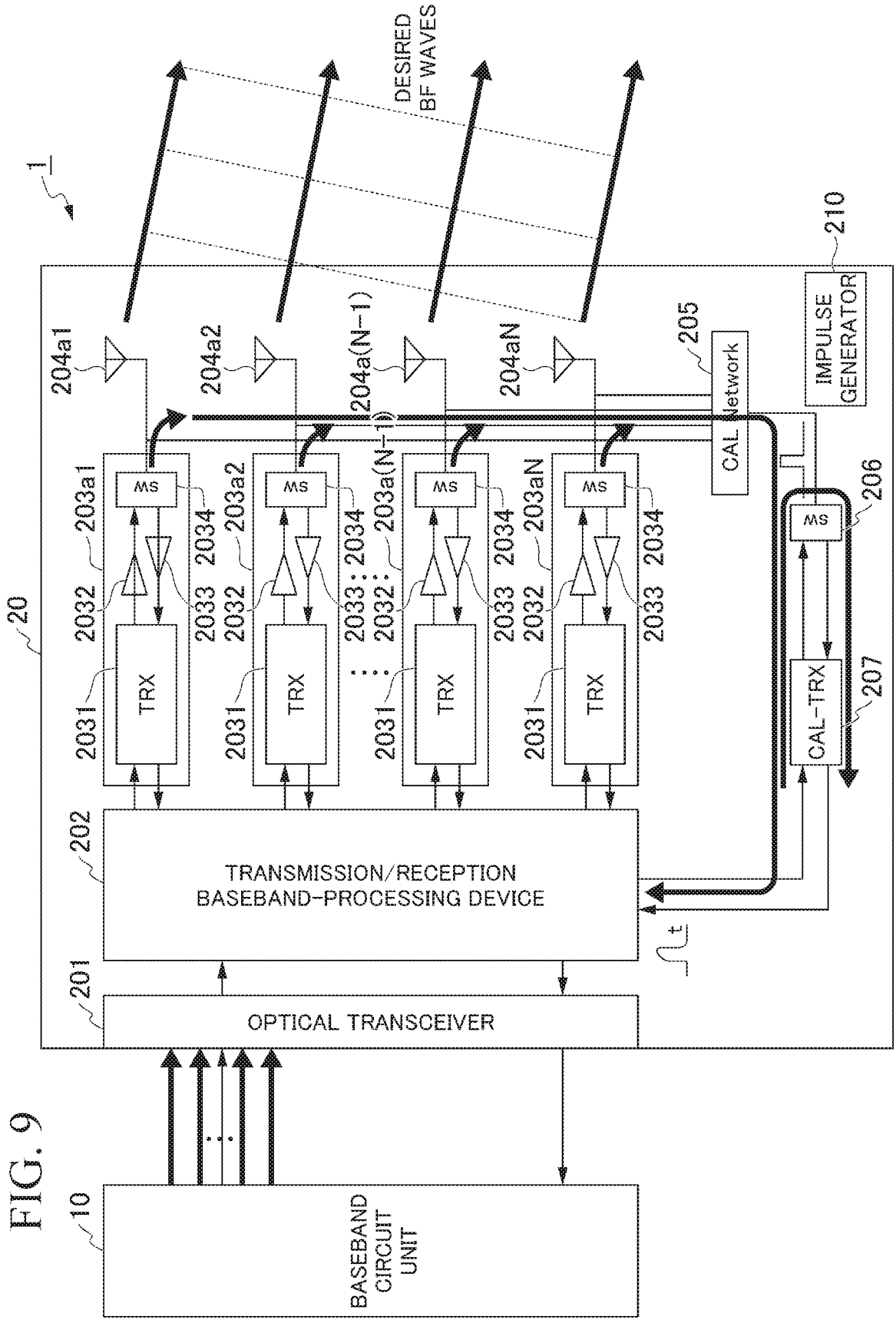

DESIRED BF WAVES
1
210
IMPULSE GENERATOR
205
CAL Network
204a1
204a2
204a(N-1)
204aN
206
MS
203a1
203a2
203a(N-1)
203aN
2034
2032
2033
2031
TRX
CAL-TRX
207
20
202
TRANSMISSION/RECEPTION BASEBAND-PROCESSING DEVICE
t
201
OPTICAL TRANSCEIVER
10
BASEBAND CIRCUIT UNIT

FIG. 9

FIG. 10

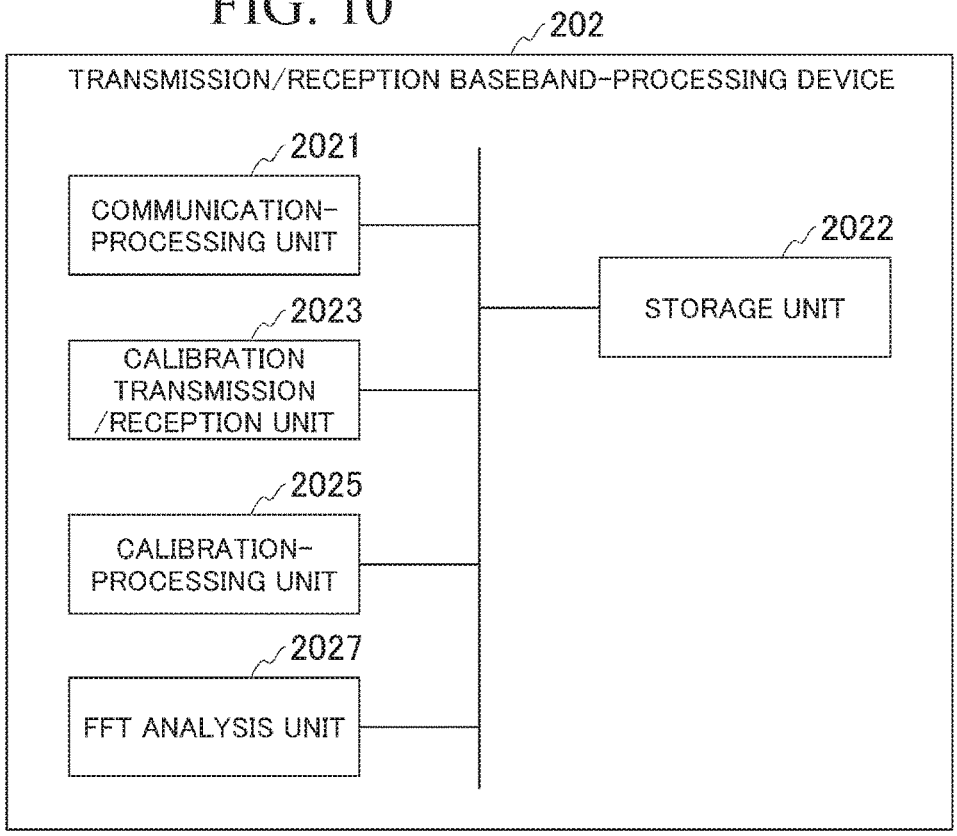

202
TRANSMISSION/RECEPTION BASEBAND-PROCESSING DEVICE
2021
COMMUNICATION-PROCESSING UNIT
2022
STORAGE UNIT
2023
CALIBRATION TRANSMISSION /RECEPTION UNIT
2025
CALIBRATION-PROCESSING UNIT
2027
FFT ANALYSIS UNIT

FIG. 11

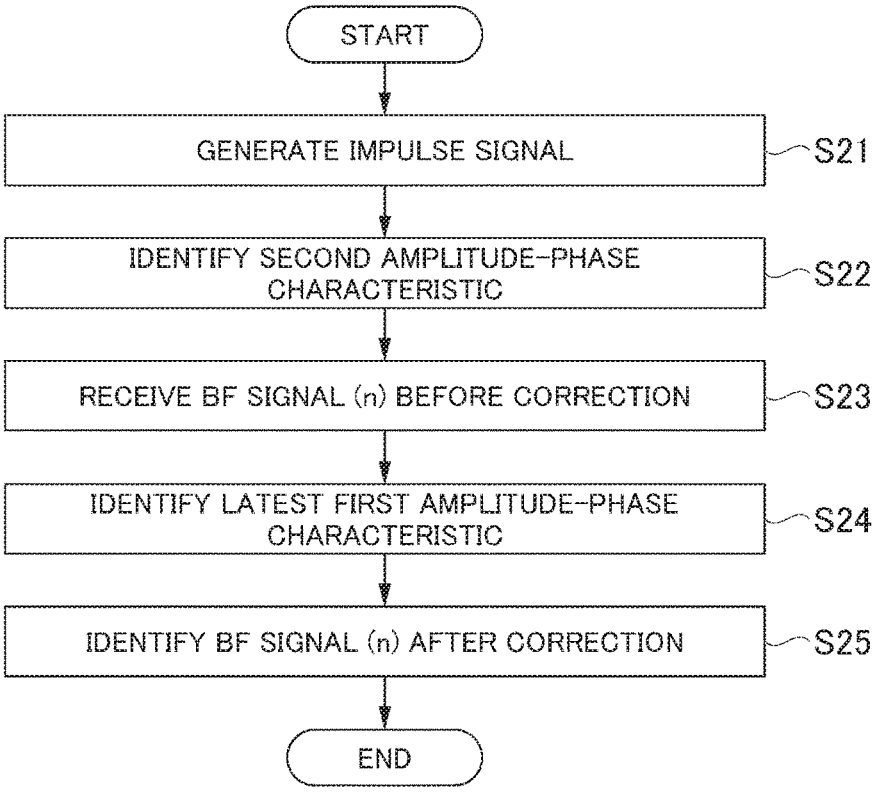

START
GENERATE IMPULSE SIGNAL
S21
IDENTIFY SECOND AMPLITUDE-PHASE CHARACTERISTIC
S22
RECEIVE BF SIGNAL (n) BEFORE CORRECTION
S23
IDENTIFY LATEST FIRST AMPLITUDE-PHASE CHARACTERISTIC
S24
IDENTIFY BF SIGNAL (n) AFTER CORRECTION
S25
END

