

DESCRIPTION

MATCHING CIRCUIT AND WIRELESS COMMUNICATION APPARATUS

Field

[0001] The present invention relates to a matching
5 circuit used in a wireless communication apparatus and the
wireless communication apparatus.

Background

[0002] An RFID (RADIO FREQUENCY IDENTIFICATION) is one
of wireless communication systems that exchange information
10 by transmitting and receiving a signal in a wireless manner.
The RFID system includes an RF tag which is an information
medium in which the information is stored, an RFID writer
which is a transmission device that transmits a wireless
signal to the RF tag to write the information into the RF
15 tag, and an RFID reader which is a reception device that
receives the wireless signal from the RF tag to read the
information stored in the RF tag. Since the RFID system
performs the exchange of the information using the wireless
signal, it is possible to read and write the information of
20 the RF tag in a non-contact manner.

[0003] Here, the RFID writer serving as the transmission
device includes a transmitting circuit that generates a
signal to be transmitted and an antenna that transmits the
signal generated in the transmitting circuit in a wireless
25 manner. This transmitting circuit has an output impedance
which is an impedance component at the time of outputting a
signal. In addition, the antenna has an input impedance
which is an impedance component when a signal is input from
the transmitting circuit. When there is a mismatch between
30 the input impedance and the output impedance, a part of the
signal (electrical signal) from the transmitting circuit is
reflected from the antenna to the transmitting circuit and

power to be transmitted from the antenna decreases, in some cases.

[0004] In regard to this, Patent Literature 1 discloses a technique of providing an antenna automatic matching circuit in a transmission device to resolve a mismatch between an input impedance and an output impedance. In addition, the antenna automatic matching circuit disclosed in Patent Literature 1 decreases the mismatch between the input impedance and the output impedance by adjusting an impedance of a diode based on a comparison value between a voltage of a signal from a radio (transmitting circuit) and a voltage of a signal from an antenna.

Citation List

Patent Literature

15 [0005] Patent Literature 1: Japanese Laid-open Patent Publication No. 11-251928

Summary

Technical Problem

[0006] Here, the antenna automatic matching circuit according to Patent Literature 1 performs a matching process based on the comparison of the voltage values of the signals from the radio and the antenna, and thus, is incapable of performing the matching on consideration of a phase difference between the input impedance and the output impedance. Accordingly, the mismatch between the input impedance and the output impedance remains, and there is a possibility that it is difficult to suitably suppress the mismatch since it is difficult to perform the matching on consideration of the phase difference between the input impedance and the output impedance with the antenna automatic matching circuit according to Patent Literature 1.

[0007] Here, in order to solve the above-described problem, an object of the present invention is to provide a

matching circuit and a wireless communication apparatus that suitably suppresses a mismatch between an input impedance of an antenna and an output impedance of a transmitting circuit.

5 Solution to Problem

[0008] To solve the above problem, a matching circuit of the present invention comprises a mismatch detection unit that is electrically connected to a transmitting circuit which is configured to generate a transmission signal and
10 an antenna which is configured to wirelessly transmit the transmission signal; a computation section that is electrically connected to the mismatch detection unit; and a matching section that is electrically connected to the computation section and the transmitting circuit, wherein
15 the mismatch detection unit includes a first directional coupling section that is configured to generate a corresponding transmission signal which is a signal corresponding to the transmission signal from the transmitting circuit, a second directional coupling section
20 that is configured to generate a corresponding reflection signal which is a signal corresponding to a reflection signal as an electrical signal to be reflected from the antenna to the transmitting circuit in response to the transmission signal, and a mismatch detection section that
25 is configured to detect an amplitude ratio and a phase difference between the transmission signal and the reflection signal based on the corresponding transmission signal and the corresponding reflection signal, the computation section is configured to transmit a matching
30 section control signal to the matching section based on the amplitude ratio and the phase difference between the transmission signal and the reflection signal detected by the mismatch detection unit, and the matching section is

configured to change a signal value of the reflection signal by changing an impedance based on the matching section control signal.

[0009] According to the matching circuit, it is possible
5 to perform a mismatch suppression process also considering the phase difference, and thus, it is possible to suitably suppress the mismatch between the output impedance of the transmitting circuit and the input impedance of the antenna.

[0010] In the matching circuit, the computation section
10 is configured to generate the matching section control signal based on a reflection coefficient which is calculated based on the amplitude ratio and the phase difference between the transmission signal and the reflection signal and represents a ratio between signal
15 values of the transmission signal and the reflection signal. According to the matching circuit, the matching process is performed using the reflection coefficient, and thus, it is possible to more suitably perform the matching process.

[0011] In the matching circuit, the matching section
20 includes a variable inductance section capable of changing an inductance and a variable capacitance section capable of changing a capacitance, and changes the impedance by changing the inductance of the variable inductance section and the capacitance of the variable capacitance section.
25 According to the matching circuit, the inductance and the capacitance are changed, and thus, it is possible to suitably perform the matching also based on the phase difference.

[0012] In the matching circuit, the variable inductance
30 section is electrically connected between the transmitting circuit and the antenna, the variable capacitance section is provided in plural including a first variable capacitance section and a second variable capacitance

section, the first variable capacitance section has one connection portion that is electrically connected between the variable inductance section and the transmission circuit and another connection portion that is grounded, and the second variable capacitance section has one connection portion that is electrically connected between the variable inductance section and the antenna and another connection portion that is grounded. According to the matching circuit, a Π -type circuit is configured, and thus, it is possible to preferably change the inductance and the capacitance.

[0013] In the matching circuit, the variable capacitance section successively changes the capacitance depending on a voltage to be applied thereto. According to the matching circuit, it is possible to change the capacitance in an analog manner, and thus, it is possible to perform finer matching.

[0014] In the matching circuit, the matching section includes a plurality of the first variable capacitance sections connected in parallel, a plurality of the second variable capacitance sections connected in parallel, and a capacitance switch section that is configured to switch each connection among the plurality of first variable capacitance sections and the plurality of second variable capacitance sections, and the computation section controls the capacitance switch section to cause the plurality of first variable capacitance sections and the plurality of second variable capacitance sections to be grounded and change a total capacitance of the plurality of first variable capacitance sections and the plurality of second variable capacitance sections. According to the matching circuit, it is possible to change the total capacitance by

switching the switch, and thus, it is possible to suitably perform the matching also based on the phase difference.

[0015] In the matching circuit, the matching section includes a plurality of the variable inductance sections and an inductance switch section that is configured to switch each connection between the plurality of variable inductance sections and the transmitting circuit, and the antenna, and causes the inductance switch section to switch the connection to change a total inductance of the plurality of variable inductance sections. According to the matching circuit, it is possible to change the total inductance using the switch, and thus, it is possible to suitably perform the matching also based on the phase difference.

[0016] In the matching circuit, the mismatch detection unit includes: a local oscillator that is configured to transmit a local oscillation signal having a predetermined frequency; a first mixing section that is electrically connected to the first directional coupling section and the local oscillator and is configured to generate a mixed transmission signal by mixing signal values of the local oscillation signal and the corresponding transmission signal; a second mixing section that is electrically connected to the second directional coupling section and the local oscillator and is configured to generate a mixed reflection signal by mixing signal values of the local oscillation signal and the corresponding reflection signal; and an amplitude and phase detection section that is configured to detect the amplitude ratio and the phase difference between the transmission signal and the reflection signal by comparing the mixed transmission signal and the mixed reflection signal. According to the matching circuit, the amplitude ratio and the phase

difference are detected using a heterodyne system, and thus, it is possible to detect the amplitude ratio and the phase difference at high accuracy without being affected by, for example, a DC offset, or the like.

5 [0017] In the matching circuit, the mismatch detection unit includes: a first mixing section that is electrically connected to the first directional coupling section and the second directional coupling section and is configured to generate a forward mixed signal by mixing signal values of
10 the corresponding transmission signal and the corresponding reflection signal; an amplitude detection section that is configured to detect amplitude of the corresponding transmission signal and amplitude of the corresponding reflection signal; a second mixing section that is
15 electrically connected to the first directional coupling section and the second directional coupling section and is configured to generate a phase-shifted mixed signal by shifting any one phase of the corresponding transmission signal and the corresponding reflection signal and mixing
20 the corresponding transmission signal and the corresponding reflection signal; and an amplitude and phase detection section that is configured to detect an amplitude ratio between the transmission signal and the reflection signal based on the amplitude of the corresponding transmission
25 signal and the amplitude of the corresponding reflection signal and is configured to detect phase difference between the transmission signal and the reflection signal by comparing the forward mixed signal and the phase-shifted mixed signal. According to the matching circuit, the
30 amplitude ratio and the phase difference are detected using a homodyne system, and thus, it is possible to detect the amplitude ratio and the phase difference at high accuracy with a simple configuration.

[0018] In the matching circuit, when amplitude of the reflection signal is equal to or larger than a predetermined threshold, the changing of the impedance performed by the matching section is stopped. According to the matching circuit, it is suppressed to perform the matching process by a signal reflected from, for example, a surrounding material, and thus, it is possible to suitably suppress the mismatch between the input impedance of the antenna and the output impedance of the transmitting circuit.

[0019] The matching circuit is electrically connected to a receiving circuit to which a reception signal received by the antenna is input and the reflection signal from the antenna is reflected. According to the matching circuit, it is possible to suitably suppress the mismatch between the output impedance of the transmitting circuit and the input impedance of the antenna.

[0020] In the matching circuit, the matching section is provided between the transmitting circuit and the antenna, and the mismatch detection unit is provided between the matching section and the antenna and is connected to the transmitting circuit via the matching section. According to the matching circuit, it is possible to stabilize the transmission signal after the matching process.

[0021] In the matching circuit, the matching section is provided between the transmitting circuit and the antenna, and the mismatch detection unit is provided between the transmitting circuit and the matching section and is connected to the antenna via the matching section. According to the matching circuit, it is possible to suppress too much increase of the reflection signal depending on the matching.

[0022] In the matching circuit, the matching section is provided between the transmitting circuit and the antenna, the mismatch detection unit is provided in plural including a first mismatch detection unit and a second mismatch
5 detection unit, the first mismatch detection unit is provided between the matching section and the antenna and is connected to the transmitting circuit via the matching section, and the second mismatch detection unit is provided between the transmitting circuit and the matching section
10 and is connected to the antenna via the matching section. According to the matching circuit, it is possible to suppress too much increase of the reflection signal depending on the matching while stabilizing the transmission signal.

15 [0023] A wireless communication apparatus of this invention comprises the matching circuit; a transmitting circuit that is electrically connected to the matching circuit and generates the transmission signal; and an antenna that is electrically connected to the matching
20 circuit and wirelessly transmits the transmission signal. According to the wireless communication apparatus, it is possible to suitably suppress the mismatch between the output impedance of the transmitting circuit and the input impedance of the antenna.

25 Advantageous Effects of Invention

[0024] According to the present invention, it is possible to suitably suppress the mismatch between the input impedance of the antenna and the output impedance of the transmitting circuit.

30 Brief Description of Drawings

[0025] FIG. 1 is a block diagram illustrating a configuration of a wireless communication apparatus according to a first embodiment.

FIG. 2 is a block diagram illustrating a configuration of a mismatch detection section.

FIG. 3 is a schematic view illustrating a configuration of a matching section.

5 FIG. 4 is a schematic view illustrating an example of a configuration of a variable coil according to the first embodiment.

FIG. 5 is a flowchart describing a process of suppressing a mismatch performed by a matching circuit
10 according to the first embodiment.

FIG. 6 is a graph illustrating voltage waveforms of a transmission signal and a reflection signal.

FIG. 7 is a graph illustrating an example of a change of a reflection coefficient on a Smith chart according to
15 adjustment of an impedance value of the matching section.

FIG. 8 is a graph illustrating an example of the change of the reflection coefficient on the Smith chart according to adjustment of the impedance value of the matching section.

20 FIG. 9 is a graph illustrating an example of the change of the reflection coefficient on the Smith chart according to adjustment of the impedance value of the matching section.

FIG. 10 is a block diagram illustrating a
25 configuration when the wireless communication apparatus according to the first embodiment includes a receiving circuit.

FIG. 11 is a block diagram illustrating a
30 configuration of a matching section according to a second embodiment.

FIG. 12 is a block diagram illustrating a configuration of a matching section according to a third embodiment.

FIG. 13 is a block diagram illustrating a configuration of a mismatch detection section according to a fourth embodiment.

FIG. 14 is a flowchart describing a process of detecting an amplitude ratio and a phase difference performed by the mismatch detection section according to the fourth embodiment.

