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United States Patent Application Publication	20250260150
Kind Code	A1
Publication Date	August 14, 2025
Inventor(s)	NIHEI; Ryota et al.

PHASE SHIFTER AND ANTENNA DEVICE

Abstract

A phase shifter including a 90 degree hybrid circuit having two reflection ends, a variable stub having a line formation layer made of vanadium dioxide and extending from each of the two reflection ends, and a ground pattern formed with a groove in which the variable stub is disposed and connected to a side end of the variable stub disposed in the groove.

Inventors: **NIHEI; Ryota (Tokyo, JP), YOSHIDA; Kohei (Tokyo, JP), FUJIO; Okumura (Kanagawa, JP)**

Applicant: **NEC Corporation** (Tokyo, JP)

Family ID: **96660135**

Assignee: **NEC Corporation (Tokyo, JP)**

Appl. No.: **18/999037**

Filed: **December 23, 2024**

Foreign Application Priority Data

JP	2024-018568	Feb. 09, 2024

Publication Classification

Int. Cl.: **H01P1/18** (20060101); **H01Q3/36** (20060101); **H01Q21/06** (20060101)

U.S. Cl.:

CPC **H01P1/18** (20130101); **H01Q3/36** (20130101); **H01Q21/065** (20130101);

Background/Summary

[0001] This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2024-018568, filed on Feb. 9, 2024, the disclosure of which is incorporated herein in its entirety by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to a phase shifter and an antenna device.

BACKGROUND ART

[0003] For mobile communication after the fifth generation mobile communication, an antenna device compatible with radio waves in a high frequency band has been developed. For example, examples of such an antenna device include a phased array antenna configured by a plurality of antenna elements. The phased array antenna can form a beam having a desired directivity by changing an excitation phase of an antenna element using a phase shifter mounted on a pre-stage of the antenna element. For example, since a phase shift range up to 360 degrees can be covered by using a switched line phase shifter, in such a way that a large scanning angle can be achieved. However, it is difficult to incorporate such a phase shifter in a small antenna device having a plurality of patch antennas.

[0004] PTL 1 (Japanese Patent Application Laid-Open No. 2019-029722) discloses a reflection-type variable phase shifter intended to continuously change a phase. The variable phase shifter of PTL 1 includes a 90 degree hybrid circuit, a pair of switches, a pair of first variable reactance elements, a pair of first stubs, and a pair of second variable reactance elements. The 90 degree hybrid circuit has a first port, a second port, a third port, and a fourth port. With respect to an input of a signal from the first port, the 90 degree hybrid circuit outputs the signal to the second port and the third port with a phase difference of 90 degrees and does not output the signal to the fourth port. The switch is provided in each of the second port and the third port. The first variable reactance element is connected to each of the pair of switches. The switch is connected to one end of the first stub. The second variable reactance element is connected to the other end of the first stub. The switch switches between connection with the first variable reactance element and connection with one end of the first stub.

[0005] According to the variable phase shifter of PTL 1, the phase shift amount can be changed by switching the connection between the second port and the third port of the 90 degree hybrid circuit and the variable reactance element and the stub. According to the variable phase shifter of PTL 1, a continuous phase shift change can be achieved by continuously changing the capacitance by applying a reverse voltage to the variable reactance element. However, in the variable phase shifter of PTL 1, it is necessary to finely control the reverse voltage to be applied to the variable reactance element, and it is difficult to obtain a stable phase shift amount.

[0006] An object of the present disclosure is to provide a phase shifter and an antenna device capable of achieving continuous phase shift change with a stable phase shift amount.

SUMMARY

[0007] A phase shifter according to an aspect of the present disclosure includes a 90 degree hybrid circuit having two reflection ends, a variable stub having a line formation layer made of vanadium dioxide and extending from each of the two reflection ends, and a ground pattern formed with a groove in which the variable stub is disposed and connected to a side end of the variable stub disposed in the groove.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Exemplary features and advantages of the present invention will become apparent from the following detailed description when taken with the accompanying drawings in which:

[0009] FIG. **1** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to the present disclosure;

[0010] FIG. **2** is a conceptual diagram for explaining an example of a 90 degree hybrid circuit according to the present disclosure;

[0011] FIG. **3** is a conceptual diagram in which a portion of a variable stub according to the present disclosure is enlarged;

[0012] FIG. **4** is a conceptual diagram for explaining a configuration of the variable stub according to the present disclosure;

[0013] FIG. **5** is a conceptual diagram illustrating an example of a configuration of the variable stub according to the present disclosure;

[0014] FIG. **6** is a conceptual diagram illustrating an example of a configuration of the variable stub according to the present disclosure;

[0015] FIG. **7** is a conceptual diagram illustrating an example of a circuit configuration of a heat generation drive circuit according to the present disclosure;

[0016] FIG. **8** is a block diagram illustrating an example of a configuration of an antenna device including a phase shifter according to the present disclosure;

[0017] FIG. **9** is a conceptual diagram illustrating an example in which a conductive portion (line) is formed in the variable stub according to the present disclosure;

[0018] FIG. **10** is a conceptual diagram in which a conductive portion (line) formed in the variable stub according to the present disclosure is enlarged;

[0019] FIG. **11** is a conceptual diagram in which a conductive portion (line) formed in the variable stub according to the present disclosure is enlarged;

[0020] FIG. **12** is a conceptual diagram illustrating an example of a cross section in an extended line region of a conductive portion (line) formed in the variable stub according to the present disclosure;

[0021] FIG. **13** is a conceptual diagram illustrating an example of a cross-section in a grounded line region of a conductive portion (line) formed in the variable stub according to the present disclosure;

[0022] FIG. **14** is a conceptual diagram illustrating an example of a conductor pattern formed on the variable stub according to the present disclosure;

[0023] FIG. **15** is a conceptual diagram illustrating an example of a conductor pattern formed on the variable stub according to the present disclosure;

[0024] FIG. **16** is a conceptual diagram illustrating an example of a conductor pattern formed on the variable stub according to the present disclosure;

[0025] FIG. **17** is an example of a table used to select a conductor pattern formed on the variable stub according to the present disclosure;

[0026] FIG. **18** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to the present disclosure;

[0027] FIG. **19** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to the present disclosure;

[0028] FIG. **20** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to the present disclosure;

[0029] FIG. **21** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to the present disclosure;

[0030] FIG. **22** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to the present disclosure;

[0031] FIG. **23** is a conceptual diagram illustrating an example of a configuration of the antenna device according to the present disclosure;

[0032] FIG. **24** is a conceptual diagram illustrating an example of a configuration of an antenna device according to the present disclosure;

[0033] FIG. **25** is a conceptual diagram illustrating an example of a matrix circuit formed on an

upper surface of a substrate according to the present disclosure;
[0034] FIG. **26** is a conceptual diagram illustrating an example of a configuration of an antenna device according to the present disclosure;
[0035] FIG. **27** is a block diagram illustrating an example of a functional configuration of the antenna device according to the present disclosure;
[0036] FIG. **28** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to the present disclosure; and
[0037] FIG. **29** is a block diagram illustrating an example of a hardware configuration that executes control according to the present disclosure.

EXAMPLE EMBODIMENT

[0038] Example embodiments of the present invention will be described below with reference to the drawings. In the following example embodiments, technically preferable limitations are imposed to carry out the present invention, but the scope of this invention is not limited to the following description. In all drawings used to describe the following example embodiments, the same reference numerals denote similar parts unless otherwise specified. In addition, in the following example embodiments, a repetitive description of similar configurations or arrangements and operations may be omitted.

First Example Embodiment

[0039] First, a phase shifter according to a first example embodiment will be described with reference to the drawings. For example, the phase shifter of the present example embodiment is mounted on an antenna device including a patch antenna, which is a type of planar antenna. The phase shifter of the present example embodiment can be applied to transmission of a transmission target radio wave and reception of a reception target radio wave arriving from the outside. For example, the phase shifter of the present example embodiment can be applied to an antenna device used for transmission and reception of a transmission/reception target signal in a high frequency band used in mobile communication after the fifth generation mobile communication. Hereinafter, the electrical length of the transmission/reception target signal on a substrate is denoted by 2 (2 is a real number).