FIG. 12

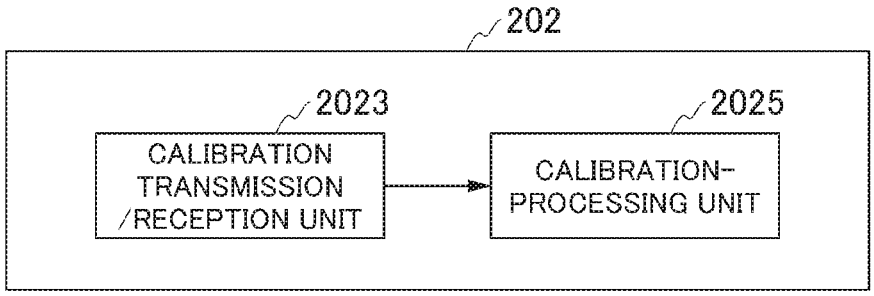
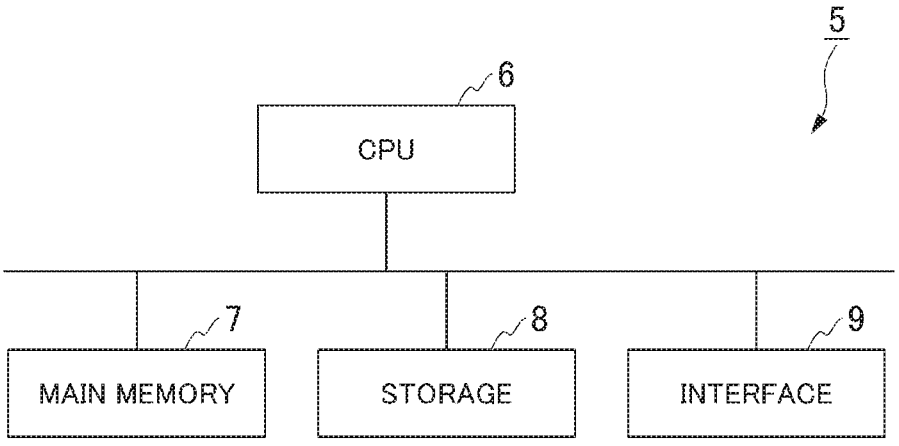

202
2023
CALIBRATION TRANSMISSION /RECEPTION UNIT
2025
CALIBRATION-PROCESSING UNIT

FIG. 13


5
6
CPU
7
MAIN MEMORY
8
STORAGE
9
INTERFACE

TRANSMISSION/RECEPTION BASEBAND-PROCESSING DEVICE, COMMUNICATION SYSTEM, CORRECTION METHOD, AND PROGRAM

INCORPORATION BY REFERENCE

[0001] This application is based upon and claims the benefit of priority from Japanese patent application No. 2018-188419, filed Oct. 3, 2018, the disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to a transmission/reception baseband-processing device, a communication system, a correction method, and a program.

Description of Related Art

[0003] With the rapid spread of radio communication, there is a problem in that frequency bands used for radio communication have become insufficient. As one of technologies for effectively using frequency bands, there is beamforming. Beamforming is a technology that enables radio communication with a predetermined communication target by radiating radio waves having directivity and is a technology capable of inhibiting interference with other radio systems and the like while maintaining the quality of signals.

[0004] As a representative technique realizing beamforming, there is a phased array. The phased array is a technology for strengthening signals in a desired direction by adjusting phases and amplitudes of radio signals fed to a plurality of antenna devices in a transmitter and synthesizing radio waves radiated from the antenna devices in a space.

[0005] As relating technologies, technologies relating to transmitters are disclosed in PCT International Publication No. WO2011/108103, Japanese Unexamined Patent Application, First Publication No. 2006-279902, or Japanese Unexamined Patent Application, First Publication No. 2005-348235.

[0006] However, in order for a transmitter to transmit a signal in a desired direction using the beamforming technology, it is necessary to perform calibration so as to correct variations in amplitude-phase characteristics of a plurality of mounted transmitters and configure the amplitude-phase characteristics to be the same such that desired signals can be acquired in each of a plurality of antenna devices.

SUMMARY OF THE INVENTION

[0007] An object of each aspect of the present invention is to provide a transmission/reception baseband-processing device, a communication system, a correction method, and a program capable of solving the problems described above.

[0008] In order to achieve the object described above, according to one aspect of the present invention, there is provided a transmission/reception baseband-processing device, including: a calibration-processing unit configured to correct an input signal input to a transmission unit on the basis of a first characteristic according to characteristics of the transmission unit of a transmission/reception front end-processing unit and a calibration reception unit that is a reception unit of a calibration transmission/reception unit and a second characteristic according to a characteristic of the calibration reception unit.

[0009] In order to achieve the object described above, according to another aspect of the present invention, there is provided a communication system, including: the transmission/reception baseband-processing device described above; and a baseband circuit unit configured to output a beamforming signal to the transmission/reception baseband-processing device.

[0010] In order to achieve the object described above, according to one aspect of the present invention, there is provided a correction method, including: correcting an input signal input to a transmission unit on the basis of a first characteristic according to characteristics of the transmission unit of a transmission/reception front end-processing unit and a calibration reception unit that is a reception unit of a calibration transmission/reception unit and a second characteristic according to a characteristic of the calibration reception unit.

[0011] In order to achieve the object described above, according to one aspect of the present invention, there is provided a program causing a computer to execute: correcting an input signal input to a transmission unit on the basis of a first characteristic according to characteristics of the transmission unit of a transmission/reception front end-processing unit and a calibration reception unit that is a reception unit of a calibration transmission/reception unit and a second characteristic according to a characteristic of the calibration reception unit.

[0012] According to each aspect of the present invention, transmitters can be correctly calibrated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. **1** is a diagram illustrating a configuration common to embodiments of the present invention and the principle of calibration;

[0014] FIG. **2** is a diagram illustrating the configuration of a communication system according to a first embodiment of the present invention;

[0015] FIG. **3** is a diagram illustrating the configuration of a transmission/reception baseband-processing device according to the first embodiment of the present invention;

[0016] FIG. **4** is a diagram illustrating one example of a data table according to the first embodiment of the present invention;

[0017] FIG. **5** is a diagram illustrating a process flow of the communication system according to the first embodiment of the present invention;

[0018] FIG. **6** is a diagram illustrating the configuration of a communication system according to a second embodiment of the present invention;

[0019] FIG. **7** is a diagram illustrating the configuration of a transmission/reception baseband-processing device according to the second embodiment of the present invention;

[0020] FIG. **8** is a diagram illustrating a process flow of the communication system according to the second embodiment of the present invention;

[0021] FIG. **9** is a diagram illustrating the configuration of a communication system according to a third embodiment of the present invention;

[0022] FIG. **10** is a diagram illustrating the configuration of a transmission/reception baseband-processing device according to a third embodiment of the present invention;

[0023] FIG. **11** is a diagram illustrating a process flow of the communication system according to the third embodiment of the present invention;

[0024] FIG. **12** is a diagram illustrating a transmission/reception baseband-processing device having a minimal configuration according to an embodiment of the present invention; and

[0025] FIG. **13** is a schematic block diagram illustrating the configuration of a computer according to at least one embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[0026] Hereinafter, embodiments will be described in detail with reference to the drawings.

<Configuration Common to Each Embodiment and Principle of Calibration>

[0027] A communication system **1** according to each embodiment of the present invention corrects differences in amplitude-phase variations between transmission/reception units that occur due to aging variations and outside air temperature variations under long-term operation by sequentially performing calibration periodically. The communication system **1**, for example, is an active antenna system (AAS).

[0028] Before communication systems **1** according to embodiments will be individually described, a configuration common to the communication systems **1** according to the embodiments and the principle of calibration common to the embodiments will be described.

Configuration Common to Embodiments

[0029] First, a configuration common to communication systems **1** according to embodiments of the present invention will be described.

[0030] The communication system **1**, as illustrated in FIG. **1**, includes a baseband circuit unit **10** and a communicator **20**. The communication system **1** performs communication using a beamforming technology and transmits a beamforming signal (hereinafter, referred to as a "BF signal") in a time-divisional manner at the time of transmission.

[0031] The baseband circuit unit **10** generates a desired BF signal (corresponding to a BF signal (n) before correction in Equation (1) to be described later) to be transmitted from antennas. The baseband circuit unit **10** outputs the generated BF signal to the communicator **20** as a digital optical signal.

[0032] The communicator **20**, as illustrated in FIG. **1**, includes an optical transceiver **201**, a transmission/reception baseband-processing device **202**, transmission/reception front end-processing units **203***a***1**, **203***a***2**, . . . , **203***a*(N−1), and **203***a*N, antennas **204***a***1**, **204***a***2**, . . . , **204***a*(N−1), and **204***a*N, a calibration network **205**, a switch **206**, and a calibration transmission/reception unit **207**.

[0033] The transmission/reception front end-processing units **203***a***1**, **203***a***2**, . . . , **203***a*(N−1), and **203***a*N will be collectively referred to as a transmission/reception front end-processing unit **203**. In addition, the antennas **204***a***1**, **204***a***2**, . . . , **204***a*(N−1), and **204***a*N will be collectively referred to as an antenna **204**.

[0034] The optical transceiver **201** converts an optical signal into an electrical signal and converts an electrical signal into an optical signal.

[0035] For example, when a transmission signal is received from the baseband circuit unit **10** as a digital optical signal, the optical transceiver **201** converts the digital optical signal into a digital electrical signal. The digital transmission signal converted into the electrical signal by the optical transceiver **201** is input to the transmission/reception baseband-processing device **202**.