FIG. 15 is a graph illustrating voltage waveforms of a transmission signal and a reflection signal.

FIG. 16 is a block diagram illustrating a configuration of a wireless communication apparatus according to a fifth embodiment.

FIG. 17 is a flowchart describing a process of determining whether to perform a matching process.

FIG. 18 is a block diagram illustrating a configuration of a wireless communication apparatus according to a sixth embodiment.

FIG. 19 is a block diagram illustrating a configuration of a wireless communication apparatus according to a seventh embodiment.

Description of Embodiments

[0026] Hereinafter, preferred embodiments of the present invention will be described in detail with reference to the drawings. Incidentally, the present invention is not limited by the embodiments, and further, encompasses any configuration obtained by combining the respective embodiments when there are a plurality of embodiments.

[0027] (First Embodiment)

FIG. 1 is a block diagram illustrating a configuration of a wireless communication apparatus according to a first embodiment. As illustrated in FIG. 1, a wireless communication apparatus 1 includes a transmitting circuit 2, an antenna 4, and a matching circuit 10. The wireless

communication apparatus 1 is an apparatus for wireless communication that generates a wireless signal using the transmitting circuit 2 and transmits the generated wireless signal using the antenna 4. The wireless communication apparatus 1 is used in an RFID (Radio Frequency Identification) system. The wireless communication apparatus 1 is an RFID writer that transmits the wireless signal to an RF tag 100 serving as an information medium in which information is stored to cause the information to be written into the RF tag 100. However, the wireless communication apparatus 1 is not limited to the RFID writer, and may be a device that is capable of transmitting the wireless signal.

[0028] The transmitting circuit 2 is, for example, a circuit that generates a transmission signal A which is an electrical signal having the information to be written into the RF tag 100. The antenna 4 is electrically connected to the transmitting circuit 2 and wirelessly transmits the transmission signal A generated by the transmitting circuit 2 to the RF tag 100, for example.

[0029] The matching circuit 10 is electrically connected to the transmitting circuit 2 and the antenna 4 and is provided between the transmitting circuit 2 and the antenna 4. The matching circuit 10 includes a mismatch detection unit 20, a computation section 28, and a matching section 30. Here, the transmitting circuit 2 has an output impedance, which is an impedance at the time of outputting a signal, and the antenna 4 has an input impedance which is an impedance when the signal is input from the transmitting circuit. When there is a mismatch between the input impedance and the output impedance, a part of the transmission signal A from the transmitting circuit 2 is reflected from the antenna 4 to the transmitting circuit 2

as a reflection signal B. When a signal value of the reflection signal B is large, the power to be wirelessly transmitted from the antenna 4 is likely to decrease. The matching circuit 10 detects the mismatch between the input impedance and the output impedance using the mismatch detection unit 20 and adjusts the mismatch using the computation section 28 and the matching section 30 to reduce the signal value of the reflection signal B.

[0030] As illustrated in FIG. 1, the matching section 30 is provided between the transmitting circuit 2 and the antenna 4 and is electrically connected to the transmitting circuit 2 and the antenna 4. In addition, the mismatch detection unit 20 is provided between the matching section 30 and the antenna 4. The mismatch detection unit 20 is electrically connected to the transmitting circuit 2 via the matching section 30. In addition, the mismatch detection unit 20 is electrically connected to the antenna 4. The computation section 28 is electrically connected to the mismatch detection unit 20 and the matching section 30.

[0031] The mismatch detection unit 20 includes a first directional coupling section 22, a second directional coupling section 24, and a mismatch detection section 26. The first directional coupling section 22 is electrically connected to the matching section 30. The second directional coupling section 24 is electrically connected to the antenna 4. The first directional coupling section 22 and the second directional coupling section 24 are electrically connected to each other. The transmitting circuit 2 is electrically connected to the antenna 4 via the matching section 30, the first directional coupling section 22, and the second directional coupling section 24 in this order. Accordingly, the transmission signal A generated by the transmitting circuit 2 is output to the

antenna 4 via the matching section 30, the first directional coupling section 22, and the second directional coupling section 24. In addition, the reflection signal B reflected by the antenna 4 is reflected to the transmitting circuit 2 via the second directional coupling section 24, the first directional coupling section 22, and the matching section 30.

[0032] In addition, the first directional coupling section 22 and the second directional coupling section 24 are electrically connected to the mismatch detection section 26. The first directional coupling section 22 and the second directional coupling section 24 are directional couplers. The first directional coupling section 22 outputs a corresponding transmission signal A1, which is an electrical signal corresponding to a signal (herein, the transmission signal A) to be transmitted to the antenna 4 from the transmitting circuit 2, to the mismatch detection section 26. In addition, the second directional coupling section 24 outputs a corresponding reflection signal B1, which is an electrical signal corresponding to a signal (herein, the reflection signal B) to be transmitted to the transmitting circuit 2 from the antenna 4, to the mismatch detection section 26. In the first embodiment, the corresponding transmission signal A1 is a voltage signal having amplitude, a phase, and a frequency which are the same as those of the transmission signal A. In addition, similarly, the corresponding reflection signal B1 is a voltage signal having amplitude, a phase, and a frequency which are the same as those of the reflection signal B. Meanwhile, each of the corresponding transmission signal A1 and the corresponding reflection signal B1 is not necessarily the voltage signal having the same amplitude, phase, and frequency as long as being a voltage signal

which has amplitude, a phase, and a frequency corresponding to those of each of the transmission signal A and the reflection signal B.

[0033] The mismatch detection section 26 is electrically connected to the computation section 28. FIG. 2 is a block diagram illustrating a configuration of the mismatch detection section. As illustrated in FIG. 2, the mismatch detection section 26 includes a local oscillator 42, a first mixing section 44, a second mixing section 45, a filter section 46, an AD conversion section 48, and an amplitude and phase detection section 49. The mismatch detection section 26 detects an amplitude ratio and a phase difference between the transmission signal A and the reflection signal B based on the corresponding transmission signal A1 and the corresponding reflection signal B1.

[0034] The local oscillator 42 is an oscillator that transmits a local electrical signal S having a predetermined frequency. As illustrated in FIG. 2, the local oscillator 42 is electrically connected to the first mixing section 44 and the second mixing section 45 and outputs the local electrical signal S to the first mixing section 44 and the second mixing section 45. Here, the reflection signal B is a reflected wave of the transmission signal A, and thus, each frequency of the transmission signal A and the reflection signal B is the same. The local electrical signal S of the local oscillator 42 has a frequency which is slightly different from the frequency of the transmission signal A and the reflection signal B. For example, the frequency of the local electrical signal S is different from the frequency of the transmission signal A and the reflection signal B by 10 MHz, but is not limited thereto.

[0035] The first mixing section 44 is electrically connected to the first directional coupling section 22. The corresponding transmission signal A1 is input from the first directional coupling section 22 to the first mixing section 44, and the local electrical signal S is input from the local oscillator 42 thereto. The first mixing section 44 is a frequency mixer and generates a mixed transmission signal A2 which is an electrical signal in which the corresponding transmission signal A1 and the local electrical signal S are mixed. To be more specific, when the frequency of the corresponding transmission signal A1 is denoted by f_A and the frequency of the local electrical signal S is denoted by f_S , the mixed transmission signal A2 is an electrical signal which has a waveform in which a waveform having a frequency of $f_A + f_S$ and a waveform having a frequency of $f_A - f_S$ overlap each other.

[0036] The second mixing section 45 is electrically connected to the second directional coupling section 24. The corresponding reflection signal B1 is input from the second directional coupling section 24 to the second mixing section 45, and the local electrical signal S is input from the local oscillator 42 thereto. The second mixing section 45 is a frequency mixer and generates a mixed reflection signal B2 which is an electrical signal in which the corresponding reflection signal B1 and the local electrical signal S are mixed. To be more specific, when the frequency of the corresponding reflection signal B1 is denoted by f_A (the same frequency as that of the corresponding transmission signal) and the frequency of the local electrical signal S is denoted by f_S , the mixed reflection signal B2 is an electrical signal which has a waveform in which the waveform having the frequency of $f_A +$

f_S and the waveform having the frequency of $f_A - f_S$ overlap each other.

[0037] The filter section 46 is electrically connected to the first mixing section 44 and the second mixing section 45. The mixed transmission signal A2 is input from the first mixing section 44 to the filter section 46, and the mixed reflection signal B2 is input from the second mixing section 45 thereto. The filter section 46 is a band-pass filter and removes a signal having a predetermined frequency from the mixed transmission signal A2 and the mixed reflection signal B2. To be more specific, the filter section 46 removes the waveform having the frequency of $f_A + f_S$ and passes only the waveform having the frequency of $f_A - f_S$ in the first embodiment. Accordingly, the filter section 46 generates a comparison transmission signal A3 having the frequency of $f_A - f_S$ from the mixed transmission signal A2. In addition, the filter section 46 generates a comparison reflection signal B3 having the frequency of $f_A - f_S$ from the mixed reflection signal B2. Incidentally, the filter section 46 may be configured to remove the waveform having the frequency of $f_A - f_S$ and generate a signal having the frequency of $f_A + f_S$. In addition, the single filter section 46 is provided in the first embodiment, but two filter sections may be provided so as to correspond to the first mixing section 44 and the second mixing section 45, respectively.

[0038] The AD conversion section 48 is electrically connected to the filter section 46. The comparison transmission signal A3 and the comparison reflection signal B3 are input to the AD conversion section 48. The AD conversion section 48 is a converter which converts an analog signal into a digital signal. The AD conversion section 48 converts the comparison transmission signal A3,

which is an analog signal, into a digital signal to generate a digital comparison transmission signal A4. In addition, the AD conversion section 48 converts the comparison reflection signal B3, which is an analog signal,
5 into a digital signal to generate a digital comparison reflection signal B4. In addition, the single AD conversion section 48 is provided in the first embodiment, but two AD conversion sections may be provided so as to correspond to the first mixing section 44 and the second
10 mixing section 45, respectively.

[0039] The amplitude and phase detection section 49 is electrically connected to the AD conversion section 48 and the computation section 28. The digital comparison transmission signal A4 and the digital comparison
15 reflection signal B4 are input to the amplitude and phase detection section 49. The amplitude and phase detection section 49 compares a signal value of the digital comparison transmission signal A4 and a signal value of the digital comparison reflection signal B4 and detects the
20 amplitude ratio and the phase difference between the voltage values of the transmission signal A and the reflection signal B. Further, the amplitude and phase detection section 49 outputs an amplitude and phase information signal C, which is an electrical signal having
25 information about the amplitude ratio and the phase difference between the transmission signal A and the reflection signal B, to the computation section 28.

[0040] Incidentally, the digital comparison transmission signal A4 is a voltage signal having amplitude and a phase
30 which are the same or proportional to those of the transmission signal A, and the digital comparison reflection signal B4 is a voltage signal having amplitude and a phase which are the same as those of the reflection

signal B. Accordingly, the amplitude and phase detection section 49 can detect the amplitude ratio and the phase difference between the transmission signal A and the reflection signal B by comparing the signal value of the digital comparison transmission signal A4 and the signal value of the digital comparison reflection signal B4.

Details of the process of detecting the amplitude ratio and the phase difference between the transmission signal A and the reflection signal B performed by the amplitude and phase detection section 49 will be described later.

[0041] As described above, the mismatch detection section 26 is configured using a heterodyne system.

[0042] The amplitude and phase information signal C having the information about the amplitude ratio and the phase difference between the transmission signal A and the reflection signal B is input to the computation section 28. The computation section 28 generates a matching section control signal D for control of the matching section 30 based on the amplitude and phase information signal C. To be more specific, the computation section 28 controls the matching section 30 such that the signal value of the reflection signal B is reduced. Details of this process performed by the computation section 28 will be described later.

[0043] FIG. 3 is a schematic view illustrating a configuration of the matching section 30. As illustrated in FIG. 3, the matching section 30 includes a variable coil 32 serving as a variable inductance section, a variable capacitor 34 serving as first variable capacitance section, and a variable capacitor 36 serving as a second variable capacitance section. The matching section 30 changes the impedance by changing an inductance of the variable coil 32 and capacitances of the variable capacitors 34 and 36

according to the matching section control signal D. As described above, the reflection signal B is generated by the mismatch between the output impedance of the transmitting circuit 2 and the input impedance of the antenna 4. The input impedance of the antenna 4 is changed depending on the change of the impedance of the matching section 30 provided between the transmitting circuit 2 and the antenna 4. Thus, if the impedance of the matching section 30 changes, the ratio between the output impedance of the transmitting circuit 2 and the input impedance of the antenna 4 changes, and the signal value of the reflection signal B also changes. In the first embodiment, the matching section 30 reduces the signal value of the reflection signal B by changing its own impedance based on the matching section control signal D.