(Configuration)

[0040] FIG. **1** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to the present disclosure. The phase shifter **10** includes a 90 degree hybrid circuit **11**, a ground pattern **12**, a variable stub **13**A and a variable stub **13**B. The variable stub **13**A and the variable stub **13**B have similar configuration. Hereinafter, when the variable stub **13**A and the variable stub **13**B are not distinguished from each other, they are referred to as variable stubs **13**.
[0041] The 90 degree hybrid circuit **11** is a 90 degree hybrid circuit including 4 transmission lines. Each of the four transmission lines forms one side of a quadrangle. A port is formed at each vertex of a quadrangle formed by the four transmission lines included in the 90 degree hybrid circuit **11**. The **90** degree hybrid circuit **11** includes a first port P.sub.1, a second port P.sub.2, a third port P.sub.3, and a fourth port P.sub.4. The first port P.sub.1 is an input end. The first port P.sub.1 receives a phase shift target signal. The second port P.sub.2 is a reflection end (also referred to as a first reflection end). The variable stub **13**A is connected to the second port P.sub.2. The third port P.sub.3 is a reflection end (also referred to as a second reflection end). The variable stub **13**B is connected to the third port P.sub.3. The fourth port P.sub.4 is an output end. The phase-shifted signal is output from the fourth port P.sub.4.
[0042] FIG. **2** is a conceptual diagram for explaining a 90 degree hybrid circuit according to the present disclosure. The 90 degree hybrid circuit **11** includes four transmission lines (R.sub.1, R.sub.2, R.sub.3, R.sub.4). The electrical length of each of the four transmission lines (R.sub.1, R.sub.2, R.sub.3, R.sub.4) is 2/4 (90 degrees). FIG. **2** is a diagram conceptually illustrating a 90 degree hybrid circuit according to the present disclosure, and is not a diagram accurately illustrating a structure of the 90 degree hybrid circuit.

[0043] The transmission line R.sub.1 is a transmission line having an electrical length of N/4. The characteristic impedance of the transmission line R.sub.1 is Z.sub.0/√2. The first end of the transmission line R.sub.1 is connected to the first port P.sub.1 (input end). Furthermore, the first end of the transmission line R.sub.1 is connected to the first end of the transmission line R.sub.2. The second end of the transmission line R.sub.1 is connected to the first end of the transmission line R.sub.4. Furthermore, the second end of the transmission line R.sub.1 is connected to the second port P.sub.2. The variable stub **13**A is connected to the second port P.sub.2.
[0044] The transmission line R.sub.2 is a transmission line having an electrical length of λ/4. The characteristic impedance of the transmission line R.sub.2 is Z.sub.0. The first end of the transmission line R.sub.2 is connected to the first port P.sub.1 (input end). Furthermore, the first end of the transmission line R.sub.2 is connected to the first end of the transmission line R.sub.1.
[0045] The second end of the transmission line R.sub.2 is connected to the fourth port P.sub.4 (output end). The second end of the transmission line R.sub.2 is connected to the first end of the transmission line R.sub.3 .
[0046] The transmission line R.sub.3 is a transmission line having an electrical length of λ/4.
[0047] The characteristic impedance of the transmission line R.sub.2 is Z.sub.0/√2. The first end of the transmission line R.sub.3 is connected to the fourth port P.sub.4 (output end). The first end of the transmission line R.sub.3 is connected to the second end of the transmission line R.sub.2. The second end of the transmission line R.sub.3 is connected to the second end of the transmission line R.sub.4 . Furthermore, the second end of the transmission line R.sub.3 is connected to the third port P.sub.3. The variable stub **13**B is connected to the third port P.sub.3.
[0048] The transmission line R.sub.4 is a transmission line having an electrical length of λ/4. The characteristic impedance of the transmission line R.sub.4 is Z.sub.0. The first end of the transmission line R.sub.4 is connected to the second end of the transmission line R.sub.1. Furthermore, the first end of the transmission line R.sub.4 is connected to the second port P.sub.2.
[0049] One of the variable stubs **13**A is connected to the second port P.sub.2. The second end of the transmission line R.sub.4 is connected to the second end of the transmission line R.sub.3 . Furthermore, the second end of the transmission line R.sub.4 is connected to the third port P.sub.3. The variable stub **13**B is connected to the third port P.sub.3.
[0050] The ground pattern **12** is a pattern made of a conductor. For example, a material of the ground pattern **12** is metal (including alloy) such as copper, aluminum, and chromium. The ground pattern **12** is electrically connected to a housing or the like set to a ground potential. The potential of the ground pattern **12** is a ground potential. A pair of grooves is formed in the ground pattern **12**. The pair of grooves formed in the ground pattern **12** has a shape extending from the second port P.sub.2 and the third port P.sub.3 of the 90 degree hybrid circuit **11**. Each of the variable stub **13**A and the variable stub **13**B is disposed in each of the pair of grooves formed in the ground pattern **12**. Inside the pair of grooves formed in the ground pattern **12**, the variable stub **13**A and the variable stub **13**B are arranged in such a way as to be in contact with the ground pattern **12**.
[0051] The variable stub **13**A and the variable stub **13**B are stubs having a line formation layer composed of vanadium dioxide VO.sub.2. The variable stub **13**A and the variable stub **13**B are stubs in which a line length utilizing the phase transition between the insulating phase and the metal phase of the vanadium dioxide VO.sub.2 is variable. Vanadium dioxide VO.sub.2 contained in the line formation layer is an insulating layer at a temperature lower than the phase transition temperature T. When the phase transition temperature T is exceeded, the vanadium dioxide VO.sub.2 contained in the insulating phase line formation layer undergoes phase transition from the insulating phase to the metal phase. The line length of the variable stub **13** changes according to the state of phase transition of the vanadium dioxide VO.sub.2 constituting the variable stub **13**.
[0052] The variable stub **13**A is disposed inside one groove (upper side in FIG. **1**) formed in the ground pattern **12**. The first end of the variable stub **13**A is connected to the second port P.sub.2 of the 90 degree hybrid circuit **11**. That is, the first end of the variable stub **13**A is connected to the

second end of the transmission line R.sub.1 and the first end of the transmission line R.sub.4 via the second port P.sub.2. A side end of the variable stub **13**A is connected to the ground pattern **12**. The second end of the variable stub **13**A may be connected to the ground pattern **12** or may not be connected to the ground pattern **12**.

[0053] The variable stub **13**B is disposed inside the other groove (the lower side in FIG. **1**) formed in the ground pattern **12**. The first end of the variable stub **13**B is connected to the third port P.sub.3 of the 90 degree hybrid circuit **11**. That is, the first end of the variable stub **13**B is connected to the second end of the transmission line R.sub.3 and the second end of the transmission line R.sub.4 via the third port P.sub.3. A side end of the variable stub **13**B is connected to the ground pattern **12**. The second end of the variable stub **13**B may be connected to the ground pattern **12** or may not be connected to the ground pattern **12**.

[0054] FIG. **3** is a conceptual diagram in which a portion of a variable stub according to the present disclosure is enlarged. In the variable stub **13**, an extended line region A.sub.1 and a grounded line region A.sub.2 are formed. The extended line region A.sub.1 is a region where a line extending from the reflection end of the 90 degree hybrid circuit **11** is formed. The line length of the variable stub **13**B is set according to the length of the conductive portion formed in the extended line region A.sub.1. The grounded line region A.sub.2 is a region where a line for grounding the line extended in the extended line region A.sub.1 to the ground pattern **12** is formed. The variable stub **13** functions as a short stub by grounding the end portion of the conductive portion formed in the extended line region A.sub.1 to the ground pattern **12** at the portion formed in the grounded line region A.sub.2. For example, the variable stub **13** can be caused to function as an open stub without grounding the end portion of the conductive portion formed in the extended line region A.sub.1.

[Variable Stub]

[0055] FIG. **4** is a conceptual diagram for explaining a configuration of the variable stub according to the present disclosure. FIG. **4** illustrates a line formation layer, a heat generation drive circuit, and a heat generating element constituting the variable stub. The heat generation drive circuit **131** and the heat generating element **132** are arrayed in a two-dimensional array form. One heat generating element **132** is associated with one heat generation drive circuit **131**. The heat generation of the heat generating element **132** is controlled via the wiring L connected to the associated heat generation drive circuit **131**. The line formation layer **133** is disposed above the heat generation drive circuit **131** and the heat generating element **132**. In FIG. **4**, illustration is made such that the line formation layer **133** is located below the heat generation drive circuit **131** and the heat generating element **132**, but in practice, the line formation layer **133** is located above the heat generation drive circuit **131** and the heat generating element **132**. Furthermore, in FIG. **4**, contact hole H (broken-line frame) is shown in a ground pattern **12**. The contact hole His an opening for electrically connecting the ground pattern **12** and the line formation layer **133**.