[0036] In addition, for example, when a reception signal is received from the transmission/reception baseband-processing device **202** as a digital electrical signal, the optical transceiver **201** converts the digital electrical signal into a digital optical signal. The digital reception signal converted into the optical signal by the optical transceiver **201** is input to the baseband circuit unit **10**.

[0037] Each of the transmission/reception front end-processing units **203** includes a transmission/reception unit **2031**, a transmission amplifier **2032**, a reception amplifier **2033**, and a switch **2034**.

[0038] The transmission/reception unit **2031** is connected to the transmission/reception baseband-processing device **202**, an input of the transmission amplifier **2032**, and an output of the reception amplifier **2033**. The switch **2034** is connected to an output of the transmission amplifier **2032**, an input of the reception amplifier **2033**, and a corresponding antenna **204**.

[0039] The transmission/reception unit **2031** performs a process of transmitting an analog transmission signal from the antenna **204**.

[0040] For example, the transmission/reception unit **2031** includes a filter and performs a filter process for an analog transmission signal such that it has a desired frequency component. Then, the transmission/reception unit **2031** outputs the transmission signal to the transmission amplifier **2032**.

[0041] In addition, the transmission/reception unit **2031** performs a process of receiving an analog signal from the connected antenna **204**.

[0042] For example, the transmission/reception unit **2031** includes a filter and performs a filter process for an analog reception signal received from the antenna **204** through the reception amplifier **2033** such that it has a desired frequency component. Then, the transmission/reception unit **2031** outputs the reception signal to the transmission/reception baseband-processing device **202**.

[0043] The transmission amplifier **2032** amplifies an analog transmission signal received from the transmission/reception unit **2031** such that it has a desired amplitude.

[0044] The reception amplifier **2033** amplifies an analog signal received from the antenna **204** such that it has a desired amplitude.

[0045] The switch **2034** connects the transmission amplifier **2032** and the antenna **204** at the time of transmission. On the other hand, the switch **2034** connects the reception amplifier **2033** and the antenna **204** at the time of reception.

[0046] Each of the antennas **204** radiates a transmission signal that is an electrical signal output by the transmission amplifier **2032** as an electromagnetic wave at the time of transmission. In addition, each of the antennas **204** outputs a received electromagnetic wave to the transmission/reception front end-processing unit **203** as an electrical signal at the time of reception.

[0047] When the transmission/reception baseband-processing device **202** is transmitting/receiving no signal through the antenna **204**, the calibration network **205**

receives signals output by the transmission/reception front end-processing units **203**. Then, the calibration network **205** selects a signal that is a measurement target among the received signals and outputs the selected signal to the transmission/reception baseband-processing device **202** through the switch **206** and the calibration transmission/reception unit **207**.

[0048] The switch **206** sets the calibration network **205** and the calibration transmission/reception unit **207** to a connected state or an open state by connecting or opening terminals thereof on the inside.

[0049] The calibration transmission/reception unit **207** is disposed for calibration. The calibration transmission/reception unit **207** includes a reception unit (one example of a calibration reception unit) and a transmission unit. The reception unit converts a signal received by each antenna **204** into a signal of a baseband frequency band that can be read by the transmission/reception baseband-processing device **202**. The transmission unit converts a signal of a baseband frequency band into a signal of a transmission frequency band.

[0050] The transmission/reception baseband-processing device **202** is a processing unit that performs a process of communication with an external device through the antenna **204**. In addition, the transmission/reception baseband-processing device **202** performs signal processing for calibration in the communication system **1**.

(Principle of Calibration)

[0051] Next, the principle of calibration common to the embodiments of the present invention will be described with reference to FIG. **1**.

[0052] For example, in a case in which the communication system **1** is an active antenna system, first, amplitude and phase characteristics (hereinafter, referred to as an "amplitude-phase characteristics) of the transmission/reception front end-processing units **203** connected to the plurality of antennas **204** are calibrated, and differences in variations of the amplitude-phase characteristics of the transmission/reception front end-processing units **203** are corrected. A transmission output absolute level is set in the Radio Act, the 3rd Generation Partnership Project (3GPP), and the like. For this reason, it is important to realize a stable transmission output absolute level within an allowed range and maintain the area coverage of a downlink such that it is constant.

[0053] More specifically, calibration of the amplitude-phase characteristics of the transmission/reception front end-processing units **203** is based on the principle described below.

[0054] First, when no signal is transmitted and received through the antenna **204**, the transmission/reception baseband-processing device **202** switches a connection destination of the calibration network **205**, for example, in order of the transmission/reception front end-processing units **203***a***1**, **203***a***2**, . . . , **203***a*(N−1), and **203***a*N. The transmission/reception baseband-processing device **202** sequentially measures a measurement target signal 1 passing through a path 1, a measurement target signal 2 passing through a path 2, . . . , a measurement target signal (N−1) passing through a path (N−1), and a measurement target signal N passing through a path N.

[0055] Here, the path 1 is a path passing through a transmission unit of the transmission/reception front end-processing unit **203***a***1**, the calibration network **205**, the switch **206**, and a reception unit of the calibration transmission/reception unit **207**. In addition, the path 2 is a path passing through a transmission unit of the transmission/reception front end-processing unit **203***a***2**, the calibration network **205**, the switch **206**, and the reception unit of the calibration transmission/reception unit **207**. The path (N−1) is a path passing through a transmission unit of the transmission/reception front end-processing unit **203***a*(N−1), the calibration network **205**, the switch **206**, and the reception unit of the calibration transmission/reception unit **207**. The path N is a path passing through a transmission unit of the transmission/reception front end-processing unit **203***a*N, the calibration network **205**, the switch **206**, and the reception unit of the calibration transmission/reception unit **207**.

[0056] Here, the measurement target signal 1, the measurement target signal 2, . . . , the measurement target signal (N−1), and the measurement target signal N can be actually measured by the transmission/reception baseband-processing device **202**.

[0057] The measurement target signal 1, the measurement target signal 2, . . . , the measurement target signal (N−1), and the measurement target signal N are signals that are each output from the reception unit of the calibration transmission/reception unit **207** when the transmission/reception baseband-processing device **202** inputs a signal of a predetermined amplitude and a predetermined phase to the transmission/reception front end-processing units **203** of the paths 1 to N. For this reason, when signals are received through the paths 1 to N, the transmission/reception baseband-processing device **202** can identify an amplitude-phase characteristic for each of the paths 1 to N on the basis of a difference between input/output signals.

[0058] The transmission/reception baseband-processing device **202** stores the path 1 and an amplitude-phase characteristic identified for the path 1 in association with each other. In addition, the transmission/reception baseband-processing device **202** stores the path 2 and an amplitude-phase characteristic identified for the path 2 in association with each other. Similarly, the transmission/reception baseband-processing device **202** stores each of the paths 3 to N and an amplitude-phase characteristic identified for each of the paths 3 to N in association with each other.

[0059] Meanwhile, the amplitude-phase characteristic of the transmission unit of the transmission/reception front end-processing unit **203***a***1**, the amplitude-phase characteristic of the transmission unit of the transmission/reception front end-processing unit **203***a***2**, . . . , the amplitude-phase characteristic of the transmission unit of the transmission/reception front end-processing unit **203***a*(N−1), and the amplitude-phase characteristic of the transmission unit of the transmission/reception front end-processing unit **203***a*N are actually desired to be corrected by the transmission/reception baseband-processing device **202**.

[0060] In other words, in the measurement target signal 1, the measurement target signal 2, . . . , the measurement target signal (N−1), and the measurement target signal N measured by the transmission/reception baseband-processing device **202**, amplitude-phase characteristics other than the amplitude-phase characteristic of the transmission unit of the transmission/reception front end-processing unit **203***a***1**, the amplitude-phase characteristic of the transmission unit of the transmission/reception front end-processing unit **203***a***2**, . . . , the amplitude-phase characteristic of the transmission unit of the transmission/reception front end-processing unit

203*a*(N−1), and the amplitude-phase characteristic of the transmission unit of the transmission/reception front end-processing unit **203***a*N that are correction targets are each included. In other words, the amplitude-phase characteristic CAL_RX of the reception unit of the calibration transmission/reception unit **207** that is an error in the correction is included.

[0061] Thus, in each embodiment of the present invention, the transmission/reception baseband-processing device **202** measures the amplitude-phase characteristic of the reception unit of the calibration transmission/reception unit **207** that is an error in the correction asynchronously with measurement of the measurement target signal 1, the measurement target signal 2, . . . , the measurement target signal (N−1), and the measurement target signal N when no signal is transmitted/received through the antenna **204**.

[0062] The transmission/reception baseband-processing device **202** corrects a BF signal acquired by the communicator **20** from the baseband circuit unit **10** on the basis of each of the measurement target signal 1, the measurement target signal 2, . . . , the measurement target signal (N−1), and the measurement target signal N that have been measured and the amplitude-phase characteristic of the reception unit of the calibration transmission/reception unit **207**.

[0063] More specifically, the transmission/reception baseband-processing device **202** performs weighted correction for a BF signal acquired from the baseband circuit unit **10** by using the following Equation (1).

$$\begin{aligned} &BF \text{ signal } (n) \text{ after correction} \\ &= BF \text{ signal } (n) \text{ before correction} \times \frac{\text{second amplitude-phase characteristic CAL_RX}}{\text{first amplitude-phase characteristic DL_CAL_Weight(n)}} \\ &= BF \text{ signal } (n) \text{ before correction} \times \frac{\text{second amplitude-phase characteristic CAL_RX}}{\text{transmission/reception front end processing } 203an \times \text{amplitude-phase characteristic CAL_RX}} \end{aligned} \tag{1}$$

[0064] In Equation (1), the BF signal (n) before correction is a BF signal acquired by the communicator **20** from the baseband circuit unit **10**. Here, n is an integer in the range of 1 to N.