[0044] The matching section control signal D includes an inductance control signal D1 which is a signal to change the inductance of the variable coil 32, a capacitance control signal D2 which is a signal to change the capacitance of the variable capacitor 34, and a capacitance control signal D3 which is a signal to change the capacitance of the variable capacitor 36. Although the details will be described later, the matching section 30 changes the signal value of the reflection signal B by changing its own impedance according to the inductance control signal D1, and the capacitance control signals D2 and D3.

[0045] As illustrated in FIG. 3, the variable coil 32 is electrically connected to the transmitting circuit 2 and the first directional coupling section 22 and is connected in series between the transmitting circuit 2 and the first directional coupling section 22. In other words, the variable coil 32 is connected in series between the

transmitting circuit 2 and the antenna 4. The variable coil 32 changes its own inductance according to the inductance control signal D1. FIG. 4 is a schematic view illustrating an example of a configuration of the variable coil according to the first embodiment. As illustrated in FIG. 4, the variable coil 32 includes a coil section 32A and a switch section 32B. One end of the coil section 32A is connected to the transmitting circuit 2. In addition, the coil section 32A is provided with contact points 32A1, 32A2, 32A3 and 32A4 at each portion for connection with the switch section 32B. The contact points 32A1, 32A2, 32A3 and 32A4 are provided at different positions in the longitudinal direction of the coil section 32A. Hereinafter, the contact points 32A1, 32A2, 32A3 and 32A4 will be described appropriately as a contact point 32A0 when not being distinguished from each other.

[0046] The switch section 32B is a switching switch that switches the connection between the first directional coupling section 22 and the contact point 32A0. To be more specific, the switch section 32B is connected to any of the contact points 32A1, 32A2, 32A3 and 32A4 of the coil section 32A according to a voltage value of the inductance control signal D1 from the computation section 28, thereby electrically connecting the coil section 32A and the first directional coupling section 22 to each other. Since the respective contact points 32A0 of the coil section 32A are provided at the positions different from each other in the longitudinal direction of the coil section 32A, the inductance of the coil section 32A is changed by changing the contact point 32A0 to which the switch section 32B is connected. In this manner, the variable coil 32 changes its own inductance by changing the contact point 32A0 of the coil section 32A to be connected to the switch section

32B, but the method of changing inductance using the variable coil 32 is not limited thereto. The variable coil 32 may employ an arbitrary method and structure of changing the inductance as long as the method and structure change its own inductance according to the inductance control signal D1. For example, the variable coil 32 may be configured to change the inductance by providing a core at an inner circumference of the coil section 32A and moving the core in the longitudinal direction of the coil section 32A according to the inductance control signal D1.

[0047] As illustrated in FIG. 3, the variable capacitor 34 is electrically connected to the transmitting circuit 2, the variable coil 32, and the computation section 28. To be more specific, the variable capacitor 34 has one connection portion 34A that is electrically connected between the transmitting circuit 2 and the variable coil 32. In addition, the variable capacitor 34 has another connection portion 34B that is grounded. Further, the variable capacitor 34 is electrically connected to the computation section 28 at the other connection portion 34B. The variable capacitor 34 changes its own capacitance according to the capacitance control signal D2. In the first embodiment, the variable capacitor 34 successively changes the capacitance according to a voltage value of the capacitance control signal D2. That is, the capacitance of the variable capacitor 34 does not change taking discrete values but successively changes according to the voltage value of the capacitance control signal D2. The variable capacitor 34 is, for example, a varicap diode. The variable capacitor 34 may be a capacitor that can change its own capacitance according to the capacitance control signal D2, and is not limited to the capacitor that successively changes its own capacitance, for example.

[0048] The variable capacitor 36 is electrically connected to the first directional coupling section 22, the variable coil 32, and the computation section 28. To be more specific, the variable capacitor 36 has one connection portion 36A that is electrically connected between the variable coil 32 and the first directional coupling section 22. In other words, the one connection portion 36A of the variable capacitor 36 is electrically connected between the variable coil 32 and the antenna 4. In addition, the variable capacitor 36 has another connection portion 36B that is grounded. Further, the variable capacitor 36 is electrically connected to the computation section 28 at the other connection portion 36B. The variable capacitor 36 changes its own capacitance according to the capacitance control signal D3. In the first embodiment, the variable capacitor 36 has the same structure as the variable capacitor 34.

[0049] In this manner, the matching section 30 changes the impedance by changing the inductance of the variable coil 32 and the capacitances of the variable capacitors 34 and 36 according to the matching section control signal D. However, the matching section 30 is not limited to being configured of the variable coil 32 and the variable capacitors 34 and 36 but may have an arbitrary configuration as long as it is possible to change its own impedance according to the matching section control signal. In addition, the variable coil 32 and the variable capacitors 34 and 36 form a Π -shaped circuit, but may be arbitrarily arrayed without being limited to the array of the Π -shaped circuit. For example, the number of the variable capacitors may be one instead of two, and further, may be three or more.

[0050] Next, a process of suppressing a mismatch performed by the matching circuit 10 will be described based on a flowchart. FIG. 5 is the flowchart describing the process of suppressing the mismatch performed by the matching circuit according to the first embodiment.

[0051] As illustrated in FIG. 5, the first directional coupling section 22 generates the corresponding transmission signal A1 from the transmission signal A (step S11A) when performing a mismatch process. The transmission signal A from the transmitting circuit 2 is input to the first directional coupling section 22. The first directional coupling section 22 generates the corresponding transmission signal A1 which is the voltage signal having the same amplitude, phase and frequency as the transmission signal A so as to correspond to the transmission signal A.

[0052] In addition, the second directional coupling section 24 generates the corresponding reflection signal B1 from the reflection signal B at the same time when the corresponding transmission signal A1 is generated (step S11B). The reflection signal B from the antenna 4 is input to the second directional coupling section 24. The second directional coupling section 24 generates the corresponding reflection signal B1 which is the voltage signal having the same amplitude, phase and frequency as the reflection signal B so as to correspond to the reflection signal B. Incidentally, step S11B is performed at the same time as step S11A, but step S11B may be performed before or after step S11A.

[0053] After the corresponding transmission signal A1 is generated, the mismatch detection section 26 generates the mixed transmission signal A2 that is the electrical signal obtained by mixing the corresponding transmission signal A1 and the local electrical signal S using the first mixing

section 44 (step S12A). The mismatch detection section 26 generates the local electrical signal S using the local oscillator 42. In the mismatch detection section 26, the corresponding transmission signal A1 and the local electrical signal S are input to the first mixing section 44. The mismatch detection section 26 generates the mixed transmission signal A2 having the waveform in which the waveform having the frequency of $f_A + f_S$ and the waveform having the frequency of $f_A - f_S$ overlap each other using the first mixing section 44.

[0054] After the corresponding reflection signal B1 is generated, the mismatch detection section 26 generates the mixed reflection signal B2 which is the electrical signal obtained by mixing the corresponding reflection signal B1 and the local electrical signal S using the second mixing section 45 (step S12B). The mismatch detection section 26 generates the local electrical signal S using the local oscillator 42. In the mismatch detection section 26, the corresponding reflection signal B1 and the local electrical signal S are input to the second mixing section 45. The mismatch detection section 26 generates the mixed reflection signal B2 having the waveform in which the waveform having the frequency of $f_A + f_S$ and the waveform having the frequency of $f_A - f_S$ overlap each other using the second mixing section 45. Incidentally, step S12B is performed at the same time as step S12A, but step S12B may be performed before or after step S12A.

[0055] After the mixed transmission signal A2 and the mixed reflection signal B2 are generated, the mismatch detection section 26 generates the comparison transmission signal A3 based on the mixed transmission signal A2 and the comparison reflection signal B3 based on the mixed reflection signal B2 using the filter section 46 (step S14).

To be more specific, the mixed transmission signal A2 is input to the filter section 46 in the mismatch detection section 26. The mismatch detection section 26 causes the filter section 46 to perform filtering on the mixed
5 transmission signal A2, thereby generating the comparison transmission signal A3 having the frequency of $f_A - f_S$. In addition, the mixed reflection signal B2 is input to the filter section 46 in the mismatch detection section 26. The mismatch detection section 26 causes the filter section
10 46 to perform filtering on the mixed reflection signal B2, thereby generating the comparison reflection signal B3 having the frequency of $f_A - f_S$. The comparison transmission signal A3 has the different frequency from the transmission signal A, but the amplitude and the phase are
15 the same therebetween. Similarly, the comparison reflection signal B3 has the different frequency from the reflection signal B, but the amplitude and the phase are the same therebetween.

[0056] After the comparison transmission signal A3 and
20 the comparison reflection signal B3 are generated, the mismatch detection section 26 causes the AD conversion section 48 to perform digital conversion of the comparison transmission signal A3 and the comparison reflection signal B3, thereby generating the digital comparison transmission
25 signal A4 and the digital comparison reflection signal B4 (step S16). For the convenience of the following processing, the mismatch detection section 26 causes the AD conversion section 48 to perform the digital conversion of the comparison transmission signal A3 and the comparison
30 reflection signal B3, which are the analog signals, thereby generating the digital comparison transmission signal A4 and the digital comparison reflection signal B4 which are the digital signals.

[0057] After the digital comparison transmission signal A4 and the digital comparison reflection signal B4 are generated, the mismatch detection section 26 calculates the amplitude ratio and the phase difference between the transmission signal A and the reflection signal B using the amplitude and phase detection section 49 (step S18). FIG. 6 is a graph illustrating voltage waveforms of the transmission signal A and the reflection signal B. In FIG. 6, the horizontal axis represents time, and the vertical axis represents a voltage (V). A waveform A4W of FIG. 6 is an example of a voltage waveform of the digital comparison transmission signal A4 when voltage values of the digital comparison transmission signal A4 are plotted for each time. A waveform B4W of FIG. 6 is an example of a voltage waveform of the digital comparison reflection signal B4 when voltage values of the digital comparison reflection signal B4 are plotted for each time.

[0058] The mismatch detection section 26 generates the waveform A4W of the digital comparison transmission signal A4 and the waveform B4W of the digital comparison reflection signal B4, as illustrated in FIG. 6, using the amplitude and phase detection section 49. The mismatch detection section 26 detects a transmission signal peak value HA, which is a peak value in the voltage values of the digital comparison transmission signal A4, based on the waveform A4W using the amplitude and phase detection section 49. In addition, the mismatch detection section 26 detects a peak time TA at which the voltage value of the digital comparison transmission signal A4 becomes the transmission signal peak value HA using the amplitude and phase detection section 49. In addition, the mismatch detection section 26 detects a reflection signal peak value HB, which is a peak value in the voltage values of the

digital comparison reflection signal B4, based on the waveform B4W using the amplitude and phase detection section 49. In addition, the mismatch detection section 26 detects a peak time TB at which the voltage value of the digital comparison reflection signal B4 becomes the reflection signal peak value HB using the amplitude and phase detection section 49.

[0059] When the amplitude ratio between the transmission signal A and the reflection signal B is denoted by P_{BA} , the mismatch detection section 26 causes the amplitude and phase detection section 49 to calculate the amplitude ratio P_{BA} based on the transmission signal peak value HA and the reflection signal peak value HB using the following Formula (1). In addition, when the phase difference between the transmission signal A and the reflection signal B is denoted by θ_{BA} , the mismatch detection section 26 causes the amplitude and phase detection section 49 to calculate the phase difference θ_{BA} based on the peak times TA and TB using the following Formula (2).

[0060]
$$P_{BA} = |HB/HA| \quad (1)$$

$$\theta_{BA} = |TB - TA| \quad (2)$$

[0061] The mismatch detection section 26 generates the amplitude and phase information signal C, which is the electrical signal having the information about the calculated amplitude ratio P_{BA} between the transmission signal A and the reflection signal B and the calculated phase difference θ_{BA} between the transmission signal A and the reflection signal B using the amplitude and phase detection section 49, and outputs the generated signal to the computation section 28.