[0056] FIGS. **5** and **6** are conceptual diagrams illustrating an example of a configuration of a variable stub according to the present disclosure. FIG. **5** illustrates a cross-sectional view of the variable stub taken along a cutting line A-A in FIG. **4**. The cutting line A-A is a cutting line for cutting the variable stub **13** in a short direction (up-down direction in the plane of drawing). The cutting line A-A passes through the heat generating element **132**. FIG. **6** illustrates a cross-sectional view of the variable stub taken along a cutting line B-B or a cutting line C-C in FIG. **4**. The cutting line B-B and the cutting line C-C are cutting lines for cutting the variable stub **13** in a longitudinal direction (left-right direction in the plane of drawing). The cutting line B-B is a cutting line for cutting a position including the wiring L in the extended line region A.sub.1. The cutting line C-C is a cutting line for cutting a position including the wiring L in the grounded line region A.sub.2.

[0057] The variable stub **13** includes a plurality of heat generation drive circuits **131**, a plurality of heat generating elements **132**, and a line formation layer **133**. The variable stub **13** is formed on the substrate **140**. For example, the substrate **140** is a plate-like member having an insulating property such as glass or epoxy resin. A matrix circuit of thin film transistors (TFTs) including a plurality of heat generation drive circuits **131** and a plurality of wirings L is formed on the upper surface of substrate **140**. The plurality of wirings L electrically connect the heat generation drive circuit **131** and the heat generating element **132**. The line formation layer **133** is formed above the plurality of heat generating elements **132**. The substrate **140** and the line formation layer **133** are insulated from each other by a first insulating layer **141**. A second insulating layer **142** is formed on the upper surface of the line formation layer **133**. A contact hole His formed in the second insulating layer **142** above the side end of the line formation layer **133**. The line formation layer **133** is electrically connected to the ground pattern **12** via the contact hole H.

[0058] The plurality of heat generation drive circuits **131** are formed on the upper surface of the substrate **140**. The plurality of heat generation drive circuits **131** are formed in a two-dimensional array form in plan view of the upper surface of the substrate **140**. The plurality of heat generation drive circuits **131** are isolated by the first insulating layer **141**. Each of the plurality of heat generation drive circuits **131** is associated with one heat generating element **132**. Each of the plurality of heat generation drive circuits **131** is used for temperature control of the associated heat generating element **132**.

[0059] Each of the plurality of heat generating elements **132** is associated with one heat generation drive circuit **131**. The heat generating element **132** is disposed obliquely above the associated heat generation drive circuit **131**. The heat generating element **132** may be disposed at a position not obliquely above the associated heat generation drive circuit **131**. The heat generating element **132** is electrically connected to the associated heat generation drive circuit **131** via the wiring L. The line formation layer **133** is formed on the upper surfaces of the plurality of heat generating elements **132**. The plurality of heat generating elements **132** are isolated by the first insulating layer **141**. The plurality of heat generating elements **132** may be isolated by a gap formed in the first insulating layer **141**. The heat generating element **132** is used to heat the line formation layer **133** on the upper side. For example, the heat generating element **132** is achieved by an alloy having nickel Ni or chromium Cr as a main component. The heat generating element **132** may be achieved by an alloy having chromium Cr, iron Fe, and aluminum Al as main components. The material of the heat generating element **132** is not particularly limited. When current is supplied, the temperature of the heat generating element **132** rises. For example, supply of current to the heat generating element **132** can be controlled using a thin film transistor (TFT). The heat of the heat generating element **132** is transferred to the line formation layer **133**.

[0060] The line formation layer **133** is disposed above the plurality of heat generating elements **132**. The lower surface of the line formation layer **133** and the upper surfaces of the plurality of heat generating elements **132** are thermally connected. The lower surface of the line formation layer **133** and the upper surfaces of the plurality of heat generating elements **132** are preferably in contact with each other. As long as the heat of the heat generating element **132** can be transferred to the line formation layer **133** and the phase transition can be controlled, another layer may be interposed between the lower surface of the line formation layer **133** and the upper surfaces of the plurality of heat generating elements **132**. The line formation layer **133** is partially heated by the heat generating element **132** at the position on the lower side generating heat.

[0061] The line formation layer **133** contains vanadium dioxide VO.sub.2. In the line formation layer **133**, a line having electrical conductivity is formed by phase transition of an insulating phase-metal phase of vanadium dioxide VO.sub.2. Vanadium dioxide VO.sub.2 contained in the line formation layer **133** has a composition that undergoes a phase transition from an insulating phase to a metal phase at a phase transition temperature T. At a temperature lower than the phase transition temperature T, the vanadium dioxide VO.sub.2 is an insulating phase. At a temperature lower than the phase transition temperature T, electricity does not flow through the vanadium dioxide VO.sub.2. At a temperature higher than the phase transition temperature T, the vanadium dioxide VO.sub.2 is a metal phase. At a temperature higher than the phase transition temperature T, electricity flows through the vanadium dioxide VO.sub.2. The phase transition of vanadium dioxide

VO.sub.2 exhibits hysteresis in temperature rise and temperature fall. Therefore, the phase transition of the insulating phase-metal phase of vanadium dioxide VO.sub.2 is adjusted in a temperature range including the phase transition temperature T.

[0062] For example, the line formation layer **133** may have a line formation layer containing vanadium dioxide VO.sub.2 to which no additive element is added. For example, an additive element may be added to vanadium dioxide VO.sub.2 contained in the line formation layer **133**. For example, an additive element for lowering the phase transition temperature may be added to vanadium dioxide VO.sub.2 contained in the line formation layer **133**. When an additive element such as tungsten W, magnesium Mg, iron Fe, molybdenum Mo, fluorine F, or niobium Nb is added, the phase transition temperature of vanadium dioxide VO.sub.2 lowers.

[0063] The first insulating layer **141** is formed on the upper surface of the substrate **140**. The first insulating layer **141** covers the sides of the heat generation drive circuit **131** and the heat generating element **132**. The line formation layer **133** is disposed above the first insulating layer **141**. For example, the first insulating layer **141** is made of a general interlayer insulating material. For example, the first insulating layer **141** is made of an inorganic material such as silicon dioxide. The material of the first insulating layer **141** may be an organic material.

[0064] The second insulating layer **142** is formed above the line formation layer **133**. For example, the second insulating layer **142** is made of a general interlayer insulating material. For example, the second insulating layer **142** is formed of a material such as silicon dioxide. A contact hole H is formed in the second insulating layer **142** above the side end of the line formation layer **133**. The line formation layer **133** and the ground pattern **12** are electrically connected via the contact hole H.

[Heat Generation Drive Circuit]

[0065] FIG. **7** is a conceptual diagram illustrating an example of a circuit configuration of a heat generation drive circuit according to the present disclosure. The heat generation drive circuit **131** includes a transistor S, a transistor D, and a capacitor C. FIG. **7** illustrates an example in which the heat generating element **132** is achieved by a resistance element. Hereinafter, a connection relationship among the transistor S, the transistor D, the capacitor C, and the heat generating element **132** will be described. In the following description, directions in the plane of drawing of FIG. **7** are shown in parentheses. FIG. **7** illustrates an example of the circuit configuration of the heat generation drive circuit according to the present disclosure, and does not limit the circuit configuration of the heat generation drive circuit.

[0066] The transistor S is used to select the heat generating element **132**. A first end (left side) of the diffusion layer of the transistor S is connected to a supply source of the voltage V.sub.data. The second end (right side) of the diffusion layer of the transistor S is connected to the first electrode (lower side) of the capacitor C and the gate (left side) of the transistor D. The gate (upper side) of the transistor S is connected to a supply source of the voltage V.sub.scan.

[0067] The capacitor C is used to control the voltage applied to the gate of the transistor D. The first electrode (lower side) of the capacitor C is connected to the second end (right side) of the diffusion layer of the transistor S and the gate (left side) of the transistor D. The second electrode (upper side) of the capacitor C is connected to a supply source of the voltage V.sub.cap. A voltage V.sub.cap is applied to the second electrode (upper side) of the capacitor C.

[0068] The transistor D is used to control the voltage to be supplied to the heat generating element **132**. A first end (upper side) of the diffusion layer of the transistor D is connected to a supply source of the voltage V.sub.a. The voltage V.sub.a is applied to the first end (upper side) of the diffusion layer of the transistor D. The second end (lower side) of the diffusion layer of the transistor D is connected to the first electrode (lower side) of the heat generating element **132**. The gate (left side) of the transistor D is connected to the second end (right side) of the diffusion layer of the transistor S and the first end (lower side) of the capacitor C.