[0065] In Equation (1), the first amplitude-phase characteristic DL_CAL_Weight(n) is the amplitude-phase characteristic of each of the paths 1 to N.

[0066] More specifically, the first amplitude-phase characteristic DL_CAL_Weight(n) includes the following information when the communication system **1** is transmitting/receiving no signal through the antenna **204**. In other words, the first amplitude-phase characteristic DL_CAL_Weight(n) includes characteristics relating to an amplitude and a phase identified by the transmission/reception baseband-processing device **202** from a difference between input/output signals of each of the path 1, the path 2, . . . , the path (N−1), and the path N while the calibration network **205** switches the connection destination in order of the transmission/reception front end-processing units **203***a***1**, **203***a***2**, . . . , **203***a*(N−1), and **203***a*N.

[0067] In addition, in this first amplitude-phase characteristic DL_CAL_Weight(n), the amplitude-phase characteristic CAL_RX of the reception unit of the calibration transmission/reception unit **207** is included.

[0068] In this way, the first amplitude-phase characteristic DL_CAL_Weight(n) includes the characteristic of the hardware of the transmission/reception front end-processing unit **203***an* and the amplitude-phase characteristic CAL_RX of the reception unit of the calibration transmission/reception unit **207**.

[0069] For example, the first amplitude-phase characteristic DL_CAL_Weight(n) is represented as an equation "(An)exp(−jθ*n*)". A first amplitude-phase characteristic DL_CAL_Weight(1) is an amplitude-phase characteristic for the path 1. A first amplitude-phase characteristic DL_CAL_Weight(2) is an amplitude-phase characteristic for the path 2. A first amplitude-phase characteristic DL_CAL_Weight(N−1) is an amplitude-phase characteristic for the path (N−1). A first amplitude-phase characteristic DL_CAL_Weight(N) is an amplitude-phase characteristic for the path N.

[0070] Here, "j" is an imaginary number. In addition, "An" is a difference between the amplitude of an output signal and the amplitude of an input signal in measurement of each path (in other words, information relating to a gain). "On" is a difference between the phase of an output signal and the phase of an input signal in measurement of each path.

[0071] The second amplitude-phase characteristic CAL_RX in Equation (1) includes a characteristic relating to the amplitude and the phase identified from a difference between input/output signals in the measurement for the reception unit of the calibration transmission/reception unit **207** that is performed for calibration.

[0072] For example, the second amplitude-phase characteristic CAL_RX is represented as an equation "(B)exp(−jβ)". Here, "B" is a difference between the amplitude of an output signal and the amplitude of an input signal (in other words, information relating to a gain) in the reception unit of the calibration transmission/reception unit **207**. In addition, "β" is a difference between the phase of an output signal and the phase of an input signal in the reception unit of the calibration transmission/reception unit **207**.

[0073] The BF signal (n) after correction is a BF signal after correcting the BF signal (n) before correction using the first amplitude-phase characteristic DL_CAL_Weight(n) (=the transmission/reception front end-processing unit **203***an* x the amplitude-phase characteristic CAL_RX) and the second amplitude-phase characteristic CAL_RX.

[0074] When calibration is performed, the transmission/reception baseband-processing device **202** substitutes the BF signal (n) before correction received from the baseband circuit unit **10** and the first amplitude-phase characteristic DL_CAL_Weight(n) identified for each of the paths 1 to N and the second amplitude-phase characteristic CAL_RX into Equation (1).

[0075] Here, more specifically, a case in which the transmission unit of the transmission/reception front end-processing unit **203***a***1** of the path 1 is corrected will be illustrated as an example. In this case, the BF signal (1) before correction for the path 1 received from the baseband circuit unit **10**, the first amplitude-phase characteristic DL_CAL_Weight(1) (=the transmission/reception front end-processing unit **203***a***1** x the amplitude-phase characteristic CAL_RX), and the second amplitude-phase characteristic CAL_RX are substituted into Equation (1). A BF signal (1) after correction that is acquired through the substitution for Equation (1) is output to the transmission unit of the transmission/reception front end-processing unit **203***a***1**.

[0076] A case in which the transmission unit of the transmission/reception front end-processing unit **203***a***2** of the path 2 is corrected will be illustrated as an example. In this case, the BF signal (2) before correction for the path 2 received from the baseband circuit unit **10**, the first amplitude-phase characteristic DL_CAL_Weight(2) (=the transmission/reception front end-processing unit **203***a***2** x the amplitude-phase characteristic CAL_RX), and the second amplitude-phase characteristic CAL_RX are substituted into Equation (1). A BF signal (2) after correction that is acquired through the substitution into Equation (1) is output to the transmission unit of the transmission/reception front end-processing unit **203***a***2**.

[0077] A case in which the transmission unit of the transmission/reception front end-processing unit **203***a*(N−1) of the path (N−1) is corrected will be illustrated as an example. In this case, the BF signal (N−1) before correction for the path (N−1) received from the baseband circuit unit **10**, the first amplitude-phase characteristic DL_CAL_Weight(N−1) (=the transmission/reception front end-processing unit **203***a* (N−1) x the amplitude-phase characteristic CAL_RX), and the second amplitude-phase characteristic CAL_RX are_ CAL_RX into Equation (1). A BF signal (N−1) after correction that is acquired through the substitution into Equation (1) is output to the transmission unit of the transmission/reception front end-processing unit **203***a*(N−1).

[0078] A case in which the transmission unit of the transmission/reception front end-processing unit **203***a*N of the path N is corrected will be illustrated as an example. In this case, the BF signal (N) before correction for the path N received from the baseband circuit unit **10**, the first amplitude-phase characteristic DL_CAL_Weight(N) (=the transmission/reception front end-processing unit **203***a*N x the amplitude-phase characteristic CAL_RX), and the second amplitude-phase characteristic CAL_RX are_CAL_RX into Equation (1). A BF signal (N) after correction that is acquired through the substitution into Equation (1) is output to the transmission unit of the transmission/reception front end-processing unit **203***a*(N).

[0079] Accordingly, a transmission BF signal(n) that is actually transmitted from each antenna **204** when the BF signal (n) after correction is input to the transmission/reception front end-processing unit **203***an* is represented by the following Equation (2). The BF signal (n) after correction in Equation (2) can be substituted in accordance with Equation (1).

(2)

$$\begin{aligned}
\text{Transmission } BF \text{ signal } (n) &= BF \text{ signal } (n)_{\text{after correction}} \times \text{transmission/reception front end processing unit 203an} \\
&= BF \text{ signal } (n)_{\text{before correction}} \times \frac{\text{second amplitude-phase characteristic CAL_RX} \times \text{transmission/reception front end-processing unit 203}an}{\text{first amplitude-phase characteristic DL_CAL_Weight(n)}} \\
&= BF \text{ signal } (n)_{\text{before correction}} \times \frac{\text{second amplitude-phase characteristic CAL_RX} \times \text{transmission/reception front end-processing unit 203}an}{\text{transmission/reception front end-processing unit 203}an \times \text{amplitude-phase characteristic CAL_RX}} \\
&= BF \text{ signal } (n)_{\text{before correction}} \times \frac{\text{second amplitude-phase characteristic CAL_RX}}{\text{amplitude-phase characteristic CAL_RX}}
\end{aligned}$$

[0080] In Equation (2), the transmission/reception front end-processing unit **203***an* is a characteristic of the transmission/reception front end-processing unit **203***an* as hardware at each time.

[0081] Here, the first amplitude-phase characteristic DL_CAL_Weight(n) represents the amplitude-phase characteristic CAL_RX at the time of measurement thereof and a characteristic of the transmission/reception front end-processing unit **203***an* as hardware. In Equation (2), a denominator "first amplitude-phase characteristic DL_CAL_Weight(n)" is substituted into "transmission/reception front end-processing unit **203***a*(*n*) x amplitude-phase characteristic CAL_RX".

[0082] In addition, the measurement of the first amplitude-phase characteristic DL_CAL_Weight(n) is measurement that is constantly performed when the communication system **1** does not perform communication through the antenna **204**. The measurement of the second amplitude-phase characteristic CAL_RX is measurement that is performed at the time of calibration. In other words, a timing at which the first amplitude-phase characteristic DL_CAL_Weight(n) is measured and a timing at which the second amplitude-phase characteristic CAL_RX is measured are configured to be asynchronous. Here, a difference between the two timings can be regarded as a timing difference of a degree that can be ignored as a change in the characteristic over time or a change in the characteristic accompanying a temperature change.

[0083] For this reason, the term "second amplitude-phase characteristic CAL_RX x transmission/reception front end-processing unit **203** an" of the numerator and the term "transmission/reception front end-processing unit **203***a*(*n*) x

amplitude-phase characteristic CAL_RX" of the denominator in Equation (2) are reduced. In other words, in accordance with the transmission/reception front end-processing units **203***a*(*n*), terms of the numerator and the denominator in Equation (2) are reduced.

[0084] As a result, the transmission BF signal (n) in Equation (2) can be represented as an equation "BF signal (n) before correction x second amplitude-phase characteristic CAL_RX/amplitude-phase characteristic CAL_RX". Here, if the second amplitude-phase characteristic CAL_RX can be acquired such that "the second amplitude-phase characteristic CAL_RX=the amplitude-phase characteristic CAL_RX", these divisional terms are cancelled out. In this way, only the desired BF signal (n) before correction is finally radiated with a predetermined transmission output level absolute value from each transmitter through the antenna **204**.

[0085] On the contrary, in a calibration method disclosed in a patent document "Japanese Unexamined Patent Application, First Publication No. 2005-348335" that is a comparison target and the like, the second amplitude-phase characteristic CAL_RX is handled as a fixed value. For this reason, since "the second amplitude-phase characteristic CAL_RX≠the amplitude-phase characteristic CAL_RX", amplitude-phase variations of all the transmitters are the same, however, there is a problem in that a transmission output level absolute value changes from a predetermined value.