[0062] Incidentally, the mismatch detection section 26 may not create the waveforms A4W and B4W using the amplitude and phase detection section 49. It is enough

when the mismatch detection section 26 can detect the transmission signal peak value HA, the reflection signal peak value HB, and the peak times TA and TB using the amplitude and phase detection section 49. For example, the mismatch detection section 26 may be configured to detect the transmission signal peak value HA, the reflection signal peak value HB, and the peak times TA and TB by causing the amplitude and phase detection section 49 to detect the voltage values of the digital comparison transmission signal A4 and the digital comparison reflection signal B4 for each time. In addition, the phase difference θ_{BA} is not limited to being calculated using the peak times TA and TB. The phase difference θ_{BA} may be calculated by comparing time at which the digital comparison transmission signal A4 becomes a predetermined voltage value and time at which a voltage value of the digital comparison reflection signal B4 becomes a value corresponding to the predetermined voltage value of the digital comparison transmission signal A4. For example, the phase difference θ_{BA} may be calculated using a difference between time at which the voltage value of the digital comparison transmission signal A4 becomes zero and time at which the voltage value of the digital comparison reflection signal B4 becomes zero.

[0063] When the amplitude ratio P_{BA} and the phase difference θ_{BA} between the transmission signal A and the reflection signal B are calculated, the computation section 28 calculates a reflection coefficient γ between the transmission signal A and the reflection signal B based on the amplitude ratio P_{BA} and the phase difference θ_{BA} (step S20). The reflection coefficient is a value which represents a ratio of a voltage and amplitude of a wave that is reflected and returns (here, the reflection signal

B) in relation to a progressing wave (here, the transmission signal A). When the reflection coefficient between the transmission signal A and the reflection signal B is denoted by γ , the reflection coefficient γ is represented by the following Formula (3) in a case where a vector value of the transmission signal A is denoted by AV and a vector value of the reflection signal B is denoted by BV.

[0064]
$$\gamma = BV/AV \quad (3)$$

10 [0065] Here, a scalar component of BV/AV on the right side of Formula (3) corresponds to the amplitude ratio P_{BA} between the transmission signal A and the reflection signal B, and a directional component (angular component) of BV/AV corresponds to the phase difference θ_{BA} between the transmission signal A and the reflection signal B. Accordingly, the reflection coefficient γ can be calculated using the amplitude ratio P_{BA} and the phase difference θ_{BA} . To be more specific, the reflection coefficient γ can be represented as the following Formula (4) using the amplitude ratio P_{BA} , the phase difference θ_{BA} , and an imaginary number j.

[0066]
$$\gamma = P_{BA} \cdot \exp(j \cdot \theta_{BA}) \quad (4)$$

[0067] Incidentally, a value of the reflection coefficient γ and the signal value of the reflection signal B are related to each other since the reflection coefficient γ is represented as the above-described Formula (3). Accordingly, to change the value of the reflection coefficient γ has the same meaning as to change the value of the reflection signal B in a case where the signal value of the transmission signal A is not changed. Although the details will be described in the following step, the computation section 28 reduces the value of the reflection

signal B by changing the impedance of the matching section 30 to reduce the value of the reflection coefficient γ .

[0068] Incidentally, when the amplitude ratio P_{BA} and the phase difference θ_{BA} calculated in step S18 are equal to or smaller than each predetermined threshold, the process may be ended without performing the process of step S20 and a step subsequent thereto. That is, when the amplitude ratio P_{BA} and the phase difference θ_{BA} are so small that there is no need of performing the matching process, the computation section 28 does not necessarily perform the matching process.

[0069] After the reflection coefficient γ is calculated, the computation section 28 changes the impedance of the matching section 30 such that the reflection coefficient γ becomes equal to or smaller than a predetermined reflection coefficient value (step S22). To be specific, the computation section 28 changes the impedance of the matching section 30 such that the reflection coefficient γ becomes a reflection coefficient value γ_0 . In the first embodiment, the reflection coefficient value γ_0 is zero. That is, the computation section 28 changes the impedance of the matching section 30 such that the reflection coefficient γ becomes zero. When the reflection coefficient γ becomes zero, the signal value of the reflection signal B also becomes zero. Incidentally, the reflection coefficient value γ_0 is not limited to being zero, but may be a predetermined value. However, the reflection coefficient value γ_0 is preferably between 0 and 0.1.

[0070] To be more specific, the computation section 28 calculates an inductance value of the variable coil 32 and capacitance values of the variable capacitors 34 and 36 (an impedance value of the matching section 30) that causes the

reflection coefficient γ to be the reflection coefficient value γ_0 .

[0071] Since the reflection coefficient value γ_0 is zero as described above, it can be said that the computation
5 section 28 calculates the inductance value of the variable coil 32 and the capacitance values of the variable capacitors 34 and 36 such that the values cause the reflection coefficient γ to move to a center point on the Smith chart. FIGS. 7 to 9 are graphs illustrating examples
10 of the change of the reflection coefficient on the Smith chart according to adjustment of the impedance value of the matching section. FIGS. 7 to 9 are the Smith charts, the horizontal axis of FIGS. 7 to 9 represents a real part of the reflection coefficient, and the vertical axis thereof
15 represents an imaginary part of the reflection coefficient. In addition, a curve SM of FIGS. 7 to 9 is an outer circle of the Smith chart.

[0072] FIG. 7 illustrates an example of a change of the value of the reflection coefficient γ in the case of
20 changing the capacitance of the variable capacitor 34. Here, a reflection coefficient value, which is a reflection coefficient value of the reflection coefficient γ calculated by the computation section 28 before changing the inductance value and the capacitance value, is denoted
25 by γ_1 . When the capacitance value of the variable capacitor 34 is changed to cause the reflection coefficient γ to move to the center point on the Smith chart, the reflection coefficient value of the reflection coefficient γ moves from the reflection coefficient value γ_1 to a
30 reflection coefficient value γ_2 along a circle CR1 corresponding to the change of the capacitance of the variable capacitor 34.

[0073] FIG. 8 illustrates an example of a change of the value of the reflection coefficient γ in the case of changing the inductance of the variable coil 32. When the inductance value of the variable coil 32 is changed to
5 cause the reflection coefficient γ to move to the center point on the Smith chart, the reflection coefficient value of the reflection coefficient γ moves from the reflection coefficient value γ_2 to a reflection coefficient value γ_3 along a circle CR2 corresponding to the change of the
10 inductance of the variable coil 32.

[0074] FIG. 9 illustrates an example of a change of the value of the reflection coefficient γ in the case of changing the capacitance of the variable capacitor 36. When the capacitance value of the variable capacitor 36 is
15 changed to cause the reflection coefficient γ to move to the center point on the Smith chart, the reflection coefficient value of the reflection coefficient γ moves from the reflection coefficient value γ_3 to the reflection coefficient value γ_0 positioned at the center point on the
20 Smith chart along a circle CR3 corresponding to the change of the capacitance of the variable capacitor 36.

Accordingly, the value of the reflection coefficient γ becomes zero, and thus, the signal value of the reflection signal B also becomes zero.

25 [0075] In this manner, the calculation of an inductance value L and capacitance values CP1 and CP2 performed by the computation section 28 can be described using the Smith chart, and the computation section 28 may perform the calculation of the inductance value L and the capacitance
30 values CP1 and CP2 actually based on the Smith chart.

[0076] In this manner, the computation section 28 calculates the inductance value L and the capacitance values CP1 and CP2. The computation section 28 outputs the

inductance control signal D1 having command information that causes the variable coil 32 to be the calculated inductance value L to the variable coil 32. In addition, the computation section 28 outputs the capacitance control signals D2 and D3 having command information that causes the variable capacitors 34 and 36 to be the calculated capacitance values CP1 and CP2 to the variable capacitors 34 and 36. The variable coil 32 changes its own inductance based on the inductance control signal D1, and each of the variable capacitors 34 and 36 changes its own capacitance based on each of the capacitance control signals D2 and D3. Accordingly, the impedance of the matching section 30 changes, and the value of the reflection coefficient γ becomes the reflection coefficient value γ_0 . That is, the signal value of the reflection signal B is reduced in this manner.

[0077] As the impedance of the matching section 30 is changed through step S22, the mismatch suppression process performed by the matching circuit 10 ends. Incidentally, the mismatch suppression process may be repeated returning to steps S11A and S11B after the impedance of the matching section 30 is changed through step S22. It is possible to more suitably reduce the signal value of the reflection signal B by repeating the mismatch suppression process.

[0078] As described above, the matching circuit 10 according to the first embodiment detects the amplitude ratio P_{BA} , the phase difference θ_{BA} between the transmission signal A and the reflection signal B using the mismatch detection section 26. Further, the matching circuit 10 generates the matching section control signal D that changes the impedance of the matching section 30 based on the amplitude ratio P_{BA} and the phase difference θ_{BA} using the computation section 28. Further, the matching circuit

10 changes its own impedance based on the matching section control signal D using the matching section 30. The matching circuit 10 changes the signal value of the reflection signal B by changing the impedance of the matching section 30.

[0079] In this manner, the matching circuit 10 can change the impedance based on the amplitude ratio P_{BA} and the phase difference θ_{BA} between the transmission signal A and the reflection signal B, and thus, can perform the impedance control according to the signal value of the reflection signal B. Accordingly, the matching circuit 10 can suitably suppress the mismatch between the output impedance of the transmitting circuit 2 and the input impedance of the antenna 4 and generation of the reflection signal B by performing the impedance control according to the signal value of the reflection signal B.

[0080] To be more specific, the matching circuit 10 detects both the amplitude ratio P_{BA} and the phase difference θ_{BA} using the mismatch detection section 26. That is, the matching circuit 10 performs the matching based on not only the voltage values of the transmission signal A and the reflection signal B but also the phase difference (imaginary component) therebetween. When the mismatch suppression process is performed without considering the phase difference, there is a possibility that the waveform between the transmission signal A and the reflection signal B is shifted, and it is difficult to suppress the mismatch. The matching circuit 10 performs the mismatch suppression process also considering the phase difference, it is possible to reliably suppress the mismatch between the output impedance of the transmitting circuit 2 and the input impedance of the antenna 4.

[0081] In addition, the matching circuit 10 calculates the reflection coefficient γ based on the amplitude ratio P_{BA} and the phase difference θ_{BA} between the transmission signal A and the reflection signal B using the computation section 28. The matching circuit 10 generates the matching section control signal D based on the reflection coefficient γ such that the reflection coefficient γ becomes the reflection coefficient value γ_0 . The matching circuit 10 can more suitably perform the matching process using the reflection coefficient.

[0082] In addition, the matching section 30 according to the first embodiment includes the variable coil 32 which is capable of changing the inductance and the variable capacitors 34 and 36 each of which is capable of changing the capacitance. The matching section 30 changes the impedance by causing the variable coil 32 and the variable capacitors 34 and 36 to change the inductance and the capacitance thereof. The matching section 30 changes the inductance and the capacitance, and thus, can suitably perform the matching also based on the phase difference.

[0083] In addition, the variable coil 32 is connected between the transmitting circuit 2 and the antenna 4. Further, the variable capacitor 34 has the one connection portion that is connected between the variable coil 32 and the transmitting circuit 2 and the other connection portion that is grounded. Further, the variable capacitor 36 has the one connection portion that is connected between the variable coil 32 and the antenna 4 and the other connection portion that is grounded. In this manner, the matching section 30 forms the Π -shaped circuit using the variable coil 32, and the variable capacitors 34 and 36. Accordingly, the matching section 30 can more preferably change the inductance and the capacitance.

[0084] In addition, each of the variable capacitors 34 and 36 successively changes the capacitance thereof depending on the voltage applied thereto. Accordingly, the matching section 30 can change the capacitance in an analog
5 manner according to the matching section control signal D, and thus, can perform finer matching.

[0085] In addition, the mismatch detection section 26 detects the amplitude ratio P_{BA} and the phase difference θ_{BA} by converting the frequencies of the transmission signal A
10 and the reflection signal B using the heterodyne system. Accordingly, the mismatch detection section 26 can detect the amplitude ratio P_{BA} and the phase difference θ_{BA} at high accuracy without being affected by, for example a DC offset or the like.

15 [0086] Incidentally, the wireless communication apparatus 1 is a transmission device that includes the transmitting circuit 2 and performs wireless transmission, but may include a receiving circuit that receives a signal from another device, for example, the RF tag 100 or the
20 like and reads information. FIG. 10 is a block diagram illustrating a configuration when the wireless communication apparatus according to the first embodiment includes the receiving circuit. As illustrated in FIG. 10, a receiving circuit 6 is electrically connected to the
25 antenna 4 via the matching section 30 and the mismatch detection unit 20. To be more specific, the receiving circuit 6 is electrically connected to the matching section 30 by being branched from a conductive wire from the matching section 30 to the transmitting circuit 2. In this
30 case, the antenna 4 receives a reception signal which is a signal from the RF tag 100, for example. The reception signal received by the antenna 4 is input to the receiving circuit 6. The receiving circuit 6 reads information

included in the reception signal, for example. In addition, the reflection signal B is reflected from the antenna 4 to the receiving circuit 6, which is similar to the transmitting circuit 2.