[0069] The first end (upper side) of the heat generating element **132** is connected to the second end

(lower side) of the diffusion layer of the transistor D. The second end (lower side) of the heat generating element **132** is connected to a supply source of the voltage V.sub.k. The voltage V.sub.k is applied to the second end (lower side) of the heat generating element **132**. When the transistor S transitions to an ON state by the application of the voltage V.sub.scan, a voltage that is a difference between the voltage V.sub.data and the voltage V.sub.cap is applied to the capacitor C. When charging of the capacitor C is completed, the transistor S transitions to an OFF state. After the transistor S transitions to the OFF state, the capacitor C holds the voltage, and the transistor D continues to maintain the ON state according to the potential. In an ON state of the transistor D, a current corresponding to a voltage corresponding to a potential difference between the voltage V.sub.a and the voltage V.sub.k and a resistance value of the heat generating element **132** flows, and the heat generating element **132** generates heat. The heat generated in the heat generating element **132** is transferred to the line formation layer **133** in thermal contact with the heat generating element **132**.
[0070] FIG. **8** is a block diagram illustrating an example of a configuration of an antenna device including a phase shifter according to the present disclosure. The antenna device **1** includes a phase shifter **10** and a control circuit **17**. The control circuit **17** is a circuit for controlling the phase shifter **10**. For example, the control circuit **17** is achieved by a microcomputer including a processor and a memory. The control circuit **17** controls the heat generation drive circuit **131** included in the variable stub **13** of the phase shifter **10** to control the conductor pattern of the line formation layer **133**. The capacitance of the variable stub **13** is adjusted according to the control of the control circuit **17**. The control circuit **17** may be configured as a component of the phase shifter **10**.
[Line Formation]
[0071] Next, the line formation control in the variable stub **13** will be described with reference to the drawings. FIGS. **9** to **13** are conceptual diagrams for explaining an example of the line formation control of the variable stub according to the present disclosure.
[0072] FIG. **9** is a conceptual diagram illustrating an example in which a conductive portion (line) is formed in the variable stub according to the present disclosure. FIG. **9** is a plan view of the variable stub viewed from an upper viewpoint. The extended line E and the grounded line G are conductive portions formed in the line formation layer **133**. The extended line E and the grounded line G are indicated by hatching different from that of the non-conductive portion. The extended line E is formed in the extended line region A.sub.1. The extended line E is extended in the extended line region A.sub.1 starting from a contact area (left side in the plane of drawing) with the reflection ends (the second port P.sub.2 and the third port P.sub.3) of the 90 degree hybrid circuit **11**. The grounded line G is formed in the grounded line region A.sub.2. The grounded line G is formed between the terminal end (right side in the plane of drawing) of the extended line E and the ground pattern **12**. The grounded line G electrically connects the terminal end (right side in the plane of drawing) of the extended line E and the ground pattern **12**.
[0073] FIGS. **10** to **11** are conceptual diagrams in which a conductive portion (line) formed in the variable stub according to the present disclosure is enlarged. FIGS. **10** to **11** are plan views of the variable stub viewed from an upper viewpoint. FIG. **11** illustrates a line formation layer, a heat generation drive circuit, and a heat generating element constituting the variable stub. In FIGS. **10** to **11**, the heat generation unit region in the variable stub **13** is indicated by a region divided by a broken line. One heat generating element is assigned to the heat generation unit region.
[0074] FIG. **12** is a conceptual diagram illustrating an example of a cross section in an extended line region of a conductive portion (line) formed in the variable stub according to the present disclosure. FIG. **12** illustrates a cross-sectional view of the variable stub taken along a cutting line B-B in FIG. **11**. The cutting line B-B is a cutting line for cutting a position including the wiring L in the extended line region A.sub.1. FIG. **12** illustrates a plurality of heat generating elements. The heat generating element **132-**B**1**, the heat generating element **132-**B**2**, and the heat generating element **132-**B**3** generate heat to a temperature exceeding the phase transition temperature of the

vanadium dioxide VO.sub.2 contained in the variable stub **13**. The heat generating element **132**-B**4** does not generate heat. The vanadium dioxide VO.sub.2 contained in the variable stub **13** located above the heat generating element **132**-B**1**, the heat generating element **132**-B**2**, and the heat generating element **132**-B**3** is phase transitioned to the metal phase. Therefore, the extended line E is formed in the variable stub **13** at a position above the heat generating element **132**-B**1**, the heat generating element **132**-B**2**, and the heat generating element **132**-B**3**.
[0075] FIG. **13** is a conceptual diagram illustrating an example of a cross-section in a grounded line region of a conductive portion (line) formed in the variable stub according to the present disclosure. FIG. **13** illustrates a cross-sectional view of the variable stub taken along a cutting line C-C in FIG. **11**. The cutting line C-C is a cutting line for cutting a position including the wiring L in the grounded line region A.sub.2. FIG. **13** illustrates a plurality of heat generating elements. The heat generating element **132**-C**2** and the heat generating element **132**-C**3** generate heat to a temperature exceeding the phase transition temperature of the vanadium dioxide VO.sub.2 contained in the variable stub **13**. The heat generating element **132**-C**1** and the heat generating element **132**-C**4** do not generate heat. The vanadium dioxide VO.sub.2 contained in the variable stub **13** located above the heat generating element **132**-C**2** and the heat generating element **132**-C**3** is phase transitioned to the metal phase. Therefore, the grounded line G is formed in the variable stub **13** at a position above the heat generating element **132**-C**2** and the heat generating element **132**-C**3**.
[0076] As illustrated in FIGS. **12** to **13**, the extended line E and the grounded line G are formed in the variable stub **13** by the plurality of heat generating elements **132** generating heat. The terminal end of the extended line E is connected to the ground pattern **12** by the grounded line G. As a result, the variable stub **13** functions as a short stub extended by the length of the extended line E. For example, it is also possible to form the extended line E and not to form the grounded line G. In such a case, the variable stub **13** functions as an open stub extended by the length of the extended line E.
[0077] FIGS. **14** to **16** are conceptual diagrams illustrating an example of a conductor pattern formed on the variable stub according to the present disclosure. FIG. **14** illustrates a conductor pattern that minimizes the extension of the extended line E and grounds the extended line E via the grounded line G. FIG. **14** illustrates a state in which the line length of the variable stub **13** is minimum. FIG. **15** illustrates a conductor pattern that extends the extended line E and grounds the extended line E via the grounded line G. FIG. **16** illustrates a conductor pattern that maximizes the extension of the extended line E and grounds the extended line E via the grounded line G. FIG. **16** illustrates a state in which the line length of the variable stub **13** is maximum. As illustrated in FIGS. **14** to **16**, the line length of the variable stub **13** can be continuously changed by controlling the phase transition of the insulating layer-metal phase of the vanadium dioxide VO.sub.2 contained in the line formation layer **133**.
[0078] FIG. **17** is an example of a table (phase shift table **130**) used to select a conductor pattern formed in the variable stub according to the present disclosure. The phase shift table **130** stores a conductor pattern P.sub.c related to a desired phase shift amount. The conductor pattern P.sub.c is associated with an address indicating a position of the heat generating element **132** caused to generate heat for forming the conductor pattern P.sub.c. The conductor pattern P.sub.c1 is associated with the phase shift amount 0. The conductor pattern P.sub.c2 is associated with the phase shift amount ¼λ. The conductor pattern P.sub.c3 is associated with the phase shift amount ½λ. For example, a desired phase shift amount is set via an input device (not illustrated). The control circuit **17** selects the heat generation drive circuit **131** to be used for forming the conductor pattern P.sub.c related to the set desired phase shift amount. As a result, a desired phase shift amount is set in the variable stub **13**.
Modified Example
[0079] Next, a modified example of the phase shifter according to the present disclosure will be described with reference to the drawings. Hereinafter, variations of the line formation layer

included in the phase shifter will be described.

[0080] FIG. **18** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to a first modified example of the present disclosure. FIG. **18** is a plan view of a portion of the variable stub viewed from an upper viewpoint. In the line formation layer **134** of the present modified example, an isolation opening I is formed in a portion between the extended line region A.sub.1 and the grounded line region A.sub.2. The isolation opening I is an opening penetrating the line formation layer **134**. Since the line formation layer **134** of the present modified example includes the isolation opening I, thermal conduction between the extended line region A.sub.1 and the grounded line region A.sub.2 is reduced. According to the present modified example, the accuracy of the width of the extended line E formed in the extended line region A.sub.1 is improved.

[0081] FIG. **19** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to a second modified example of the present disclosure. FIG. **19** is a plan view of a portion of the variable stub viewed from an upper viewpoint. In the grounded line region A.sub.2, the line formation layer **135** is separated for each column (up-down direction in the plane of drawing) associated with each heat generating element **132**. That is, in the grounded line region A.sub.2 of the line formation layer **135**, the portion heated by the adjacent heat generating element **132** is thermally isolated. On the other hand, in the extended line region A**1**, the line formation layer **135** is not separated for each column (up-down direction in the plane of drawing) associated with each heat generating element **132**. According to the present modified example, the edge (side end) of the extended line E formed in the extended line region A.sub.1 can be accurately set. In addition, according to the present modified example, the edge (side end) of the grounded line G formed in the grounded line region A.sub.2 can be accurately set.