[0086] Thus, in this embodiment, the BF signal (n) before correction is corrected by applying the first amplitude-phase characteristic DL_CAL_Weight(n) measured as described above and the second amplitude-phase characteristic CAL_RX to Equation (1). In this way, as represented in Equation (2), the transmission BF signal (n) can be set as the BF signal (n) before correction (in other words, a desired BF signal to be transmitted from the antenna **204**).

[0087] The principle of calibration common to embodiments of the present invention has been described above.

First Embodiment

(Configuration of Communication System **1**)

[0088] A communication system **1** according to a first embodiment of the present invention, as illustrated in FIG. **2**, includes a baseband circuit unit **10** and a communicator **20**. The communication system **1** includes a temperature sensor **208**. The communication system **1** measures a second amplitude-phase characteristic CAL_RX at each temperature in advance at the time of a test immediately before shipment of the communicator **20** or the like. The communication system **1** stores measurement results in a data table as correction values and performs calibration using the correction values.

[0089] In FIG. **2**, an input-detecting device **30** used in a case in which the data table is generated is illustrated. The input-detecting device **30** will be described together with generation of a data table TBL**1** to be described later.

[0090] The communicator **20** includes an optical transceiver **201**, a transmission/reception baseband-processing device **202**, transmission/reception front end-processing units **203**, antennas **204**, a calibration network **205**, a switch **206**, a calibration transmission/reception unit **207**, and a temperature sensor **208** and an input-detecting unit **209** (not illustrated in FIG. **2**).

[0091] The input-detecting unit **209**, when performing calibration, detects a signal for calibration that is output by the transmission/reception baseband-processing device **202** at the position of the switch **206**. The input-detecting unit **209** outputs a result of the detection to the transmission/reception baseband-processing device **202**.

[0092] The temperature sensor **208** measures a temperature at the communicator **20**. The temperature sensor **208** outputs a result of the measurement of the temperature to the transmission/reception baseband-processing device **202**. In addition, it is preferable that the temperature sensor **208** be disposed near a processing unit of the communicator **20** having the highest influence on calibration when the temperature of the communicator **20** varies, for example, the calibration transmission/reception unit **207**.

[0093] The transmission/reception baseband-processing device **202**, as illustrated in FIG. **3**, includes a communication-processing unit **2021**, a storage unit **2022**, a calibration transmission/reception unit **2023**, a temperature information-acquiring unit **2024**, a calibration-processing unit **2025**, and a calibration signal-generating unit **2026**.

[0094] The communication-processing unit **2021** performs a process of communicating with an external device through the antennas **204**.

[0095] For example, the communication-processing unit **2021** includes a DA converter and converts a digital transmission signal received from the baseband circuit unit **10** into an analog transmission signal. Then, the communication-processing unit **2021** outputs the analog transmission signal to the transmission/reception front end-processing unit **203**.

[0096] In addition, for example, the communication-processing unit **2021** includes an AD converter and converts an analog reception signal received from the transmission/reception front end-processing unit **203** into a digital reception signal. Then, the communication-processing unit **2021** outputs the digital reception signal to the baseband circuit unit **10** through the optical transceiver **201**.

[0097] The storage unit **2022** stores various kinds of information required for a process performed by the transmission/reception baseband-processing device **202**. For example, the storage unit **2022** stores Equation (1) used for identifying a BF signal (n) after correction. In addition, for example, the storage unit **2022** stores a data table TBL**1** as illustrated in FIG. **4** in which a plurality of temperatures of the communicator **20** and correction values each corresponding to the plurality of temperatures are associated with each other.

[0098] Temperatures and correction values in the data table TBL**1** are the correction values determined by measuring second amplitude-phase characteristics CAL_RX for a plurality of temperatures in advance. For example, at the time of a test immediately before the shipment of the communicator **20**, the communicator **20** is put into a thermostatic chamber, and the temperature of the thermostatic chamber is changed such that measured values measured by the temperature sensor **208**, for example, become −30 degrees, 0 degrees, 25 degrees, and 50 degrees. A second amplitude-phase characteristic CAL_RX measured at each of such temperatures is a correction value at each temperature.

[0099] In addition, details of the measurement of a second amplitude-phase characteristic CAL_RX at each temperature will be described later.

[0100] The calibration signal-generating unit **2026** outputs a signal having a predetermined amplitude and a predetermined phase used for generating a data table TBL**1** to the calibration transmission/reception unit **207** through the calibration transmission/reception unit **2023**.

[0101] In addition, the calibration signal-generating unit **2026** outputs a signal having a predetermined amplitude and a predetermined phase to each of the transmission/reception front end-processing units **203** through the calibration transmission/reception unit **2023**.

[0102] For example, when the transmission/reception baseband-processing device **202** is transmitting/receiving no signal through the antenna **204**, the calibration signal-generating unit **2026** outputs, through the calibration transmission/reception unit **2023**, the BF signal (n) before correction received from the baseband circuit unit **10** in order of the paths 1 to N.

[0103] The temperature information-acquiring unit **2024** acquires a result of measurement of a temperature of the communicator **20** from the temperature sensor **208** at predetermined times. Here, the predetermined time, for example, is a time representing a time interval at which the transmission/reception baseband-processing device **202** performs the process of calibration (for example, a time of about 1 millisecond to several hundreds of milliseconds).

[0104] When a result of measurement of the temperature of the communicator **20** is acquired, the temperature information-acquiring unit **2024** outputs the result of the measurement to the calibration-processing unit **2025**.

[0105] The calibration-processing unit **2025** performs the process of calibration for the communicator **20** on the basis of signals transmitted and received when the transmission/reception baseband-processing device **202** is transmitting/receiving no signal through the antenna **204**.

[0106] For example, when the transmission/reception baseband-processing device **202** is transmitting/receiving no signal through the antennas **204**, the calibration-processing unit **2025** transmits a predetermined input signal to each of the paths 1 to N and receives an output signal of each of the paths. Then, the calibration-processing unit **2025** identifies a first amplitude-phase characteristic DL_CAL_Weight(n) on the basis of a relationship between input/output signals. In addition, the calibration-processing unit **2025** transmits a predetermined input signal to the calibration transmission/reception unit **207** and identifies a second amplitude-phase characteristic CAL_RX on the basis of transmitted and received signals. Then, the calibration-processing unit **2025** corrects the BF signal (n) before correction by applying the first amplitude-phase characteristic DL_CAL_Weight(n) and the second amplitude-phase characteristic CAL_RX to Equation (1).

(Generation of Data Table TBL**1**)

[0107] Next, generation of the data table TBL**1** will be described.

[0108] The generation of the data table TBL**1** is performed before the shipment of the communicator **20**, for example, at the time of a test immediately before the shipment of the communicator **20**. The input-detecting device **30**, as illustrated in FIG. **2**, is connected to the switch **206**. The input-detecting device **30** is a device that can measure a signal from the switch **206** using the amplitude and the phase of an input signal transmitted from the transmission/reception baseband-processing device **202** as references and is disconnected from the switch **206** when the generation of the data table TBL**1** ends.

[0109] Before the shipment of the communicator **20**, the communicator **20** is put into a thermostatic chamber, and the temperature of the thermostatic chamber is changed. Then, measurement as below is performed at each temperature, and a correction value is identified.

[0110] The calibration-processing unit **2025** transmits an input signal having a predetermined amplitude and a predetermined phase to the calibration transmission/reception unit **207** through the calibration transmission/reception unit **2023** when the data table TBL**1** is generated.

[0111] The transmission unit of the calibration transmission/reception unit **207** receives an input signal from the transmission/reception baseband-processing device **202** and outputs an output signal to the switch **206**. This output signal is returned to the transmission/reception baseband-processing device **202** through the reception unit of the calibration transmission/reception unit **207**.

[0112] The input-detecting device **30** measures a signal from the switch **206**. The input-detecting device **30** transmits a result of the measurement representing the amplitude and the phase of the measured signal to the transmission/reception baseband-processing device **202**.

[0113] The calibration-processing unit **2025** receives the result of the measurement representing the amplitude and the phase from the input-detecting device **30** through the calibration transmission/reception unit **2023**.

[0114] In addition, the calibration-processing unit **2025** receives, through the calibration transmission/reception unit **2023**, the signal returned to the transmission/reception baseband-processing device **202** from the switch **206** through the reception unit of the calibration transmission/reception unit **207**.

[0115] The calibration-processing unit **2025** calculates an amplitude-phase characteristic of a gain of the transmission unit of the calibration transmission/reception unit **207** on the basis of a difference between the result of the measurement representing the amplitude and the phase received from the input-detecting device **30** and a predetermined input signal transmitted to the calibration transmission/reception unit **207**.

[0116] In addition, the calibration-processing unit **2025** calculates an amplitude-phase characteristic of a gain combining the transmission unit and the reception unit of the calibration transmission/reception unit **207** on the basis of a difference between the signal returned to the transmission/reception baseband-processing device **202** from the switch **206** through the reception unit of the calibration transmission/reception unit **207** and the predetermined input signal transmitted to the calibration transmission/reception unit **207**.

[0117] Then, the calibration-processing unit **2025** subtracts the amplitude-phase characteristic of the gain of the transmission unit of the calibration transmission/reception unit **207** from the amplitude-phase characteristic of the gain combining the transmission unit and the reception unit of the calibration transmission/reception unit **207**. The calibration-processing unit **2025** identifies a result of the subtraction as a second amplitude-phase characteristic CAL_RX that is an amplitude-phase characteristic of the gain of the reception unit of the calibration transmission/reception unit **207**. The

second amplitude-phase characteristic CAL_RX identified by the calibration-processing unit **2025** is a correction value.

[0118] The calibration-processing unit **2025** writes the identified correction value and the temperature in the data table TBL**1** in association with each other. One example of the data table TBL**1** is illustrated in FIG. **4**.