5 [0087] (Second Embodiment)

Next, a second embodiment of the present invention will be described. A wireless communication apparatus 1a according to the second embodiment is different from the wireless communication apparatus 1 according to the first
10 embodiment in terms of a configuration of a matching section. To be more specific, a matching section 30a of the wireless communication apparatus 1a according to the second embodiment changes its own capacitance by switching a switch. The wireless communication apparatus 1a
15 according to the second embodiment has the common configuration as the wireless communication apparatus 1 according to the first embodiment in terms of other points, and thus, the description for the common points will be omitted.

20 [0088] FIG. 11 is a schematic view illustrating the configuration of the matching section according to the second embodiment. As illustrated in FIG. 11, the matching section 30a according to the second embodiment includes capacitors 34a1, 34a2, 36a1 and 36a2 and switch sections
25 37a1, 37a2, 38a1 and 38a2. The capacitors 34a1 and 34a2 form a variable capacitor unit 34a. The capacitors 36a1 and 36a2 form a variable capacitor unit 36a. The matching section 30a switches the switch sections 37a1, 37a2, 38a1 and 38a2 according to a control signal of a control part of
30 a computation section 28a to change the total capacitance of the variable capacitor unit 34a obtained by summing up capacitances of the capacitors 34a1 and 34a2 and the total

capacitance of the variable capacitor unit 36a obtained by summing up capacitances of the capacitors 36a1 and 36a2.

[0089] As illustrated in FIG. 11, the capacitor 34a1 is electrically connected to the transmitting circuit 2 and
5 the variable coil 32. To be more specific, the capacitor 34a1 has one connection portion 34Aa1 that is electrically connected between the transmitting circuit 2 and the variable coil 32. In addition, the capacitor 34a1 has another connection portion 34Ba1 that is grounded via the
10 switch section 37a1.

[0090] The switch section 37a1 causes the other connection portion 34Ba1 of the capacitor 34a1 to be grounded by switching of a switch. The switch section 37a1 is electrically connected to the computation section 28a
15 and switches the switch according to a signal of the computation section 28a.

[0091] The capacitor 34a1 is grounded via the other connection portion 34Ba1 by turning on the switch of the switch section 37a1. Accordingly, the capacitor 34a1
20 operates as a capacitor.

[0092] The capacitor 34a2 and the switch section 37a2 have the same configurations as the capacitor 34a1 and the switch section 37a1 and are connected in parallel with the capacitor 34a1 and the switch section 37a1. Accordingly,
25 the total capacitance of the variable capacitor unit 34a is changed as the switch sections 37a1 and 37a2 are switched by the computation section 28a.

[0093] As illustrated in FIG. 11, the capacitor 36a1 is electrically connected to the variable coil 32 and the
30 first directional coupling section 22. To be more specific, the capacitor 36a1 has one connection portion 36Aa1 that is electrically connected between the variable coil 32 and the first directional coupling section 22. In addition, the

capacitor 36a1 has another connection portion 36Ba1 that is grounded via the switch section 38a1.

[0094] The switch section 38a1 causes the other connection portion 36Ba1 of the capacitor 36a1 to be grounded by switching of a switch. The switch section 38a1 is electrically connected to the computation section 28a and switches the switch according to the signal of the computation section 28a.

[0095] The capacitor 36a1 is grounded via the other connection portion 36Ba1 by turning on the switch of the switch section 38a1. Accordingly, the capacitor 36a1 operates as a capacitor.

[0096] The capacitor 36a2 and the switch section 38a2 have the same configurations as the capacitor 36a1 and the switch section 38a1 and are connected in parallel with the capacitor 36a1 and the switch section 38a1. Accordingly, the total capacitance of the variable capacitor unit 36a is changed as the switch sections 38a1 and 38a2 are switched by the computation section 28a.

[0097] In this manner, the matching section 30a according to the second embodiment changes the total capacitance of each of the variable capacitor unit 34a and the variable capacitor unit 36a by switching each switch of the switch sections 37a1, 37a2, 38a1 and 38a2. The matching section 30a according to the second embodiment changes its own impedance by changing the total capacitance of each of the variable capacitor unit 34a and the variable capacitor unit 36a. Accordingly, the matching section 30a can suitably perform matching also based on the phase difference, which is similar to the matching section 30 according to the first embodiment. Incidentally, each of the variable capacitor unit 34a and the variable capacitor unit 36a includes two capacitors, but may include three or

more capacitors that are connected in parallel with each other without being limited thereto.

[0098] (Third Embodiment)

Next, a third embodiment of the present invention will
5 be described. A wireless communication apparatus 1b according to the third embodiment is different from the wireless communication apparatus 1 according to the first embodiment in terms of a configuration of a matching section. To be more specific, a matching section 30b of
10 the wireless communication apparatus 1b according to the third embodiment changes an inductance by switching a switch. The wireless communication apparatus 1b according to the third embodiment has the common configuration as the wireless communication apparatus 1 according to the first
15 embodiment in terms of other points, and thus, the description for the common points will be omitted.

[0099] FIG. 12 is a schematic view illustrating the configuration of the matching section according to the third embodiment. As illustrated in FIG. 12, the matching
20 section 30b according to the third embodiment includes coil sections 32b1 and 32b2, conductive wires 35b1, 35b2 and 35b3, and switch sections 39b1, 39b2, 39b3 and 39b4. The coil sections 32b1 and 32b2 form a variable coil unit 32b. The matching section 30b switches the switch sections 39b1,
25 39b2, 39b3 and 39b4 according to a control signal of a control part of a computation section 28b to change the total capacitance of the variable coil unit 32b obtained by summing up inductances of the coil sections 32b1 and 32b2.

[0100] The coil sections 32b1 and 32b2 are provided in
30 series between the transmitting circuit 2 and the first directional coupling section 22. The conductive wire 35b1 is provided between the coil section 32b1 and the coil section 32b2. In other words, the coil section 32b1 is

provided between the transmitting circuit 2 and the conductive wire 35b1, and the coil section 32b2 is provided between the conductive wire 35b1 and the first directional coupling section 22.

5 [0101] The conductive wire 35b2 is provided between the transmitting circuit 2 and the conductive wire 35b1 in parallel with the coil section 32b1. The conductive wire 35b3 is provided between the conductive wire 35b1 and the first directional coupling section 22 in parallel with the
10 coil section 32b2.

[0102] The switch section 39b1 is provided between the transmitting circuit 2, and the coil section 32b1 and the conductive wire 35b2. The switch section 39b1 is electrically connected to the computation section 28b. The
15 switch section 39b1 switches the connection between the transmitting circuit 2 and the coil section 32b1 and the connection between the transmitting circuit 2 and the conductive wire 35b2 according to the control signal of the control part of the computation section 28b.

20 [0103] The switch section 39b2 is provided between the coil section 32b1 and the conductive wire 35b2, and the conductive wire 35b1. The switch section 39b2 is electrically connected to the computation section 28b. The switch section 39b2 switches the connection between the
25 coil section 32b1 and the conductive wire 35b1 and the connection between the conductive wire 35b2 and the conductive wire 35b1 according to the control signal of the control part of the computation section 28b.

[0104] The switch section 39b3 is provided between the
30 conductive wire 35b1, and the coil section 32b2 and the conductive wire 35b3. The switch section 39b3 is electrically connected to the computation section 28b. The switch section 39b3 switches the connection between the

conductive wire 35b1 and the coil section 32b2 and the connection between the conductive wire 35b1 and the conductive wire 35b3 according to the control signal of the control part of the computation section 28b.

- 5 [0105] The switch section 39b4 is provided between the coil section 32b2 and the conductive wire 35b3, and the first directional coupling section 22. The switch section 39b4 is electrically connected to the computation section 28b. The switch section 39b4 switches the connection
- 10 between the coil section 32b2 and the first directional coupling section 22 and the connection between the conductive wire 35b3 and the first directional coupling section 22 according to the control signal of the control part of the computation section 28b.
- 15 [0106] The matching section 30b has the above-described configuration, and thus, changes the number of coils to be electrically connected to the transmitting circuit 2 and the first directional coupling section 22 by switching the switch section according to the control signal of the
- 20 control part of the computation section 28b. The matching section 30b changes the total capacitance of the variable coil unit 32b by changing the number of the coils to be connected to the transmitting circuit 2 and the first directional coupling section 22. The matching section 30b
- 25 changes its own inductance by changing the total capacitance of the variable coil unit 32b. Accordingly, the matching section 30b can suitably perform matching also based on the phase difference, which is similar to the matching section 30 according to the first embodiment.
- 30 Incidentally, the variable coil unit 32b is configured of two coils, but may be configured of three or more coils.
- [0107] (Fourth Embodiment)

Next, a fourth embodiment of the present invention will be described. A wireless communication apparatus 1c according to the fourth embodiment is different from the wireless communication apparatus 1 according to the first embodiment in terms of a configuration of a mismatch detection section. To be more specific, a mismatch detection section 26c of the wireless communication apparatus 1c according to the fourth embodiment detects an amplitude ratio and a phase difference between a transmission signal and a reflection signal using a homodyne system. The wireless communication apparatus 1c according to the fourth embodiment has the common configuration as the wireless communication apparatus 1 according to the first embodiment in terms of other points, and thus, the description for the common points will be omitted.

[0108] FIG. 13 is a block diagram illustrating the configuration of the mismatch detection section according to the fourth embodiment. As illustrated in FIG. 13, the mismatch detection section 26c according to the fourth embodiment includes a phase shift section 43c, a first mixing section 44c, a second mixing section 45c, a filter section 46c, an AD conversion section 48c, an amplitude and phase detection section 49c, a first amplitude detection section 51c, and a second amplitude detection section 52c.

[0109] The first mixing section 44c is electrically connected to the first directional coupling section 22 and the second directional coupling section 24. The corresponding transmission signal A1 is input from the first directional coupling section 22 to the first mixing section 44c, and the corresponding reflection signal B1 is input from the second directional coupling section 24 thereto. The first mixing section 44c generates a forward

mixed signal E_{c1} which is an electrical signal in which the corresponding transmission signal A_1 and the corresponding reflection signal B_1 are mixed. The forward mixed signal E_{c1} is the electrical signal which has a waveform in which
5 a waveform having a frequency ($2 \cdot f_A$) obtained by summing up frequencies of the corresponding transmission signal A_1 and the corresponding reflection signal B_1 and a waveform having a frequency (zero, that is, a DC component) of a difference between the frequency of the corresponding
10 transmission signal A_1 and the frequency of the corresponding reflection signal B_1 overlap each other.

[0110] The phase shift section 43c is electrically connected to the second directional coupling section 24. The corresponding reflection signal B_1 is input from the
15 second directional coupling section 24 to the phase shift section 43c. The phase shift section 43c generates a phase-shifted reflection signal B_{1c}' by shifting a phase of the corresponding reflection signal B_1 by 90 degrees. Incidentally, the phase shift section 43c may shift the
20 phase of the corresponding reflection signal B_1 by a predetermined value, and the shifted value is not limited to 90 degrees.

[0111] The second mixing section 45c is electrically connected to the first directional coupling section 22 and
25 the phase shift section 43c. The corresponding transmission signal A_1 is input from the first directional coupling section 22 to the first mixing section 44c, and the phase-shifted reflection signal B_{1c}' is input from the phase shift section 43c thereto. The second mixing section
30 45c generates a phase-shifted mixed signal E_{c1}' which is an electrical signal in which the corresponding transmission signal A_1 and the phase-shifted reflection signal B_{1c}' are mixed. The phase-shifted mixed signal E_{c1}' is the

electrical signal which has a waveform in which a waveform having a frequency ($2 \cdot f_A$) obtained by summing up frequencies of the corresponding transmission signal A1 and the phase-shifted reflection signal B1c' and a waveform
5 having a frequency (zero, that is, a DC component) of a difference between the frequency of the corresponding transmission signal A1 and the frequency of the phase-shifted reflection signal B1c' overlap each other.

[0112] The first amplitude detection section 51c is
10 electrically connected to the first directional coupling section 22. The corresponding transmission signal A1 is input from the first directional coupling section 22 to the first amplitude detection section 51c. The first amplitude detection section 51c performs diode detection of the
15 corresponding transmission signal A1, thereby generating a transmission amplitude signal Fc1 which is an electrical signal of the DC component of the corresponding transmission signal A1. The transmission amplitude signal Fc1 is obtained by performing the diode detection of the
20 corresponding transmission signal A1 which is an AC component. Accordingly, a voltage value of the transmission amplitude signal Fc1 corresponds to an amplitude value of the corresponding transmission signal A1. That is, the first amplitude detection section 51c detects
25 the amplitude value of the corresponding transmission signal A1 by generating the transmission amplitude signal Fc1.