[0082] FIGS. **20** to **21** are conceptual diagrams illustrating an example of a configuration of a phase shifter according to a third modified example of the present disclosure. FIG. **20** is a plan view of a portion of the variable stub viewed from an upper viewpoint. FIG. **21** is a cross-sectional view taken along a cutting line D-D in FIG. **20**. In the present modified example, the line formation layer **136** including the extended line region A.sub.1 in which the extended line E is formed and the line formation layer **137** including the grounded line region A.sub.2 in which the grounded line G is formed are separated. The line formation layer **136** included in the extended line region A.sub.1 and the line formation layer **137** included in the grounded line region A.sub.2 are electrically connected by a connection member **125**. The material of the connection member **125** is not limited as long as it has electrical conductivity. The connection member **125** is preferably made of a material having high electrical conductivity and low thermal conductivity. For example, the connection member **125** may be made of a material containing vanadium dioxide VO.sub.2. Since the line formation layer **136** and the line formation layer **137** of the present modified example are separated from each other, thermal conduction between the extended line region A.sub.1 and the grounded line region A.sub.2 is reduced. According to the present modified example, the accuracy of the width of the extended line E formed in the extended line region A.sub.1 is improved.

[0083] FIG. **22** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to a fourth modified example of the present disclosure. FIG. **22** is a plan view of a portion of the variable stub viewed from an upper viewpoint. In the grounded line region A.sub.2, the line formation layer **138** is formed for each heat generating element **132**. The plurality of line formation layers **138** are separated from each other for each column (up-down direction in the plane of drawing) associated with each heat generating element **132**. That is, in the grounded line region A.sub.2, the line formation layer **138** heated by the adjacent heat generating element **132** is thermally isolated. On the other hand, in the extended line region A.sub.1, the line formation layer **136** is not separated for each column (up-down direction in the plane of drawing) associated with each heat generating element **132**. The line formation layer **136** included in the extended line region A.sub.1 and a plurality of line formation layers **138** included in the grounded line region

A.sub.2 are electrically connected by the connection member **125**. Similarly to the third modified example, the connection member **125** is not limited as long as it has electrical conductivity. Since the plurality of line formation layers **138** are separated from each other, thermal conduction between the extended line region A.sub.1 and the grounded line region A.sub.2 is reduced. According to the present modified example, the edge (side end) of the extended line E formed in the extended line region A.sub.1 can be accurately set. In addition, according to the present modified example, the edge (side end) of the grounded line G formed in the grounded line region A.sub.2 can be accurately set.

[0084] As described above, the phase shifter according to the present example embodiment includes the 90 degree hybrid circuit, the ground pattern, and the variable stub. The 90 degree hybrid circuit is a 90 degree hybrid circuit having two reflection ends. Two grooves in which variable stubs are disposed are formed in the ground pattern. The ground pattern is connected to the side ends of the variable stubs disposed in each of the two grooves. The variable stub has a line formation layer made of vanadium dioxide. One variable stub is disposed in each of the two grooves formed in the ground pattern. The variable stub is connected to each of the two reflection ends of the 90 degree hybrid circuit. The variable stub is extended from each of the two reflection ends.

[0085] The phase shifter of the present example embodiment includes a line formation layer made of vanadium dioxide. By performing temperature control, an extended line corresponding to the phase transition of the insulating phase-metal phase of vanadium dioxide is formed in the line formation layer. A continuous phase shift amount can be stably set in the line formation layer by controlling the line length of the extended line to be formed. Therefore, according to the phase shifter of the present example embodiment, a continuous phase shift change can be achieved with a stable phase shift amount.

[0086] In one aspect of the present example embodiment, the variable stub includes a plurality of heat generating elements and a plurality of heat generation drive circuits. The plurality of heat generating elements are arranged in an array form along one surface of the line formation layer. Each of the plurality of heat generation drive circuits is disposed one by one in association with each of the plurality of heat generating elements. Each of the plurality of heat generating elements is thermally connected to the line formation layer. Each of the plurality of heat generation drive circuits causes the heat generating element to generate heat to a temperature exceeding the phase transition temperature of vanadium dioxide contained in the line formation layer according to the selection of the heat generating element. According to the present aspect, a desired phase shift amount can be set by selecting a heat generating element according to the phase shift amount.

[0087] In one aspect of the present example embodiment, the line formation layer includes an extended line region and a grounded line region. The extended line region is extended from each of the two reflection ends of the 90 degree hybrid circuit. The grounded line region connects the extended line region and the ground pattern. According to the present aspect, a desired phase shift amount can be set by forming an extended line having a line length corresponding to the phase shift amount in the extended line region of the line formation layer.

[0088] In one aspect of the present example embodiment, an extended line extending from each of two reflection ends of the 90 degree hybrid circuit is formed in the extended line region. In the grounded line region, a grounded line for short circuiting the terminal end of the extended line formed in the extended line region to the ground pattern is formed. According to the present aspect, a desired phase shift amount can be set by forming an extended line having a line length corresponding to the phase shift amount in the extended line region of the line formation layer.

[0089] In one aspect of the present example embodiment, an extended line having a line length corresponding to a desired phase shift amount is formed in an extended line region. A grounded line connecting the terminal end of the extended line formed in the extended line region and the ground pattern is formed in the grounded line region. According to the present aspect, the short stub having a line length corresponding to a desired phase shift amount is formed.

[0090] In one aspect of the present example embodiment, in the line formation layer, an opening is formed between the extended line region and the grounded line region. In the line formation layer of the present aspect, thermal conduction between the extended line region and the grounded line region is reduced by the opening formed between the extended line region and the grounded line region. Therefore, according to the present aspect, the accuracy of the width of the extended line formed in the extended line region is improved.

[0091] In one aspect of the present example embodiment, the extended line region and the grounded line region are separated in the line formation layer. The extended line region and the grounded line region are electrically connected by the plurality of connection members arranged in association with the heat generating elements adjacent to each other in the direction perpendicular to the extending direction. In the line formation layer of the present aspect, the extended line region and the grounded line region are separated. In the line formation layer of the present aspect, thermal conduction between the extended line region and the grounded line region is reduced.

[0092] Therefore, according to the present aspect, the accuracy of the width of the extended line formed in the extended line region is improved.

[0093] In one aspect of the present example embodiment, a heat generation drive circuit that causes a heat generating element used for forming an extended line and a grounded line related to a conductor pattern related to a desired phase shift amount to generate heat is selected using a phase shift table in which the conductor pattern related to the phase shift amount is registered. In the line formation layer, an extended line and a grounded line related to the conductor pattern set using the phase shift table are formed. According to the present aspect, a desired phase shift amount can be easily set using the phase shift table.

Second Example Embodiment

[0094] Next, an antenna device according to a second example embodiment will be described with reference to the drawings. A planar antenna of the present example embodiment includes a patch antenna, which is a type of planar antenna. Hereinafter, description of a transmission device for transmitting a radio wave from the planar antenna and a reception device for receiving a radio wave received by the planar antenna will be omitted. For example, the planar antenna of the present example embodiment is used for transmission and reception of electromagnetic waves in a high frequency band expected to be applied to mobile communication of Beyond 5 Generation (B5G) subsequent to 5 Generation (5G). For example, the planar antenna of the present example embodiment is used for transmission and reception of signals of millimeter waves and terahertz waves. The planar antenna of the present example embodiment may be used for transmission and reception of signals other than millimeter waves and terahertz waves.

[0095] The antenna device of the present example embodiment includes the phase shifter according to the first example embodiment. For example, the phase shifter is formed using a manufacturing process technology of micro Light Emitting Diode (LED) display. In addition, the planar antenna of the present example embodiment includes a switching element formed using a manufacturing process technology of a thin-film transistor (TFT). The planar antenna of the present example embodiment is manufactured by combining a manufacturing process technology of a micro LED display (micro LED process technology) and a manufacturing process technology of a thin film transistor (TFT process technology). The planar antenna of the present example embodiment may be manufactured using a technology other than the micro LED process technology and the TFT process technology.

(Configuration)

[0096] FIG. **23** is a conceptual diagram illustrating an example of a configuration of the antenna device according to the present disclosure. FIG. **23** illustrates an example of an external appearance of the antenna device. The antenna device **2** includes a planar antenna **200**. An antenna array **20** is arranged on the upper surface of the planar antenna **200**. The antenna array **20** includes a plurality of patch antennas P. The plurality of patch antennas P are arrayed in a two-dimensional array form. In the example of FIG. **23**, the plurality of patch antennas P are arrayed along the X direction and the Y direction. The plurality of patch antennas P are phased arrayed. That is, the antenna device **2** functions as a phased array antenna.