[0119] The data table TBL**1** is generated as described above.

(Process of Calibration)

[0120] Next, the process of calibration performed by the communication system **1** will be described.

[0121] Here, the process flow of the communication system **1** illustrated in FIG. **5** will be described.

[0122] It is assumed that a data table TBL**1** has been generated in advance and has been written in the storage unit **2022**. In addition, it is assumed that, when the transmission/reception baseband-processing device **202** is transmitting/receiving no signal through the antennas **204**, the calibration-processing unit **2025** identifies a first amplitude-phase characteristic DL_CAL_Weight(n) on the basis of a relationship between input and output signals for each of the paths 1 to N. Furthermore, it is assumed that the calibration-processing unit **2025** receives a result of measurement of the temperature of the communicator **20** measured by the temperature sensor **208** for every predetermined time (for example, for every one second).

[0123] The baseband circuit unit **10** outputs a BF signal (n) before correction to the communicator **20**.

[0124] The calibration network **205** receives the BF signal (n) before correction from the baseband circuit unit **10** (Step S**1**).

[0125] When the BF signal (n) before correction is received from the baseband circuit unit **10**, the calibration network **205** identifies a result of measurement of a latest temperature received from the temperature sensor **208** (Step S**2**).

[0126] The calibration network **205** identifies a temperature that is the closest to the identified temperature in the data table TBL**1**. Then, the calibration network **205** identifies a correction value associated with the identified temperature in the data table TBL**1** (Step S**3**).

[0127] In addition, when the BF signal (n) before correction is received from the baseband circuit unit **10**, the calibration network **205** identifies a latest first amplitude-phase characteristic DL_CAL_Weight(n) (Step S**4**).

[0128] The calibration network **205** substitutes the BF signal (n) before correction received from the baseband circuit unit **10** into the BF signal (n) before correction in Equation (1). The calibration network **205** substitutes the latest first amplitude-phase characteristic DL_CAL_Weight (n) into the first amplitude-phase characteristic DL_CAL_Weight(n) in Equation (1) and substitutes the identified correction value into the second amplitude-phase characteristic CAL_RX in Equation (1). In this way, the calibration network **205** identifies a BF signal (n) after correction using Equation (1) (Step S**5**). The calibration network **205** outputs the identified BF signal (n) after correction to a corresponding transmission/reception front end-processing unit **203**.

[0129] The process described above is performed when the calibration network **205** receives a BF signal (n) before correction from the baseband circuit unit **10**.

[0130] The process of calibration performed by the communication system **1** according to the first embodiment of the present invention has been described above.

(Summing-Up of First Embodiment)

[0131] The communication system **1** according to the first embodiment of the present invention has been described above.

[0132] In order to correct and eliminate variations in the amplitude-phase characteristics of transmission/reception units connected to a plurality of antennas within an active antenna system (AAS) under an operation in a time division duplex (TDD) mode, it is required to perform calibration of the transmission/reception units.

[0133] In addition, in order to correct differences in amplitude-phase variations between transmission/reception units that occur due to outside air temperature variations and aging variations under a long-time operation of the communication system, it is important to eliminate such differences by sequentially performing calibration periodically.

[0134] By performing calibration in a communication system, differences in the amplitudes and phases of a plurality of transmission/reception units are corrected, and the amplitudes and the phases can be configured to be the same. At that time, it is required that the transmission output absolute levels of all the transmitters in the communication system are within an allowed range. The allowed range of the transmission output absolute level is set according to standards standardized by the Radio Act and the Third Generation Partnership Project (3GPP) and the like, it is necessary to obey the allowed range, and it is important to realize a stable transmission output absolute level and to maintain a down link (DL) area coverage (a service region of a link from the center of a network such as a base station or a server to users present in the vicinity thereof) to be constant.

[0135] In the communicator **20** included in the communication system **1**, the transmission/reception baseband-processing device **202** includes the calibration transmission/reception unit **2023** and the calibration-processing unit **2025**. The calibration transmission/reception unit **2023** receives a first signal according to the characteristics of the transmission unit of the transmission/reception front end-processing unit **203** and the reception unit of the calibration transmission/reception unit **207** and a second signal according to the characteristic of the reception unit of the calibration transmission/reception unit **207**.

[0136] The calibration-processing unit **2025** corrects an input signal input to the transmission unit of the transmission/reception front end-processing unit **203** on the basis of the first signal and the second signal. Then, the calibration-processing unit **2025** corrects an input signal input to the transmission unit of the transmission/reception front end-processing units **203** using a correction value determined in advance on the basis of a result of measurement of the temperature of the communicator **20**.

[0137] By employing such a configuration, the transmission/reception baseband-processing device **202** can correct the characteristic of the communicator **20** relating to the amplitude and the phase accompanying a temperature change, and a difference in amplitude and phase variations between the transmission/reception front end-processing units **203** can be eliminated.

[0138] In addition, by employing such a configuration, "second amplitude-phase characteristic CAL_RX=the amplitude-phase characteristic CAL_RX" in Equation (2), and accordingly, a beamforming signal is radiated from the antennas with a predetermined transmission output level absolute value. For this reason, the allowed range of the transmission output absolute level is obeyed, a stable transmission output absolute level is realized, and a DL area coverage (a service region of a link from the center of a network such as a base station or a server to users present in the vicinity thereof) can be maintained to be constant.

[0139] As a result, in the communication system **1** according to the first embodiment of the present invention, amplitude and phase characteristics of the transmission/reception front end-processing units **203** can be configured to be the same, and the transmission output absolute level can be maintained to be constant.

Second Embodiment

(Configuration of Communication System **1**)

[0140] A communication system **1** according to a second embodiment of the present invention, as illustrated in FIG. **6**, includes a baseband circuit unit **10** and a communicator **20**. The communication system **1** compensates for differences in amplitude and phase variations between transmission/reception units that occur due to aging variations and outside air temperature variations under long-term operation by sequentially performing calibration periodically.

[0141] More specifically, the communication system **1** according to the second embodiment of the present invention sequentially estimates a change in the characteristic of a transmission/reception front end-processing unit **203** on the basis of a difference between a signal transmitted to a transmission unit of a calibration transmission/reception unit **207** and a signal returned to a transmission/reception baseband-processing device **202**. The signal transmitted to the transmission unit of the calibration transmission/reception unit **207** is transmitted from the transmission/reception baseband-processing device **202** to the transmission unit of the calibration transmission/reception unit **207**. The signal returned to the transmission/reception baseband-processing device **202** passes through the transmission unit of the calibration transmission/reception unit **207**, turned back by a switch **206**, passes through a reception unit of the calibration transmission/reception unit **207**, and returns to the transmission/reception baseband-processing device **202**.

[0142] The communicator **20** includes an optical transceiver **201**, a transmission/reception baseband-processing device **202**, transmission/reception front end-processing units **203**, antennas **204**, a calibration network **205**, a switch **206**, a calibration transmission/reception unit **207**, and an input-detecting unit **209**.

[0143] The input-detecting unit **209** detects a calibration signal output by the transmission/reception baseband-processing device **202** at a position of the switch **206** when calibration is performed. The input-detecting unit **209** outputs a result of the detection to the transmission/reception baseband-processing device **202**.

[0144] The transmission/reception baseband-processing device **202**, as illustrated in FIG. **7**, includes a communication-processing unit **2021**, a storage unit **2022**, a calibration transmission/reception unit **2023**, a calibration-processing unit **2025**, and a calibration signal-generating unit **2026**.

[0145] The storage unit **2022** stores various kinds of information that is required for a process performed by the transmission/reception baseband-processing device **202**. For example, the storage unit **2022** stores Equation (1) used for identifying a BF signal (n) after correction.

(Process of Calibration)

[0146] Next, the process of calibration performed by the communication system **1** will be described. Here, the process flow of the communication system **1** illustrated in FIG. **8** will be described. In addition, it is assumed that, when the transmission/reception baseband-processing device **202** is transmitting/receiving no signal through the antennas **204**, the calibration-processing unit **2025** constantly identifies a first amplitude-phase characteristic DL_CAL_Weight(n) on the basis of a relationship between input and output signals for each of the paths 1 to N.

[0147] The calibration-processing unit **2025** transmits an input signal having a predetermined amplitude and a predetermined phase to the calibration transmission/reception unit **207**.

[0148] The transmission unit of the calibration transmission/reception unit **207** receives an input signal from the transmission/reception baseband-processing device **202** and outputs an output signal to the switch **206**. This output signal returns to the transmission/reception baseband-processing device **202** through the reception unit of the calibration transmission/reception unit **207**.

[0149] The input-detecting unit **209** measures a signal from the switch **206**. The input-detecting unit **209** transmits a result of the measurement representing the amplitude and the phase of the measured signal to the transmission/reception baseband-processing device **202**.

[0150] The calibration-processing unit **2025** receives the result of the measurement representing the amplitude and the phase from the input-detecting unit **209** through the calibration transmission/reception unit **2023**.

[0151] In addition, the calibration-processing unit **2025** receives, through the calibration transmission/reception unit **2023**, the signal returned to the transmission/reception baseband-processing device **202** from the switch **206** through the reception unit of the calibration transmission/reception unit **207**.

[0152] The calibration-processing unit **2025** subtracts a result of measurement representing the amplitude and the phase received from the input-detecting unit **209**, in other words, an amplitude-phase characteristic of the transmission unit of the calibration transmission/reception unit **207** from an amplitude-phase characteristic that has passed through the transmission/reception unit of the calibration transmission/reception unit **207**. Accordingly, the calibration-processing unit **2025** calculates a second amplitude-phase characteristic CAL_RX.

[0153] In other words, the calibration-processing unit **2025** calculates an amplitude-phase characteristic of a gain combining the transmission unit and the reception unit of the calibration transmission/reception unit **207** on the basis of a difference between a signal that has returned from the switch **206** to the transmission/reception baseband-processing device **202** through the reception unit of the calibration transmission/reception unit **207** and a predetermined input signal transmitted to the calibration transmission/reception unit **207**.