[0113] The second amplitude detection section 52c is electrically connected to the second directional coupling
30 section 24. The corresponding reflection signal B1 is input from the second directional coupling section 24 to the second amplitude detection section 52c. The first amplitude detection section 51c performs diode detection of

the corresponding reflection signal B1, thereby generating a reflection amplitude signal Fc1' which is an electrical signal of the DC component of the corresponding reflection signal B1. The reflection amplitude signal Fc1' is
5 obtained by performing the diode detection of the corresponding reflection signal B1 which is an AC component. Accordingly, a voltage value of the reflection amplitude signal Fc1' corresponds to an amplitude value of the corresponding reflection signal B1. That is, the second
10 amplitude detection section 52c detects the amplitude value of the corresponding reflection signal B1 by generating the reflection amplitude signal Fc1'. Incidentally, the second amplitude detection section 52c may be electrically connected to the phase shift section 43c and generate the
15 reflection amplitude signal Fc1' from the phase-shifted reflection signal B1c'.

[0114] The filter section 46c is electrically connected to the first mixing section 44c and the second mixing section 45c, and the forward mixed signal Ec1 and the
20 phase-shifted mixed signal Ec1' are input thereto. The filter section 46c removes the waveform having the frequency of $2 \cdot f_A$ from the forward mixed signal Ec1 and generates a forward comparison signal Ec2 having a voltage signal as a DC component. The filter section 46c removes
25 the waveform having the frequency of $2 \cdot f_A$ from the phase-shifted mixed signal Ec1' and generates a phase-shifted comparison signal Ec2' having a voltage signal as a DC component.

[0115] In addition, the filter section 46c is
30 electrically connected to the first amplitude detection section 51c and the second amplitude detection section 52c, and the transmission amplitude signal Fc1 and the reflection amplitude signal Fc1' are input thereto.

Although the transmission amplitude signal $Fc1$ and the reflection amplitude signal $Fc1'$ are the DC components, the filter section 46c performs filtering on the transmission amplitude signal $Fc1$ and the reflection amplitude signal $Fc1'$ to remove noise components and generates a transmission amplitude signal $Fc2$ and a reflection amplitude signal $Fc2'$.

[0116] The AD conversion section 48c is electrically connected to the filter section 46c and converts the forward comparison signal $Ec2$ and the phase-shifted comparison signal $Ec2'$ into digital signals to generate a digital forward comparison signal $Ec3$ and a digital phase-shifted comparison signal $Ec3'$.

[0117] In addition, the AD conversion section 48c converts the transmission amplitude signal $Fc2$ and the reflection amplitude signal $Fc2'$ into digital signals to generate a digital transmission amplitude signal $Fc3$ and a digital reflection amplitude signal $Fc3'$.

[0118] The amplitude and phase detection section 49c is electrically connected to the AD conversion section 48c and a computation section 28c. The digital forward comparison signal $Ec3$ and the digital phase-shifted comparison signal $Ec3'$ are input to the amplitude and phase detection section 49c. The amplitude and phase detection section 49c compares a signal value of the digital forward comparison signal $Ec3$ and a signal value of the digital phase-shifted comparison signal $Ec3'$ and detects the phase difference between the transmission signal A and the reflection signal B.

[0119] In addition, the amplitude and phase detection section 49c detects the amplitude ratio between the transmission signal A and the reflection signal B based on each amplitude value of the digital transmission amplitude

signal Fc3 and the digital reflection amplitude signal Fc3'. Further, the amplitude and phase detection section 49c outputs an amplitude and phase information signal Cc, which is an electrical signal having information about the
5 amplitude ratio and the phase difference between the transmission signal A and the reflection signal B, to the computation section 28c.

[0120] Next, a description will be given regarding a method of detecting the amplitude ratio and the phase
10 difference between the transmission signal A and the reflection signal B performed by the mismatch detection section 26c using a flowchart. FIG. 14 is a flowchart describing a process of detecting the amplitude ratio and the phase difference performed by the mismatch detection
15 section according to the fourth embodiment. When the amplitude ratio and the phase difference are detected as illustrated in FIG. 14, first, the corresponding transmission signal A1 and the corresponding reflection signal B1 are input to the first mixing section 44c, and
20 the corresponding reflection signal B1 is input to the phase shift section 43c.

[0121] The mismatch detection section 26c mixes the corresponding transmission signal A1 and the corresponding reflection signal B1 using the first mixing section 44c to
25 generate the forward mixed signal Ec1 (step S32A).

[0122] In addition, the mismatch detection section 26c shifts the phase of the corresponding reflection signal B1 by 90 degrees using the phase shift section 43c to generate the phase-shifted reflection signal B1c' (step S30B).

30 [0123] In addition, after the phase-shifted reflection signal B1c' is generated, the mismatch detection section 26c mixes the corresponding transmission signal A1 and the phase-shifted reflection signal B1c' using the second

mixing section 45c to generate the phase-shifted mixed signal E_{c1}' (step S32B). Incidentally, step S32A is performed at the same time as step S32B, but the invention is not limited thereto. The order of processing step S32A, and step S30B and step S32B is arbitrary.

[0124] In addition, the mismatch detection section 26c performs the diode detection on the corresponding transmission signal A1 and the corresponding reflection signal B1 using the first amplitude detection section 51c and the second amplitude detection section 52c to generate the transmission amplitude signal F_{c1} and the reflection amplitude signal F_{c1}' (step S33). To be more specific, the first amplitude detection section 51c generates the transmission amplitude signal F_{c1} , which is the DC component having the voltage value corresponding to the amplitude value of the corresponding transmission signal A1, to detect the amplitude value of the corresponding transmission signal A1. In addition, the second amplitude detection section 52c generates the reflection amplitude signal F_{c1}' , which is the DC component having the voltage value corresponding to the amplitude value of the corresponding reflection signal B1 to detect the amplitude value of the corresponding reflection signal B1. Incidentally, step S33 may be performed at any timing before, after or at the same time as step S30B, step S32A or step S32B as long as being performed before step S34 to be described later.

[0125] After generating the forward mixed signal E_{c1} and the phase-shifted mixed signal E_{c1}' , and the transmission amplitude signal F_{c1} and the reflection amplitude signal F_{c1}' , the mismatch detection section 26c performs the filtering on the forward mixed signal E_{c1} and the phase-shifted mixed signal E_{c1}' , and the transmission amplitude

signal Fc1 and the reflection amplitude signal Fc1' using the filter section 46c to generate the forward comparison signal Ec2, the phase-shifted comparison signal Ec2', the transmission amplitude signal Fc2, and the reflection amplitude signal Fc2' (step S34). The forward comparison signal Ec2 and the phase-shifted comparison signal Ec2' are the electrical signals each of which has a DC voltage component whose voltage value is not displaced. The transmission amplitude signal Fc2 and the reflection amplitude signal Fc2' are also the electrical signal each of which has a DC voltage component obtained by removing the noise from each of the transmission amplitude signal Fc1 and the reflection amplitude signal Fc1'.

[0126] After generating the forward comparison signal Ec2 and the phase-shifted comparison signal Ec2', and the transmission amplitude signal Fc2 and the reflection amplitude signal Fc2', the mismatch detection section 26c converts the forward comparison signal Ec2 and the phase-shifted comparison signal Ec2', and the transmission amplitude signal Fc2 and the reflection amplitude signal Fc2' into the digital signals using the AD conversion section 48c to generate the digital forward comparison signal Ec3 and the digital phase-shifted comparison signal Ec3', and the digital transmission amplitude signal Fc3 and the digital reflection amplitude signal Fc3' (step S36).

[0127] After generating the digital forward comparison signal Ec3 and the digital phase-shifted comparison signal Ec3', and the digital transmission amplitude signal Fc3 and the digital reflection amplitude signal Fc3', the mismatch detection section 26c calculates the amplitude ratio and the phase difference between the transmission signal A and the reflection signal B using the amplitude and phase detection section 49c (step S38). The amplitude and phase

detection section 49c calculates the amplitude ratio between the transmission signal A and the reflection signal B using the digital transmission amplitude signal Fc3 and the digital reflection amplitude signal Fc3'. In addition, the amplitude and phase detection section 49c calculates the phase difference between the transmission signal A and the reflection signal B using the digital forward comparison signal Ec3 and the digital phase-shifted comparison signal Ec3'.

10 [0128] To be more specific, the digital transmission amplitude signal Fc3 has the voltage value corresponding to the amplitude value of the corresponding transmission signal A1 (that is, an amplitude value of the transmission signal A), and the digital reflection amplitude signal Fc3' has the voltage value corresponding to the amplitude value of the corresponding reflection signal B1 (that is, an amplitude value of the reflection signal B). To be more specific, the voltage value of the digital transmission amplitude signal Fc3 is the same value as the amplitude value of the transmission signal A, and the voltage value of the digital reflection amplitude signal Fc3' is the same value as the amplitude value of the reflection signal B in the present embodiment. Accordingly, the amplitude and phase detection section 49c can calculate the amplitude ratio between the transmission signal A and the reflection signal B based on the voltage value of the digital transmission amplitude signal Fc3 and the voltage value of the digital reflection amplitude signal Fc3'. When the voltage value of the digital transmission amplitude signal Fc3 (that is, the amplitude value of the transmission signal A) is denoted by I_A and the voltage value of the digital reflection amplitude signal Fc3' (that is, the amplitude value of the reflection signal B) is denoted by

I_B , the amplitude and phase detection section 49c calculates the amplitude ratio P_{BA} using the following Formula (5).

$$[0129] \quad P_{BA} = I_B/I_A \quad (5)$$

5 [0130] FIG. 15 is a graph illustrating voltage waveforms of the transmission signal and the reflection signal. In FIG. 15, the horizontal axis represents time, and the vertical axis represents a voltage (V). A waveform W of FIG. 15 is an example of a voltage waveform of the digital forward comparison signal Ec3 when voltage values of the digital forward comparison signal Ec3 are plotted for each time. A waveform W' of FIG. 15 is an example of a voltage waveform of the digital phase-shifted comparison signal Ec3' when voltage values of the digital phase-shifted comparison signal Ec3' are plotted for each time. Incidentally, the digital forward comparison signal Ec3 and the digital phase-shifted comparison signal Ec3' are the electrical signals each of which has the DC voltage component whose voltage value is not displaced, and thus, 15 the waveforms W and W' become straight lines.

[0131] The mismatch detection section 26c generates the waveform W of the digital forward comparison signal Ec3 and the waveform W' of the digital phase-shifted comparison signal Ec3', as illustrated in FIG. 15, using the amplitude and phase detection section 49c. The mismatch detection section 26c detects a forward voltage value H_c , which is a voltage value of the digital forward comparison signal Ec3, and a phase-shifted voltage value H_c' , which is a voltage value of the digital phase-shifted comparison signal Ec3', 25 based on the waveform W and the waveform W' using the amplitude and phase detection section 49c. The mismatch detection section 26c calculates the phase difference θ_{BA} using the following Formula (6) based on the forward

30

voltage value H_c and the phase-shifted voltage value H_c' using the amplitude and phase detection section 49c.

$$[0132] \quad \theta_{BA} = \text{atan2}(H_c, H_c') \quad (6)$$

[0133] The mismatch detection section 26c generates the amplitude and phase information signal C_c , which is the electrical signal having the information about the calculated amplitude ratio P_{BA} between the transmission signal A and the reflection signal B and the calculated phase difference θ_{BA} between the transmission signal A and the reflection signal B using the amplitude and phase detection section 49c, and outputs the generated signal to the computation section 28c. Accordingly, the process of detecting the amplitude ratio and the phase difference between the transmission signal A and the reflection signal B performed by the mismatch detection section 26c ends. Incidentally, the mismatch detection section 26c does not necessarily create the waveforms W and W' , and may detect the forward voltage value H_c and the phase-shifted voltage value H_c' by reading the voltage value of the digital forward comparison signal $Ec3$ and the voltage value of the digital phase-shifted comparison signal $Ec3'$.

[0134] As above, the mismatch detection section 26c according to the fourth embodiment detects the amplitude ratio P_{BA} , the phase difference θ_{BA} by converting the frequencies of the transmission signal A and the reflection signal B using the homodyne system. Accordingly, the mismatch detection section 26c can detect the amplitude ratio P_{BA} , the phase difference θ_{BA} at high accuracy without providing a local oscillator.