[0097] A first drive circuit **271** and a second drive circuit **272** are mounted on the antenna device **2**. The first drive circuit **271** and the second drive circuit **272** are circuits used to select the patch antenna P to be driven. An address associated to each of the patch antennas P can be selected by driving the first drive circuit **271** and the second drive circuit **272**. The first drive circuit **271** and the second drive circuit **272** may be formed on the surface of the planar antenna **200** or may be formed inside the planar antenna **200**.

[0098] FIG. **24** is a conceptual diagram illustrating an example of a configuration of an antenna device according to the present disclosure. FIG. **24** is a cross-sectional view of the antenna device **2** taken along a cutting line passing through the patch antenna P. The antenna device **2** includes a patch antenna P, an insulating layer, a ground layer, a signal line layer, a substrate **220**, and a phase shifter forming layer. The insulating layer includes a first insulating layer **241**, a second insulating layer **242**, a third insulating layer **243**, and a fourth insulating layer **244**. The ground layer includes a first ground layer **251**, a second ground layer **252**, and a third ground layer **253**. The signal line layer includes a signal line L.sub.s1 and a signal line L.sub.s2. The phase shifter **21** associated with the patch antenna P is formed in the phase shifter forming layer. FIG. **24** illustrates an example in which the signal line layer and the patch antenna P are formed in different layers. The antenna device according to the present example embodiment may be configured as a coplanar side antenna in which the signal line layer and the patch antenna P are formed in the same layer. The third ground layer **253** may not be provided, and substrate **220** may be disposed at a position of the fourth insulating layer **244**.

[0099] The antenna array **20** is disposed on the upper surface of the first insulating layer **241**. The antenna array **20** includes a plurality of patch antennas P. Although a single patch antenna P is illustrated in FIG. **24**, the antenna device **2** includes a plurality of patch antennas P. The plurality of patch antennas P are arranged in a lattice shape along two directions orthogonal to each other. The plurality of patch antennas P are phased arrayed. The patch antenna P is a plate-shaped radiation element. For example, the patch antenna P has a square shape. The shape of the patch antenna P is not limited to a square shape, and may be a circular shape or other shapes.

[0100] The patch antenna P is power supplied by an electromagnetic coupling power supplying method. The patch antenna P is electromagnetically coupled to the signal line L.sub.s2 formed below the second insulating layer **242** via the slot S.sub.0. The patch antenna P is excited by electromagnetic coupling between the patch antenna P and the signal line L.sub.s2 via the slot S.sub.0. The impedance can be matched by arranging the open end of the signal line L.sub.s2 at a position away from immediately below the slot S.sub.0 by about ¼ wavelength and adjusting the dimension of the slot S.sub.0. For example, the shape of the slot S.sub.0 is rectangular. For example, the shape of the slot S.sub.0 may be a shape other than a rectangle, such as a dog-bone shape.

[0101] The patch antenna P has a structure equivalent to that of a microstrip line whose both ends are opened. The resonance frequency of the patch antenna P is an integral multiple of ½ of a wavelength equivalent to the length of one side of the patch antenna P. The size of the patch antenna P is set according to the wavelength of the transmission target radio wave. Since the patch antenna P is an open type resonator that resonates at a resonance frequency, the Q factor decreases due to radio wave radiation. In order to avoid a decrease in the Q factor due to radio wave radiation and to operate the patch antenna P as a resonator, it is preferable that the dielectric constants of the materials of the insulating layer and the substrate **220** are as high as possible. As the dielectric constants of the materials of the insulating layer and the substrate **220** become higher, the transmission of radio waves can be further suppressed. When the material of the insulating layer and the substrate **220** is a high dielectric, the thickness of the insulating layer and the substrate **220** and the width of the patch antenna P are set to be sufficiently small with respect to the wavelength of the radio wave used in communication. For example, in a case where the material of the insulating layer and the substrate **220** is a low dielectric, a microstrip antenna can be configured by increasing the thickness of the insulating layer and the width of the patch antenna P with respect to the wavelength of the transmission target radio wave to increase the radiation amount.

[0102] The patch antenna P is preferably configured such that a signal (radio wave) is easily radiated into space. On the other hand, an internal wiring such as a signal line or a wiring is configured such that a signal is less likely to be radiated. That is, it is better the smaller the dielectric constant required at the periphery of the patch antenna P, and it is better the larger the better the dielectric constant required around the internal wiring. Therefore, it is preferable that different manufacturing processes are applied to the structure around the patch antenna P and the structure around the internal wiring. For example, by applying a method of forming a structure around the patch antenna P by a liquid crystal process and forming a structure around the internal wiring by a thin film process, the structure of the antenna device **2** of the present example embodiment can be achieved.

[0103] The first insulating layer **241** forms a surface of the antenna device **2**. The first insulating layer **241** is stacked on the upper surface of the first ground layer **251**. For example, the material of the first insulating layer **241** is glass, glass epoxy, tetrafluoroethylene, epoxy, or the like. As long as communication radio waves can be transmitted and received, the first insulating layer **241** may be made of a material other than glass, glass epoxy, tetrafluoroethylene, epoxy, or the like.

[0104] The first ground layer **251** is stacked on the upper surface of the second insulating layer **242**. The first insulating layer **241** is stacked on an upper surface of the first ground layer **251**. For example, a material of the first ground layer **251** is metal (including alloy) such as copper, aluminum, and chromium. The potential of the first ground layer **251** is a ground potential. An opening is formed in the first ground layer **251**. The opening formed in the first ground layer **251** is referred to as a slot S.sub.0. The slot So is formed below the patch antenna P. The signal line L.sub.s2 is extended immediately below the slot S.sub.0. The signal propagated through the signal line L.sub.s2 is propagated to the patch antenna P by electromagnetic coupling EC between the signal line L.sub.s2 and the patch antenna P.

[0105] The second insulating layer **242** is formed above the signal line layer. The first ground layer **251** is formed on an upper surface of the second insulating layer **242**. An opening (air gap) may be formed in a portion of the second insulating layer **242** corresponding to a position below the patch antenna P. When the air gap is formed, the dielectric constant between the signal line L.sub.s2 and the patch antenna P lowers. That is, in order to lower the dielectric constant between the signal line L.sub.s2 and the patch antenna P, an air gap merely needs to be formed. For example, the material of the second insulating layer **242** is glass, glass epoxy, tetrafluoroethylene, epoxy, or the like. As long as communication radio waves can be transmitted and received, the second insulating layer **242** may be made of a material other than glass, glass epoxy, tetrafluoroethylene, epoxy, or the like.

[0106] The signal line layer is formed on the upper surface of the third insulating layer **243**. The second insulating layer **242** is stacked on the upper surface of the signal line layer. The signal line layer includes a signal line L.sub.s1 and a signal line L.sub.s2. The signal line L.sub.s1 (first signal line) is connected to a signal source (not illustrated). The signal sent out from the signal source is propagated to the signal line L.sub.s1. The signal before the phase shift is propagated to the signal line L.sub.s1. The signal line L.sub.s2 (second signal line) is extended in such a way as to pass below the slot S.sub.0 of the first ground layer **251**. Capacitances corresponding to the dielectric constants of the first insulating layer **241** and the second insulating layer **242** are formed between the signal line L.sub.s2 and the patch antenna P. In the signal line L.sub.s2, the phase-shifted signal phase-shifted by the phase shifter **21** is propagated to the patch antenna P by the electromagnetic coupling EC via the slot S.sub.0.