[0154] Then, the calibration-processing unit **2025** subtracts the amplitude-phase characteristic of the gain of the transmission unit of the calibration transmission/reception unit **207** from the amplitude-phase characteristic of the gain combining the transmission unit and the reception unit of the calibration transmission/reception unit **207**. The calibration-processing unit **2025** identifies a result of the subtraction as a second amplitude-phase characteristic CAL_RX that is the amplitude-phase characteristic of the gain of the reception unit of the calibration transmission/reception unit **207** (Step S**11**).

[0155] The calibration network **205** receives the BF signal (n) before correction from the baseband circuit unit **10** (Step S**12**).

[0156] When the BF signal (n) before correction is received from the baseband circuit unit **10**, the calibration network **205** identifies a latest first amplitude-phase characteristic DL_CAL_Weight(n) (Step S**13**).

[0157] The calibration network **205** substitutes the BF signal (n) before correction received from the baseband circuit unit **10** into the BF signal (n) before correction in Equation (1). The calibration network **205** substitutes the latest first amplitude-phase characteristic DL_CAL_Weight (n) into the first amplitude-phase characteristic DL_CAL_Weight(n) in Equation (1) and substitutes the identified second amplitude-phase characteristic CAL_RX into the second amplitude-phase characteristic CAL_RX in Equation (1). In this way, the calibration network **205** identifies a BF signal (n) after correction (Step S**14**). The calibration network **205** outputs the identified BF signal (n) after correction to a corresponding transmission/reception front end-processing unit **203**.

[0158] The process described above is performed at every time interval at which an aging change in the characteristic of the communicator **20** and a temperature change of the communicator **20** can be regarded as being sufficiently small.

[0159] The process of calibration of the communication system **1** according to the second embodiment of the present invention has been described above.

(Summing-Up of Second Embodiment)

[0160] The communication system **1** according to the second embodiment of the present invention has been described above.

[0161] In the communicator **20** included in the communication system **1** according to the second embodiment of the present invention, the transmission/reception baseband-processing device **202** includes the calibration transmission/reception unit **2023**, the calibration-processing unit **2025**, and the calibration signal-generating unit **2026**.

[0162] The calibration transmission/reception unit **2023** receives a first signal according to the characteristics of the transmission unit of the transmission/reception front end-processing unit **203** and the reception unit of the calibration transmission/reception unit **207** and a second signal according to the characteristics of the reception unit of the calibration transmission/reception unit **207**. The calibration-processing unit **2025** corrects an input signal input to the transmission unit of the transmission/reception front end-processing unit **203** on the basis of the first signal and the second signal. The calibration signal-generating unit **2026** generates an input signal input to the transmission unit of the transmission/reception front end-processing unit **203**.

[0163] Then, the calibration transmission/reception unit **2023** outputs the input signal generated by the calibration signal-generating unit **2026** to the transmission unit of the calibration transmission/reception unit **207** and acquires the second signal output by the reception unit of the calibration transmission/reception unit **207**. The calibration-processing unit **2025** corrects the input signal input to the transmission unit of the transmission/reception front end-processing unit **203** on the basis of the first signal and the second signal acquired by the calibration signal-generating unit **2026**.

[0164] By employing this configuration, the transmission/reception baseband-processing device **202** can perform calibration including an aging change in the characteristic of the communicator **20**. By sequentially performing calibration periodically, a difference in the amplitude-phase variation between the transmission/reception front end-processing units **203** can be eliminated.

[0165] In addition, by employing this configuration, "second amplitude-phase characteristic CAL_RX=amplitude-phase characteristic CAL_RX" in Equation (2), and accordingly, a beamforming signal is radiated from the antennas with a predetermined transmission output level absolute value. For this reason, the allowed range of the transmission output absolute level is obeyed, the stable the transmission output absolute level is realized, and a DL area coverage (a service region of a link from the center of a network such as a base station or a server to users present in the vicinity thereof) can be maintained to be constant.

[0166] As a result, in the communication system **1** according to the second embodiment of the present invention, the amplitudes and the phases of the transmission/reception front end-processing units **203** can be configured to be the same, and the transmission output absolute level can be maintained to be constant.

Third Embodiment

(Configuration of Communication System **1**)

[0167] Next, a communication system **1** according to a third embodiment of the present invention will be described.

[0168] The communication system **1** according to the third embodiment of the present invention, as illustrated in FIG. **9**, includes a baseband circuit unit **10** and a communicator **20**. In the communication system **1**, a transmission/reception baseband-processing device **202** receives, through a calibration transmission/reception unit **207**, an impulse signal input to a switch **206**. The communication system **1** sequentially estimates and corrects changes in the characteristics of the transmission/reception front end-processing units **203** by analyzing a signal received by the transmission/reception baseband-processing device **202**.

[0169] The communicator **20**, as illustrated in FIG. **9**, includes an optical transceiver **201**, a transmission/reception baseband-processing device **202**, transmission/reception front end-processing units **203**, antennas **204**, a calibration network **205**, a switch **206**, a calibration transmission/reception unit **207**, and an impulse generator **210**.

[0170] The transmission/reception baseband-processing device **202**, as illustrated in FIG. **10**, includes a communication-processing unit **2021**, a storage unit **2022**, a calibration transmission/reception unit **2023**, a calibration-processing unit **2025**, and an FFT analysis unit **2027**.

[0171] The impulse generator **210** generates an impulse signal that is an input signal for a calibration process.

[0172] The impulse generator **210** outputs the generated impulse signal from the switch **206** to the calibration transmission/reception unit **207**. For example, the impulse generator **210** outputs an impulse signal used for estimating a change in the characteristic of the transmission/reception front end-processing unit **203**. The impulse generator **210** sequentially outputs impulse signals to the transmission/reception baseband-processing device **202** through the switch **206** and the reception unit of the calibration transmission/reception unit **207** when the transmission/reception baseband-processing device **202** is transmitting/receiving no signal through the antennas **204**.

[0173] The calibration transmission/reception unit **2023** receives a signal from the impulse generator **210** through the reception unit of the calibration transmission/reception unit **207**. The signal received from the impulse generator **210**, through the reception unit of the calibration transmission/reception unit **207** by the calibration transmission/reception unit **2023**, has an amplitude smaller than that of the signal generated by the impulse generator **210** (in other words, a signal having a "rounded" waveform). The calibration transmission/reception unit **2023** outputs the received impulse signal to the FFT analysis unit **2027**.

[0174] The FFT analysis unit **2027** receives the signal having the rounded waveform from the impulse generator **210**. The FFT analysis unit **2027** stores a frequency spectrum including amplitude-phase information of the impulse signal generated by the impulse generator **210** in advance. The FFT analysis unit **2027** calculates a difference by subtracting a frequency spectrum acquired by performing an FFT analysis (Fourier transform) for the signal having the rounded waveform received from the calibration transmission/reception unit **2023** from the frequency spectrum of the impulse signal stored in advance. Accordingly, the FFT analysis unit **2027** can identify a reception characteristic (amplitude-phase frequency characteristic) of the calibration transmission/reception unit **207**. The FFT analysis unit **2027** outputs a result of the Fourier transform to the calibration-processing unit **2025**.

[0175] When the transmission/reception baseband-processing device **202** is transmitting/receiving no signal through the antennas **204**, the calibration-processing unit **2025**, similar to the calibration-processing unit **2025** according to the second embodiment of the present invention, transmits a predetermined input signal of each of the paths 1 to N and receives an output signal through the path through which the input signal has been transmitted. Then, the calibration-processing unit **2025** identifies a first amplitude-phase characteristic DL_CAL_Weight(n) on the basis of a difference between input and output signals that have been transmitted and received.

[0176] In addition, the calibration-processing unit **2025** receives a result of the Fourier transform from the FFT analysis unit **2027**. Here, the result of the Fourier transform received from the FFT analysis unit **2027** by the calibration-processing unit **2025** represents an amplitude-phase characteristic for each frequency. For this reason, the calibration-processing unit **2025** can identify a second amplitude-phase characteristic CAL_RX that is the amplitude-phase characteristic of the reception unit of the calibration transmission/reception unit **207** from the result of the Fourier transform.

[0177] Then, the calibration-processing unit **2025** substitutes the BF signal (n) before correction received from the baseband circuit unit **10** into the BF signal (n) before correction in Equation (1). The calibration-processing unit **2025** substitutes the latest first amplitude-phase characteristic DL_CAL_Weight(n) into the first amplitude-phase characteristic DL_CAL_Weight(n) in Equation (1) and substitutes the identified second amplitude-phase characteristic CAL_RX into the second amplitude-phase characteristic CAL_RX in Equation (1). In this way, the calibration-processing unit **2025** identifies a BF signal (n) after correction.

(Process of Calibration)

[0178] Next, the process of calibration performed by the communication system **1** will be described. Here, the process flow of the communication system **1** illustrated in FIG. **11** will be described. In addition, it is assumed that, when the transmission/reception baseband-processing device **202** is transmitting/receiving no signal through the antennas **204**, the calibration-processing unit **2025** constantly identifies a first amplitude-phase characteristic DL_CAL_Weight(n) on the basis of a relationship between input and output signals for each of the paths 1 to N.

[0179] The impulse generator **210** generates an impulse signal that is an input signal used for a calibration process (Step S**21**). The impulse generator **210** outputs the generated impulse signal from the switch **206** to the calibration transmission/reception unit **207**.

[0180] The reception unit of the calibration transmission/reception unit **207** receives an impulse signal from the impulse generator **210** and outputs an output signal to the transmission/reception baseband-processing device **202**.

[0181] The FFT analysis unit **2027** receives the output signal from the reception unit of the calibration transmission/reception unit **207** through the calibration transmission/reception unit **2023**.