[0135] (Fifth Embodiment)

Next, a fifth embodiment of the present invention will be described. The wireless communication apparatus 1d according to the fifth embodiment is different from the

wireless communication apparatus 1 according to the first embodiment in terms of determining whether to perform a matching process based on voltage and amplitude values of the reflection signal B. The wireless communication apparatus 1d according to the fifth embodiment has the common configuration as the wireless communication apparatus 1 according to the first embodiment in terms of other points, and thus, the description for the common points will be omitted.

10 [0136] FIG. 16 is a block diagram illustrating a configuration of the wireless communication apparatus according to the fifth embodiment. The wireless communication apparatus 1d according to the fifth embodiment includes the receiving circuit 6, a computation section 28d, and a reception confirmation section 60d. Although the details will be described later, the computation section 28d determines whether to perform the matching process based on the voltage and amplitude values of the reflection signal B. The reception confirmation section 60d is electrically connected to the computation section 28d. The reception confirmation section 60d confirms whether the wireless communication apparatus 1d has received a reception signal from the RF tag 100 and transmits a result of the confirmation to the computation section 28d.

25 [0137] Here, a signal from the antenna 4 toward the transmitting circuit 2 is not limited to the reflection signal B which corresponds to the transmission signal A. For example, when an object such as a wall 101 is present around the wireless communication apparatus 1d, there may be a case where the transmission signal A wirelessly transmitted from the antenna 4 is reflected by the surrounding object, and a sub-reflection signal reflected

by the surrounding object is received by the antenna 4. The sub-reflection signal received by the antenna 4 is transmitted from the antenna 4 toward the transmitting circuit 2. In this case, the mismatch detection section 26 sometimes detects even the sub-reflection signal as the reflection signal B, and a mismatch suppression process is not suitably performed.

[0138] When such a sub-reflection signal is input to the antenna 4, the amplitude of the reflection signal B detected by the mismatch detection section 26 increases. Accordingly, the computation section 28d determines that the reception signal or the sub-reflection signal is input and stops the matching process, when a reflection signal peak value HB, which is a voltage peak value of the reflection signal B detected by the mismatch detection section 26, is larger than a predetermined value (amplitude threshold).

[0139] However, when the wireless communication apparatus 1d is arranged at a certain portion and is used under the environment where the wall 101 or the like is present therearound, the sub-reflection signal caused by the wall 101 or the like is constantly input to the wireless communication apparatus 1d. In this case, it is preferable that the wireless communication apparatus 1d perform the matching process based on a reflection signal including this sub-reflection signal. Accordingly, the computation section 28d causes the matching process to be performed based on the reflection signal including the sub-reflection signal when the value of the reflection signal peak value HB is constant for a predetermined time even in a case where the reflection signal peak value HB is larger than the amplitude threshold.

[0140] A description will be given regarding the process of determining whether to perform the matching process depending on interference of the surrounding material described above on the basis of a flowchart. FIG. 17 is the flowchart describing the process of determining whether to perform the matching process. As illustrated in FIG. 17, the computation section 28d determines whether the amplitude value of the reflection signal B detected by the mismatch detection section 26 is larger than the predetermined amplitude threshold (step S42). To be more specific, the computation section 28d determines whether the reflection signal peak value HB detected by the mismatch detection section 26 is larger than the amplitude threshold. Here, it is preferable that the predetermined amplitude threshold be a value which is equal to or larger than 10% of the amplitude value of the transmission signal A (the transmission signal peak value HA), for example.

[0141] When the amplitude value of the reflection signal B is larger than the predetermined amplitude threshold (Yes in step S42), the computation section 28d monitors this amplitude value of the reflection signal B and confirms whether the amplitude value of the reflection signal B is constant for the predetermined time (step S44). Incidentally, the computation section 28d determines that the amplitude value of the reflection signal B (the reflection signal peak value HB) is constant even if the amplitude value of the reflection signal B (the reflection signal peak value HB) is changed within a predetermined range. This predetermined range is a range, for example, where the amplitude value of the reflection signal B (the reflection signal peak value HB) is not less than the predetermined amplitude threshold in step S42.

[0142] When it is determined that the amplitude value of the reflection signal B is constant for the predetermined time (Yes in step S44), the computation section 28d causes the matching section 30 to perform the matching process (step S46). In addition, when it is determined that the amplitude value of the reflection signal B is not constant for the predetermined time (No in step S44), the computation section 28d stops the matching process. When the amplitude value of the reflection signal B (the reflection signal peak value HB) is constant, it is considered that the sub-reflection signals having the same value are constantly input, and the wireless communication apparatus 1d is steadily arranged at the certain portion. Thus, the computation section 28d causes the matching process to be performed based on the reflection signal considered as including the sub-reflection signal when the amplitude value of the reflection signal B is constant. In addition, the sub-reflection signal is changed when the amplitude value of the reflection signal B (the reflection signal peak value HB) is not constant, and thus, it is considered that the wireless communication apparatus 1d is not arranged steadily at the certain portion. Thus, the computation section 28d stops the performing of the matching process based on the reflection signal considered as including the sub-reflection signal. Incidentally, when the amplitude value of the reflection signal B is not larger than the predetermined amplitude threshold (No in step S42), the process proceeds to step S46, and the computation section 28d causes the matching process to be performed.

[0143] In this manner, the computation section 28d according to the fifth embodiment stops the matching process without changing the impedance of the matching

section 30 based on the reflection signal considered as including the sub-reflection signal when the amplitude value of the reflection signal B is larger than the predetermined amplitude threshold. Accordingly, the wireless communication apparatus 1d according to the fifth embodiment can prevent the matching process from being unsuitably performed based on the sub-reflection signal and suitably suppress a mismatch between an input impedance of the antenna and an output impedance of the transmitting circuit, for example.

[0144] In addition, when the wireless communication apparatus 1d includes the receiving circuit 6, for example, there is a case where the reception signal as a signal from the RF tag 100 is received by the antenna 4. The reception signal received by the antenna 4 is also transmitted from the antenna 4 to the transmitting circuit 2. In this case, the mismatch detection section 26 sometimes detects even the reception signal as the reflection signal B, and the mismatch suppression process is not suitably performed.

[0145] Here, the reception confirmation section 60d confirms whether the wireless communication apparatus 1d has received the reception signal from the RF tag 100. The reception confirmation section 60d transmits a result of the confirmation on whether the reception signal has been received to the computation section 28d. When the reception signal has been received, the computation section 28d stops the matching process. That is, the computation section 28d stops the changing of the impedance performed by the matching section 30 when the wireless communication apparatus 1d has received the reception signal from a communication target such as the RF tag 100. Accordingly, the wireless communication apparatus 1d according to the fifth embodiment can prevent the matching process from

being unsuitably performed based on the reception signal and suitably suppress the mismatch between the input impedance of the antenna and the output impedance of the transmitting circuit, for example.

5 [0146] (Sixth Embodiment)

Next, a sixth embodiment of the present invention will be described. A wireless communication apparatus 1e according to the sixth embodiment is different from the wireless communication apparatus 1 according to the first
10 embodiment in terms of a portion at which a mismatch detection unit is arranged. The wireless communication apparatus 1e according to the sixth embodiment has the common configuration as the wireless communication apparatus 1 according to the first embodiment in terms of
15 other points, and thus, the description for the common points will be omitted. FIG. 18 is a block diagram illustrating a configuration of the wireless communication apparatus according to the sixth embodiment.

[0147] As illustrated in FIG. 18, a mismatch detection
20 unit 20e is provided between the transmitting circuit 2 and a matching section 30e in a matching circuit 10e included in the wireless communication apparatus 1e according to the sixth embodiment. The mismatch detection unit 20e is electrically connected to the antenna 4 via the matching
25 section 30e. In addition, the wireless communication apparatus 1e also includes the receiving circuit 6.

[0148] In the wireless communication apparatus 1 according to the first embodiment, the reflection signal B is input to the mismatch detection unit 20 before passing
30 through the matching section 30 (at the upstream side of the matching section 30). On the other hand, a reflection signal Be is input to the mismatch detection unit 20e after passing through the matching section 30e (at the downstream

side of the matching section 30) in the wireless communication apparatus 1e according to the sixth embodiment. Accordingly, the mismatch detection unit 20e according to the sixth embodiment detects amplitude and phase differences based on a reflection signal at a position closer to the receiving circuit 6. Accordingly, the wireless communication apparatus 1e according to the sixth embodiment can more suitably reduce the reflection signal to be reflected to the receiving circuit 6.

Incidentally, the wireless communication apparatus 1e does not necessarily include the receiving circuit 6. Even in this case, the mismatch detection unit 20e detects the amplitude and phase differences based on a reflection signal at a position closer to the transmitting circuit 2.

Accordingly, the wireless communication apparatus 1e can suppress too much increase of the reflection signal depending on the matching, for example.

[0149] (Seventh Embodiment)

Next, a seventh embodiment of the present invention will be described. A wireless communication apparatus 1f according to the seventh embodiment is different from the wireless communication apparatus 1 according to the first embodiment in terms that a plurality of mismatch detection units are arranged. The wireless communication apparatus 1f according to the seventh embodiment has the common configuration as the wireless communication apparatus 1 according to the first embodiment in terms of other points, and thus, the description for the common points will be omitted. FIG. 19 is a block diagram illustrating a configuration of the wireless communication apparatus according to the seventh embodiment.

[0150] As illustrated in FIG. 19, a matching circuit 10f included in the wireless communication apparatus 1f

according to the seventh embodiment includes a first mismatch detection unit 20f1 and a second mismatch detection unit 20f2. The first mismatch detection unit 20f1 is provided between a matching section 30f and the antenna 4. The first mismatch detection unit 20f1 is electrically connected to the transmitting circuit 2 via the matching section 30f. The second mismatch detection unit 20f2 is provided between the transmitting circuit 2 and the matching section 30f. The second mismatch detection unit 20f2 is electrically connected to the antenna 4 via the matching section 30f. Each of the first mismatch detection unit 20f1 and the second mismatch detection unit 20f2 is electrically connected to a computation section 28f. In addition, the wireless communication apparatus 1f includes the receiving circuit 6. [0151] The first mismatch detection unit 20f1 includes a first directional coupling section 22f1, a second directional coupling section 24f1, and a mismatch detection section 26f1. A transmission signal Af1 after passing through the matching section 30f (at the downstream side of the matching section 30f) is input to the mismatch detection section 26f1 of the first mismatch detection unit 20f1. In addition, a reflection signal Bf1 before passing through the matching section 30f (at the upstream side of the matching section 30f) is input to the mismatch detection section 26f1 of the first mismatch detection unit 20f1. That is, the transmission signal Af1 and the reflection signal Bf1, each of which is at a position close to the antenna 4, are input to the mismatch detection section 26f1 of the first mismatch detection unit 20f1. The computation section 28f calculates a reflection coefficient γ_{el} based on the transmission signal Af1 and the reflection signal Bf1.

[0152] The second mismatch detection unit 20f2 includes a first directional coupling section 22f2, a second directional coupling section 24f2, and a mismatch detection section 26f2. A transmission signal Af2 before passing through the matching section 30f (at the upstream side of the matching section 30f) is input to the mismatch detection section 26f2 of the second mismatch detection unit 20f2. In addition, a reflection signal Bf2 after passing through the matching section 30f (at the downstream side of the matching section 30f) is input to the mismatch detection section 26f2 of the second mismatch detection unit 20f2. That is, the transmission signal Af2 and the reflection signal Bf2, each of which is at a position close to the receiving circuit 6, are input to the mismatch detection section 26f2 of the second mismatch detection unit 20f2. The computation section 28f calculates a reflection coefficient ye2 based on the transmission signal Af2 and the reflection signal Bf2.

[0153] The computation section 28f performs a matching process by controlling an impedance of the matching section 30f based on the calculated reflection coefficient ye1 and reflection coefficient ye2. For example, the computation section 28f calculates an average reflection coefficient ye3 by averaging the reflection coefficient ye1 and the reflection coefficient ye2 in a predetermined rate and controls the impedance of the matching section 30f based on the average reflection coefficient ye3. Incidentally, the computation section 28f is not limited to the configuration of performing the matching process based on the average reflection coefficient ye3 as long as performing the matching process based on the calculated reflection coefficient ye1 and reflection coefficient ye2.