[0107] The third insulating layer **243** is formed above the second ground layer **252**. A signal line layer is formed on the upper surface of the third insulating layer **243**. For example, the material of the third insulating layer **243** is glass, glass epoxy, tetrafluoroethylene, epoxy, or the like. As long as communication radio waves can be transmitted and received, the third insulating layer **243** may be made of a material other than glass, glass epoxy, tetrafluoroethylene, epoxy, or the like.
[0108] The second ground layer **252** is stacked on the upper surface of the fourth insulating layer **244**. The second insulating layer **242** is stacked on an upper surface of the second ground layer **252**. For example, a material of the second ground layer **252** is metal (including alloy) such as copper, aluminum, and chromium. The potential of the second ground layer **252** is a ground potential. Two types of openings are formed in second ground layer **252**. The two types of openings formed in the second ground layer **252** are referred to as a slot S.sub.1 and a slot S.sub.2. The slot S.sub.1 is formed at a position between the signal line L.sub.s1 and the phase shifter **21**. The slot S.sub.2 is formed at a position between the signal line L.sub.s2 and the phase shifter **21**. Capacitances corresponding to the dielectric constants of the third insulating layer **243** and the fourth insulating layer **244** are formed between the signal line L.sub.s1 and the phase shifter **21**. Similarly, capacitances corresponding to the dielectric constants of the third insulating layer **243** and the fourth insulating layer **244** are formed between the signal line L.sub.s2 and the phase shifter **21**. The signal propagated through the signal line L.sub.s1 is propagated to the phase shifter **21** by the electromagnetic coupling EC via the slot S.sub.1. The signal propagated to the phase shifter **21** is phase-shifted by the phase shift amount set in the phase shifter **21** and propagated to the signal line L.sub.s2 by the electromagnetic coupling EC via the slot S.sub.2.
[0109] The fourth insulating layer **244** is formed above the phase shifter forming layer. The second ground layer **252** is formed on an upper surface of the fourth insulating layer **244**. For example, the material of the fourth insulating layer **244** is glass, glass epoxy, tetrafluoroethylene, epoxy, or the like. As long as communication radio waves can be transmitted and received, the fourth insulating layer **244** may be made of a material other than glass, glass epoxy, tetrafluoroethylene, epoxy, or the like.
[0110] In the phase shifter forming layer, the phase shifter **21** is formed for each patch antenna P. The phase shifter forming layer is formed on the upper surface of the substrate **220**. The fourth insulating layer **244** is formed on the upper surface of the phase shifter forming layer. Two types of openings (slot S.sub.1, slot S.sub.2) are formed in the second ground layer **252** above phase shifter **21**. The signal line L.sub.s1 is disposed above the phase shifter **21** via the slot S.sub.1. The signal line L.sub.s2 is disposed above the phase shifter **21** via the slot S.sub.2. The signal propagated through the signal line L.sub.s1 is propagated to the phase shifter **21** by the electromagnetic coupling EC via the slot S.sub.1. The signal propagated to the phase shifter **21** is phase-shifted by the phase shift amount set in the phase shifter **21** and propagated to the signal line L.sub.s2 by the electromagnetic coupling EC via the slot S.sub.2.
[0111] The substrate **220** is disposed below the phase shifter forming layer. On the upper surface of the substrate **220**, a matrix circuit, TFT wiring, and a phase shifter **21** are formed. The matrix circuit has a structure in which a plurality of thin-film transistors (TFT) are arranged in a two-dimensional array form. For example, the TFT included in the matrix circuit is formed using a TFT process technology. The TFT wiring includes a plurality of selection lines used to select a phase shifter **21** and a plurality of data lines used to write phase shift data to the phase shifter **21**. For example, a material of the substrate **220** is glass, glass epoxy, tetrafluoroethylene, epoxy, or the like. As long as communication radio waves can be transmitted and received, the substrate **220** may be made of a material other than glass, glass epoxy, tetrafluoroethylene, epoxy, or the like.
[0112] FIG. **25** is a conceptual diagram illustrating an example of a matrix circuit formed on an upper surface of a substrate according to the present disclosure. FIG. **25** is a plan view of a surface on which the matrix circuit is formed as viewed from an upper viewpoint. TFT wiring is formed in the phase shifter forming layer. The TFT wiring includes a selection line group G.sub.Ls including

a plurality of selection lines and a data line group G.sub.Ld including a plurality of data lines. Each of the plurality of selection lines included in the selection line group G.sub.Ls is used to select the phase shifter **21**. Each of the plurality of data lines included in the data line group G.sub.La is used for propagation of a signal radiated via the phase shifter **21**. The TFT wiring may include wiring other than the selection line group G.sub.Ls and the data line group G.sub.Ld.

[0113] The third ground layer **253** is disposed on the lower surface of the substrate **220**. The third ground layer **253** is made of a conductor. For example, a material of the third ground layer **253** is metal (including alloy) such as copper, aluminum, and chromium. The potential of the third ground layer **253** is a ground potential. Therefore, a capacitance corresponding to the dielectric constant of the substrate **220** is formed between the phase shifter **21** and the third ground layer **253**.

[0114] A signal supplied from a signal source (not illustrated) to the signal line L.sub.s1 is propagated to the phase shifter **21** by electromagnetic coupling via the slot S.sub.1. The signal propagated to phase shifter **21** is phase-shifted according to the phase shift amount set in phase shifter **21**. The phase-shifted signal is propagated to the signal line L.sub.s2 from the phase shifter **21** by electromagnetic coupling via the slot S.sub.2. The signal phase-shifted by the phase shifter **21** is propagated through the signal line L.sub.s2 and reaches below the patch antenna P. The signal that has reached below the patch antenna P is propagated from the signal line L.sub.s2 to the patch antenna P by electromagnetic coupling via the slot S.sub.0. The signal propagated to the patch antenna P is transmitted as a radio signal from the phased array antenna configured by the plurality of patch antennas P.

[0115] FIG. **26** is a conceptual diagram illustrating an example of a configuration of an antenna device according to the present disclosure. The antenna device illustrated in FIG. **26** is different from the antenna device illustrated in FIG. **24** in that a fourth ground layer is formed on the same layer as the phase shifter forming layer. The fourth ground layer **254** is electrically connected to third ground layer **253** by a plurality of vias **255** penetrating fourth insulating layer **244**. The plurality of vias **255** are formed inside the through hole penetrating the fourth insulating layer **244**. The fourth ground layer **254** is grounded to the same potential as the third ground layer **253** by the plurality of vias **255**. As compared with the configuration of FIG. **24**, the configuration of FIG. **26** can be grounded more reliably inside the antenna device.

[0116] FIG. **27** is a block diagram illustrating an example of a functional configuration of the antenna device according to the present disclosure. The antenna device **2** includes an antenna array **20**, a phase shifter **21**, a matrix circuit **22**, a control circuit **28**, and a signal source **29**.

[0117] The matrix circuit **22** has a configuration in which a plurality of thin-film transistors (TFT) are arrayed in a two-dimensional array form. The matrix circuit **22** is formed using a TFT process technology. Each of the plurality of TFTs included in the matrix circuit **22** is associated with one of the plurality of patch antennas P included in the antenna array **20**. For example, the TFT includes a semiconductor layer such as amorphous silicon or polysilicon. Each of the plurality of pixels formed in the matrix circuit **22** is associated with the patch antenna P.

[0118] The phase shifter **21** is disposed for each antenna unit. The phase shifter **21** is the phase shifter **10** according to the first example embodiment. The phase shifter **21** is associated with the patch antenna P. The heat generation drive circuit (not illustrated) included in the phase shifter **21** is associated with each of the plurality of pixels formed in the matrix circuit **22**. The heat generating element (not illustrated) included in the phase shifter **21** generates heat in accordance with selection of the heat generation drive circuit. An extended line having a line length corresponding to a desired phase shift amount is set in a line formation layer (not illustrated) included in the phase shifter **21**. The line length of the extended line is adjusted according to the set conductor pattern. As a result, a phase shift amount corresponding to the line length of the extended line is set in the phase shifter **21**.

[0119] The drive circuit **27** includes a first drive circuit **271** and a second drive circuit **272**. The first drive circuit **271** is a circuit for performing addressing in the X direction. The second drive circuit **272** is a circuit for performing addressing in the Y direction. The drive circuit **27** drives the TFTs included in the matrix circuit **22** under the control of the control circuit **28**. The drive circuit **27** individually drives the plurality of TFTs included in the matrix circuit **22**.

[0120] The control circuit **28** drives the drive circuit **27** according to an external control signal. The control circuit **28** drives the drive circuit **27** by an active matrix drive system. The control circuit **28** drives the first drive circuit **271** and the second drive circuit **272** in conjunction with each other to designate an address associated with each patch antenna P. In addition, the control circuit **28** outputs a control signal from the outside to the signal source **29**.

[0121] For example, the control circuit **28** is achieved by a microcomputer or a microcontroller. For example, the control circuit **28** includes a Central Processing Unit (CPU), a Random Access Memory (RAM), a Read Only Memory (ROM), a flash memory, and the like. The control circuit **28** executes control and process corresponding to a program stored in advance. The control circuit **28** executes control and process corresponding to a program according to a preset schedule and timing, an external control instruction, and the like. For example, the control circuit **28** controls the antenna array **20** including the plurality of patch antennas P included in the planar antenna **200** to transmit a radio wave having directivity from the antenna array **20**. As described above, the antenna array **20** is used as a phased array antenna.

[0122] The signal source **29** is connected to the phase shifter **21** via a signal line. In addition, the signal source **29** is connected to the control circuit **28**. The signal source **29** transmits a signal to the phase shifter **21** under the control of the control circuit **28**. The signal source **29** may be configured to receive a signal from the outside without passing through the control circuit **28**.

[0123] The signal reaching the signal input unit of the phase shifter **21** through the signal line (not illustrated) connected to the TFT in the ON state is phase-shifted by the phase shift amount set in the phase shifter **21**. The phase-shifted signal is propagated from the signal line to the patch antenna P by electromagnetic coupling. The radio wave derived from the signal propagated to the patch antenna P is transmitted from the patch antenna P. Furthermore, the radio wave transmitted from the patch antenna P is based on a signal output from a transmission circuit (not illustrated). The information included in the signal is not particularly limited.