[0182] The FFT analysis unit **2027** calculates a frequency spectrum including amplitude-phase information of the signal received from the reception unit of the calibration transmission/reception unit **207**. The FFT analysis unit **2027** identifies a second amplitude-phase characteristic CAL_RX by subtracting the calculated frequency spectrum from the frequency spectrum of the impulse signal, which has been stored, generated by the impulse generator **210** (Step S**22**).

[0183] The calibration network **205** receives the BF signal (n) before correction from the baseband circuit unit **10** (Step S**23**).

[0184] When the BF signal (n) before correction is received from the baseband circuit unit **10**, the calibration network **205** identifies a latest first amplitude-phase characteristic DL_CAL_Weight(n) (Step S**24**).

[0185] The calibration network **205** substitutes the BF signal (n) before correction received from the baseband circuit unit **10** into the BF signal (n) before correction in Equation (1). The calibration network **205** substitutes the latest first amplitude-phase characteristic DL_CAL_Weight (n) into the first amplitude-phase characteristic DL_CAL_Weight(n) in Equation (1) and substitutes the second amplitude-phase characteristic CAL_RX identified by the FFT analysis unit **2027** into the second amplitude-phase characteristic CAL_RX in Equation (1). In this way, the calibration network **205** identifies a BF signal (n) after correction (Step S**25**). The calibration network **205** outputs the identified BF signal (n) after correction to a corresponding transmission/reception front end-processing unit **203**.

[0186] The process described above is performed at every time interval at which an aging change in the characteristic of the communicator **20** and a temperature change of the communicator **20** can be regarded as being sufficiently small.

[0187] The process of calibration of the communication system **1** according to the third embodiment of the present invention has been described above.

[0188] The communication system **1** according to the third embodiment of the present invention has been described above.

[0189] In the communicator **20** included in the communication system **1** according to the third embodiment of the present invention, the transmission/reception baseband-processing device **202** includes the calibration transmission/reception unit **2023**, the calibration-processing unit **2025**, and the FFT analysis unit **2027**.

[0190] The calibration transmission/reception unit **2023** receives a first signal according to the characteristics of the transmission unit of the transmission/reception front end-processing unit **203** and the reception unit of the calibration transmission/reception unit **207** and a second signal according to the characteristics of the reception unit of the calibration transmission/reception unit **207**. The calibration-processing unit **2025** corrects an input signal input to the transmission unit of the transmission/reception front end-processing unit **203** on the basis of the first signal and the second signal. The FFT analysis unit **2027** calculates a difference between the frequency spectrum acquired by performing a Fourier transform for the second signal received by the calibration transmission/reception unit **2023** and the impulse signal stored in advance.

[0191] Then, the calibration-processing unit **2025** corrects an input signal input to the transmission unit of the transmission/reception front end-processing unit **203** on the basis of the first signal and the result of the Fourier transform.

[0192] By employing this configuration, the transmission/reception baseband-processing device **202**, similar to the communication system **1** according to the second embodiment of the present invention, can perform calibration including an aging change in the characteristic of the communicator **20**. By sequentially performing calibration periodically, a difference in the amplitude-phase variation between the transmission/reception front end-processing units **203** can be eliminated.

[0193] In addition, by employing this configuration, "second amplitude-phase characteristic CAL_RX=amplitude-phase characteristic CAL_RX" in Equation (2), and accordingly, a beamforming signal is radiated from the antennas with a predetermined transmission output level absolute value. For this reason, the allowed range of the transmission output absolute level is obeyed, the stable transmission output absolute level is realized, and a DL area coverage (a service region of a link from the center of a network such as a base station or a server to users present in the vicinity thereof) can be maintained to be constant.

[0194] As a result, in the communication system **1** according to the third embodiment of the present invention, the amplitudes and the phases of the transmission/reception front end-processing units **203** can be configured to be the same, and the transmission output absolute level can be maintained to be constant.

[0195] The transmission/reception baseband-processing device **202** having a minimal configuration according to an embodiment of the present invention will be described.

[0196] The transmission/reception baseband-processing device **202** having the minimal configuration according to an embodiment of the present invention, as illustrated in FIG. **12**, includes a calibration transmission/reception unit **2023** and a calibration-processing unit **2025**.

[0197] The calibration transmission/reception unit **2023** receives a first signal according to the characteristics of the transmission unit of the transmission/reception front end-processing unit and the reception unit of the calibration transmission/reception unit and a second signal according to the characteristic of the reception unit described above.

[0198] The calibration-processing unit **2025** corrects an input signal input to the transmission unit described above on the basis of the first signal described above and the second signal described above.

[0199] By configuring the transmission/reception baseband-processing device **202** in this way, the transmitters can be correctly calibrated. As a result, the transmission/reception baseband-processing device **202** can configure the amplitudes and the phases of the transmission/reception front end-processing units of the transmitter to be the same and maintain the transmission output absolute level to be constant.

[0200] In addition, regarding processes according to an embodiment of the present invention, the order of the processes may be changed in a range in which appropriate processes can be performed.

[0201] Each of the storage unit **2022** and other storage devices according to an embodiment of the present invention may be provided at any position in a range in which information can be appropriately transmitted and received. In addition, a plurality of storage units **2022** or a plurality of other storage devices may be present, and data may be stored therein in a distributed manner in a range in which information can be appropriately transmitted and received.

[0202] While the embodiments of the present invention have been described, each of the transmission/reception baseband-processing device **202** described above and the other control devices may include a computer system on the inside thereof. The procedure of the process described above is stored in a computer-readable recording medium in the form of a program, and the process described above is performed by a computer reading and executing the program. A specific example of the computer is illustrated below.

[0203] FIG. **13** is a schematic block diagram illustrating the configuration of a computer according to at least one embodiment.

[0204] The computer **5**, as illustrated in FIG. **13**, includes a CPU **6**, a main memory **7**, a storage **8**, and an interface **9**.

[0205] For example, each of the transmission/reception baseband-processing device **202** described above and other control devices is mounted in the computer **5**. An operation of each processing unit described above is stored in the storage **8** in the form of a program. The CPU **6** reads the program from the storage **8**, expands the program in the main memory **7**, and executes the process described above in accordance with the program. In addition, the CPU **6** secures a storage area corresponding to each storage unit described above in the main memory **7** in accordance with the program.

[0206] Examples of the storage **8** include a hard disk drive (HDD), a solid-state drive (SSD), a magnetic disk, a magneto-optical disk, a compact disc read-only memory (CD-ROM), a digital versatile disc read-only memory (DVD-ROM), a semiconductor memory, and the like. The storage **8** may be an internal medium directly connected to a bus of the computer **5** or an external medium connected to the computer **5** through the interface **9** or a communication line. In addition, in a case in which the program is transmitted to the computer **5** using a communication line, the computer **5** that has received the program may expand the program into the main memory **7** and execute the process described above. The storage **8** is a non-transitory type storage medium in at least one embodiment.

[0207] In addition, the program described above may realize a part of the function described above. Furthermore, the program described above may be a file that can realize the function described above in combination with another program stored in the computer system in advance, in other words, a so-called differential file (differential program).

[0208] While preferred embodiments of the invention have been described and illustrated above, it should be understood that these are exemplary of the invention and are not to be considered as limiting. Additions, omissions, substitutions, and other modifications can be made without departing from the spirit or scope of the present invention. Accordingly, the invention is not to be considered as being limited by the foregoing description, and is only limited by the scope of the appended claims.

What is claimed is:

1. A transmission/reception baseband-processing device, comprising:

a calibration-processing unit configured to correct an input signal input to a transmission unit on the basis of a first characteristic according to characteristics of the transmission unit of a transmission/reception front end-processing unit and a calibration reception unit that is a reception unit of a calibration transmission/reception unit and a second characteristic according to a characteristic of the calibration reception unit.

2. The transmission/reception baseband-processing device according to claim **1**, wherein the calibration-processing unit corrects the second characteristic using a correction value determined in advance on the basis of a result of measurement of a temperature of a communicator.

3. The transmission/reception baseband-processing device according to claim **1**, further comprising:

a calibration signal-generating unit configured to generate the input signal; and

a calibration transmission/reception unit configured to output the input signal generated by the calibration signal-generating unit from the transmission unit of the calibration transmission/reception unit to the calibration reception unit,

wherein the calibration-processing unit acquires the second characteristic according to the characteristic of the calibration reception unit by subtracting the input signal from a signal that has reached the calibration reception unit and corrects the input signal input to the transmission unit on the basis of the first characteristic and the second characteristic.

4. The transmission/reception baseband-processing device according to claim **1**, further comprising:

a calibration transmission/reception unit configured to input an impulse to the calibration reception unit; and

an FFT analysis unit configured to have a function of a Fourier transform acquiring the second characteristic according to the characteristic of the calibration reception unit by subtracting a frequency spectrum of the impulse at an output of the calibration reception unit from a frequency spectrum of the input impulse stored in advance,

wherein the calibration-processing unit corrects the input signal input to the transmission unit on the basis of the first characteristic and the second characteristic acquired as a result of the Fourier transform.

5. A communication system, comprising:

the transmission/reception baseband-processing device including a calibration-processing unit configured to correct an input signal input to a transmission unit on the basis of a first characteristic according to characteristics of the transmission unit of a transmission/reception front end-processing unit and a calibration reception unit that is a reception unit of a calibration transmission/reception unit and a second characteristic according to a characteristic of the calibration reception unit; and

a baseband circuit unit configured to output a beamforming signal to the transmission/reception baseband-processing device.

6. A correction method, comprising:

correcting an input signal input to a transmission unit on the basis of a first characteristic according to characteristics of the transmission unit of a transmission/reception front end-processing unit and a calibration reception unit that is a reception unit of a calibration transmission/reception unit and a second characteristic according to a characteristic of the calibration reception unit.

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