[0154] In this manner, the wireless communication apparatus 1f according to the seventh embodiment performs the matching process based on the transmission signal Af1 and the reflection signal Bf1 at the position close to the antenna 4 and the transmission signal Af2 and the reflection signal Bf2 at the position close to the receiving circuit 6. When the matching process is performed based on the transmission signal Af1 and the reflection signal Bf1, the control is performed based on the signals at the position close to the antenna 4, and thus, it is possible to stabilize a transmission signal after performing the matching process. In addition, when the matching process is performed based on the transmission signal Af2 and the reflection signal Bf2, the control is performed based on the signals at the position close to the receiving circuit 6, and thus, it is possible to more suitably reduce a reflection signal reflected to the receiving circuit 6. The wireless communication apparatus 1f according to the seventh embodiment performs the matching process based on the transmission signal Af1 and the reflection signal Bf1 and, the transmission signal Af2 and the reflection signal Bf2, and thus, can suitably reduce the reflection signal reflected to the receiving circuit 6 while stabilizing the transmission signal.

[0155] Incidentally, the wireless communication apparatus 1f does not necessarily include the receiving circuit 6. In this case, the transmission signal Af2 and the reflection signal Bf2 can be said as the signals at the position close to the transmitting circuit 2. Accordingly, the wireless communication apparatus 1f can suppress too much increase of the reflection signal depending on the matching while stabilizing the transmission signal.

[0156] Although the embodiments of the present invention have been described as above, these embodiments are not limited to the content of the embodiments. In addition, the above-described components include those easily
5 conceived by the person skilled in the art and those substantially the same, that is, those in the range of equivalency. Further, the above-described component may be combined as appropriate. Further, various components can be omitted, replaced or changed within the scope without
10 departing from a gist of the above-described embodiments or the like.

Reference Signs List

[0157] 1, 1a, 1b, 1c, 1d, 1e, 1f WIRELESS COMMUNICATION
APPARATUS

15 2 TRANSMITTING CIRCUIT
4 ANTENNA
6 RECEIVING CIRCUIT
10, 10e, 10f MATCHING CIRCUIT
20, 20e MISMATCH DETECTION UNIT
20 20f1 FIRST MISMATCH DETECTION UNIT
20f2 SECOND MISMATCH DETECTION UNIT
22 FIRST DIRECTIONAL COUPLING SECTION
24 SECOND DIRECTIONAL COUPLING SECTION
26, 26c, 26f1, 26f2 MISMATCH DETECTION SECTION
25 28, 28a, 28b, 28c, 28d, 28f COMPUTATION SECTION
30, 30a, 30b, 30e, 30f MATCHING SECTION
32 VARIABLE COIL
32A, 32b1, 32b2 COIL SECTION
32B, 37a1, 37a2, 38a1, 38a2, 39b1, 39b2, 39b3, 39b4,
30 SWITCH SECTION
32b VARIABLE COIL UNIT
32A0, 32A1, 32A2, 32A3, 32A4 CONTACT POINT
34, 36 VARIABLE CAPACITOR

34a1, 34a2, 36a1, 36a2 CAPACITOR
34a, 36a VARIABLE CAPACITOR UNIT
34A, 34B, 36A, 36B CONNECTION PORTION
35b1, 35b2, 35b3 CONDUCTIVE WIRE
5 42 LOCAL OSCILLATOR
43c PHASE SHIFT SECTION
44, 44c FIRST MIXING SECTION
45, 45c SECOND MIXING SECTION
46, 46c FILTER SECTION
10 48, 48c AD CONVERSION SECTION
49, 49c AMPLITUDE AND PHASE DETECTION SECTION
51c FIRST AMPLITUDE DETECTION SECTION
52c SECOND AMPLITUDE DETECTION SECTION
60d RECEPTION CONFIRMATION SECTION
15 100 RF TAG
101 WALL
A TRANSMISSION SIGNAL
A1 CORRESPONDING TRANSMISSION SIGNAL
A2 MIXED TRANSMISSION SIGNAL
20 A3 COMPARISON TRANSMISSION SIGNAL
A4 DIGITAL COMPARISON TRANSMISSION SIGNAL
A4W, B4W, W, W' WAVEFORM
Af1, Af2 TRANSMISSION SIGNAL
B REFLECTION SIGNAL
25 B1 CORRESPONDING REFLECTION SIGNAL
B1c' PHASE-SHIFTED REFLECTION SIGNAL
B2 MIXED REFLECTION SIGNAL
B3 COMPARISON REFLECTION SIGNAL
B4 DIGITAL COMPARISON REFLECTION SIGNAL
30 Bf1, Bf2 REFLECTION SIGNAL
C, Cc AMPLITUDE AND PHASE INFORMATION SIGNAL
CR1, CR2, CR3 CIRCLE
D MATCHING SECTION CONTROL SIGNAL

D1 INDUCTANCE CONTROL SIGNAL
D2, D3 CAPACITANCE CONTROL SIGNAL
Ec1 FORWARD MIXED SIGNAL
Ec1' PHASE-SHIFTED MIXED SIGNAL
5 Ec2 FORWARD COMPARISON SIGNAL
Ec2' PHASE-SHIFTED COMPARISON SIGNAL
Ec3 DIGITAL FORWARD COMPARISON SIGNAL
Ec3' DIGITAL PHASE-SHIFTED COMPARISON SIGNAL
Fc1, Fc2 TRANSMISSION AMPLITUDE SIGNAL
10 Fc1', Fc2' REFLECTION AMPLITUDE SIGNAL
Fc3 DIGITAL TRANSMISSION AMPLITUDE SIGNAL
Fc3' DIGITAL REFLECTION AMPLITUDE SIGNAL
HA TRANSMISSION SIGNAL PEAK VALUE
HB REFLECTION SIGNAL PEAK VALUE
15 Hc FORWARD VOLTAGE VALUE
Hc' PHASE-SHIFTED VOLTAGE VALUE
P_{BA} AMPLITUDE RATIO
S LOCAL ELECTRICAL SIGNAL
TA, TB PEAK TIME
20 γ , γ_{e1} , γ_{e2} REFLECTION COEFFICIENT
 γ_{e3} AVERAGE REFLECTION COEFFICIENT
 θ_{BA} PHASE DIFFERENCE

CLAIMS

1. A matching circuit comprising:

a mismatch detection unit that is electrically connected to a transmitting circuit which is configured to generate a transmission signal and an antenna which is configured to wirelessly transmit the transmission signal;

a computation section that is electrically connected to the mismatch detection unit; and

a matching section that is electrically connected to the computation section and the transmitting circuit,

wherein the mismatch detection unit includes a first directional coupling section that is configured to generate a corresponding transmission signal which is a signal corresponding to the transmission signal from the transmitting circuit, a second directional coupling section that is configured to generate a corresponding reflection signal which is a signal corresponding to a reflection signal as an electrical signal to be reflected from the antenna to the transmitting circuit in response to the transmission signal, and a mismatch detection section that is configured to detect an amplitude ratio and a phase difference between the transmission signal and the reflection signal based on the corresponding transmission signal and the corresponding reflection signal,

the computation section is configured to transmit a matching section control signal to the matching section based on the amplitude ratio and the phase difference between the transmission signal and the reflection signal detected by the mismatch detection unit, and

the matching section is configured to change a signal value of the reflection signal by changing an impedance based on the matching section control signal.

2. The matching circuit according to claim 1, wherein
the computation section is configured to generate the
matching section control signal based on a reflection
coefficient which is calculated based on the amplitude
ratio and the phase difference between the transmission
signal and the reflection signal and represents a ratio
between signal values of the transmission signal and the
reflection signal.
3. The matching circuit according to claim 1 or 2,
wherein
the matching section includes a variable inductance
section capable of changing an inductance and a variable
capacitance section capable of changing a capacitance, and
changes the impedance by changing the inductance of the
variable inductance section and the capacitance of the
variable capacitance section.
4. The matching circuit according to claim 3, wherein
the variable inductance section is electrically
connected between the transmitting circuit and the antenna,
the variable capacitance section is provided in plural
including a first variable capacitance section and a second
variable capacitance section,
the first variable capacitance section has one
connection portion that is electrically connected between
the variable inductance section and the transmission
circuit and another connection portion that is grounded,
and
the second variable capacitance section has one
connection portion that is electrically connected between
the variable inductance section and the antenna and another
connection portion that is grounded.

5. The matching circuit according to claim 3 or 4,
wherein

the variable capacitance section successively changes
5 the capacitance depending on a voltage to be applied
thereto.

6. The matching circuit according to claim 3 or 4,
wherein

10 the matching section includes a plurality of the first
variable capacitance sections connected in parallel, a
plurality of the second variable capacitance sections
connected in parallel, and a capacitance switch section
that is configured to switch each connection among the
15 plurality of first variable capacitance sections and the
plurality of second variable capacitance sections, and
the computation section controls the capacitance
switch section to cause the plurality of first variable
capacitance sections and the plurality of second variable
20 capacitance sections to be grounded and change a total
capacitance of the plurality of first variable capacitance
sections and the plurality of second variable capacitance
sections.

25 7. The matching circuit according to any one of claims 3
to 6, wherein

the matching section includes a plurality of the
variable inductance sections and an inductance switch
section that is configured to switch each connection
30 between the plurality of variable inductance sections and
the transmitting circuit, and the antenna, and causes the
inductance switch section to switch the connection to

change a total inductance of the plurality of variable inductance sections.

8. The matching circuit according to any one of claims 1
5 to 7, wherein

the mismatch detection unit includes:

a local oscillator that is configured to transmit a local oscillation signal having a predetermined frequency;

a first mixing section that is electrically connected
10 to the first directional coupling section and the local oscillator and is configured to generate a mixed transmission signal by mixing signal values of the local oscillation signal and the corresponding transmission signal;

15 a second mixing section that is electrically connected to the second directional coupling section and the local oscillator and is configured to generate a mixed reflection signal by mixing signal values of the local oscillation signal and the corresponding reflection signal; and

20 an amplitude and phase detection section that is configured to detect the amplitude ratio and the phase difference between the transmission signal and the reflection signal by comparing the mixed transmission signal and the mixed reflection signal.

25

9. The matching circuit according to any one of claims 1 to 7, wherein

the mismatch detection unit includes:

a first mixing section that is electrically connected
30 to the first directional coupling section and the second directional coupling section and is configured to generate a forward mixed signal by mixing signal values of the

corresponding transmission signal and the corresponding reflection signal;

an amplitude detection section that is configured to detect amplitude of the corresponding transmission signal
5 and amplitude of the corresponding reflection signal;

a second mixing section that is electrically connected to the first directional coupling section and the second directional coupling section and is configured to generate a phase-shifted mixed signal by shifting any one phase of
10 the corresponding transmission signal and the corresponding reflection signal and mixing the corresponding transmission signal and the corresponding reflection signal; and

an amplitude and phase detection section that is configured to detect an amplitude ratio between the
15 transmission signal and the reflection signal based on the amplitude of the corresponding transmission signal and the amplitude of the corresponding reflection signal and is configured to detect phase difference between the transmission signal and the reflection signal by comparing
20 the forward mixed signal and the phase-shifted mixed signal.

10. The matching circuit according to any one of claims 1 to 9, wherein

when amplitude of the reflection signal is equal to or
25 larger than a predetermined threshold, the changing of the impedance performed by the matching section is stopped.

11. The matching circuit according to any one of claims 1 to 10, wherein

30 the matching circuit is electrically connected to a receiving circuit to which a reception signal received by the antenna is input and the reflection signal from the antenna is reflected.

12. The matching circuit according to any one of claims 1 to 11, wherein

the matching section is provided between the
5 transmitting circuit and the antenna, and

the mismatch detection unit is provided between the matching section and the antenna and is connected to the transmitting circuit via the matching section.

10 13. The matching circuit according to any one of claims 1 to 11, wherein

the matching section is provided between the transmitting circuit and the antenna, and

the mismatch detection unit is provided between the
15 transmitting circuit and the matching section and is connected to the antenna via the matching section.

14. The matching circuit according to any one of claims 1 to 11, wherein

20 the matching section is provided between the transmitting circuit and the antenna,

the mismatch detection unit is provided in plural including a first mismatch detection unit and a second mismatch detection unit,

25 the first mismatch detection unit is provided between the matching section and the antenna and is connected to the transmitting circuit via the matching section, and

the second mismatch detection unit is provided between the transmitting circuit and the matching section and is
30 connected to the antenna via the matching section.

15. A wireless communication apparatus comprising:

the matching circuit according to any one of claims 1 to 14;

a transmitting circuit that is electrically connected to the matching circuit and generates the transmission
5 signal; and

an antenna that is electrically connected to the matching circuit and wirelessly transmits the transmission signal.