[0124] In addition, the radio wave received by the patch antenna P is received according to the capacitance based on the dielectric constant of the dielectric such as the insulating layer or the TFT substrate interposed between the patch antenna P and the signal line. The phase of the received radio wave is phase-shifted by the phase shift amount set in phase shifter **21**. The phase-shifted signal is received by a reception circuit (not illustrated) through the signal line. Information included in the signal received by the reception circuit is decoded by a decoder (not illustrated).

[0125] As described above, the antenna device according to the present example embodiment includes the phase shifter according to the first example embodiment and the antenna array in which a plurality of patch antennas are arranged in a two-dimensional array form. The phase shifter is arranged in association with each of the plurality of patch antennas.

[0126] The antenna device of the present example embodiment includes a phase shifter having a line formation layer made of vanadium dioxide. By performing temperature control, an extended line having a line length corresponding to the phase transition of the insulating phase-metal phase of vanadium dioxide is formed in the line formation layer. A continuous phase shift amount can be stably set in the line formation layer by controlling the line length of the extended line to be formed. In the plurality of phase shifters included in the antenna device of the present example embodiment, a continuous phase shift change is achieved with a stable phase shift amount. An optional phase shift amount can be set for each of the plurality of patch antennas. Therefore, according to the antenna device of the present example embodiment, a phased array antenna capable of transmitting a radio wave having directivity in an optional direction can be achieved.

Third Example Embodiment

[0127] Next, a phase shifter according to a third example embodiment will be described with

reference to the drawings. The phase shifter of the present example embodiment has a configuration obtained by simplifying the phase shifter of the first example embodiment.
[0128] FIG. **28** is a conceptual diagram illustrating an example of a configuration of a phase shifter according to the present disclosure. The phase shifter **30** includes a **90** degree hybrid circuit **31**, a ground pattern **32**, and a variable stub **33**.
[0129] The 90 degree hybrid circuit **31** has two reflection ends. The ground pattern **32** is formed with a groove in which the variable stub **33** is disposed, and is connected to a side end of the variable stub **33** disposed in the groove. The variable stub **33** has a line formation layer made of vanadium dioxide and is extended from each of the two reflection ends.
[0130] The phase shifter of the present example embodiment includes a line formation layer made of vanadium dioxide. By performing temperature control, an extended line having a line length corresponding to the phase transition of the insulating phase-metal phase of vanadium dioxide is formed in the line formation layer. A continuous phase shift amount can be stably set in the line formation layer by controlling the line length of the extended line to be formed. Therefore, according to the phase shifter of the present example embodiment, a continuous phase shift change can be achieved with a stable phase shift amount.
(Hardware)
[0131] Next, a hardware configuration for executing control and process in the present disclosure will be described with reference to the drawings. Here, an example of such a hardware configuration is the information processing device **90** (computer) in FIG. **29**. The information processing device **90** in FIG. **29** is a configuration example for executing control and process in the present disclosure, and does not limit the scope of the present disclosure.
[0132] As illustrated in FIG. **29**, the information processing device **90** includes a processor **91**, a memory **92**, an auxiliary storage device **93**, an input/output interface **95**, and a communication interface **96**. In FIG. **29**, the interface is abbreviated as an interface (I/F). The processor **91**, the memory **92**, the auxiliary storage device **93**, the input/output interface **95**, and the communication interface **96** are connected to each other via a bus **98** in such a way as to be able to communicate data. In addition, the processor **91**, the memory **92**, the auxiliary storage device **93**, and the input/output interface **95** are connected to a network such as the Internet or an intranet via the communication interface **96**.
[0133] The processor **91** develops a program (command) stored in the auxiliary storage device **93** or the like in the memory **92**. For example, the program is a software program for executing control and process in the present disclosure. The processor **91** executes the program developed in the memory **92**. The processor **91** executes control and process in the present disclosure by executing a program.
[0134] The memory **92** is a storage device having an area in which a program is developed. A program stored in the auxiliary storage device **93** or the like is developed in the memory **92** by the processor **91**. The memory **92** is achieved by, for example, a volatile memory such as a Dynamic Random Access Memory (DRAM). In addition, a nonvolatile memory such as a Magnetoresistive Random Access Memory (MRAM) may be applied as the memory **92**.
[0135] The auxiliary storage device **93** stores various data such as programs. For example, the auxiliary storage device **93** is achieved by a local disk such as a hard disk or a flash memory. Various data may be stored in the memory **92**, and the auxiliary storage device **93** may be omitted.
[0136] The input/output interface **95** is an interface for connecting the information processing device **90** and a peripheral device based on a standard or a specification. The communication interface **96** is an interface for connecting to an external system or device through a network such as the Internet or an intranet based on a standard or a specification. The input/output interface **95** and the communication interface **96** may be shared as an interface to connect to an external device.
[0137] Input devices such as a keyboard, a mouse, and a touch panel may be connected to the information processing device **90** as necessary. These input devices are used to input information

and settings. When a touch panel is used as the input device, a screen having a touch panel function serves as an interface. The processor **91** and the input device are connected via the input/output interface **95**.

[0138] The information processing device **90** may be provided with a display device for displaying information. In a case where a display device is provided, the information processing device **90** includes a display control device (not illustrated) for controlling display of the display device. The information processing device **90** and the display device are connected via the input/output interface **95**.

[0139] The information processing device **90** may be provided with a drive device. The drive device mediates reading of data and a program stored in a recording medium and writing of a processing result of the information processing device **90** to the recording medium between the processor **91** and the recording medium (program recording medium). The information processing device **90** and the drive device are connected via an input/output interface **95**.

[0140] The above is an example of a hardware configuration for enabling control and process in the present disclosure. The hardware configuration of FIG. **29** is an example of a hardware configuration for executing control and process in the present disclosure, and does not limit the scope of the present disclosure. A program for causing a computer to execute control and process in the present disclosure is also included in the scope of the present disclosure.

[0141] A program recording medium on which a program for executing process in the present example embodiment is recorded is also included in the scope of the present invention. For example, the program recording medium is a computer-readable non-transitory recording medium. The recording medium can be achieved by, for example, an optical recording medium such as a compact disc (CD) or a digital versatile disc (DVD). The recording medium may be achieved by a semiconductor recording medium such as a universal serial bus (USB) memory or a secure digital (SD) card. Furthermore, the recording medium may be achieved by a magnetic recording medium such as a flexible disk, or another recording medium.

[0142] The components in the present disclosure may be optionally combined. The components in the present disclosure may be implemented by software. The components in the present disclosure may be implemented by a circuit.

[0143] The previous description of embodiments is provided to enable a person skilled in the art to make and use the present invention. Moreover, various modifications to these example embodiments will be readily apparent to those skilled in the art, and the generic principles and specific examples defined herein may be applied to other embodiments without the use of inventive faculty. Therefore, the present invention is not intended to be limited to the example embodiments described herein but is to be accorded the widest scope as defined by the limitations of the claims and equivalents.

[0144] Further, it is noted that the inventor's intent is to retain all equivalents of the claimed invention even if the claims are amended during prosecution.

[0145] Some or all the above example embodiments may be described as the following supplementary notes, but are not limited to the following.

(Supplementary Note 1)

[0146] A phase shifter comprising:

[0147] a 90 degree hybrid circuit having two reflection ends,

[0148] a variable stub having a line formation layer made of vanadium dioxide and extending from each of the two reflection ends, and

[0149] a ground pattern formed with a groove in which the variable stub is disposed and connected to a side end of the variable stub disposed in the groove.

(Supplementary Note 2)

[0150] The phase shifter according to supplementary note 1, wherein the variable stub includes:

[0151] a plurality of heat generating elements arranged in an array form along one surface of the

line formation layer, and
[0152] a heat generation drive circuit arranged in association with each of the plurality of heat generating elements,
[0153] each of the plurality of heat generating elements is
[0154] thermally connected to the line formation layer, and
[0155] each of the plurality of heat generation drive circuits
[0156] causes the heat generating element to generate heat to a temperature exceeding a phase transition temperature of vanadium dioxide contained in the line formation layer according to selection of the heat generating element.
(Supplementary Note 3)
[0157] The phase shifter according to supplementary note 2, wherein
[0158] the line formation layer includes:
[0159] an extended line region extending from each of the two reflection ends of the 90 degree hybrid circuit, and
[0160] a grounded line region connecting the extended line region and the ground pattern.
(Supplementary Note 4)
[0161] The phase shifter according to supplementary note **3**, wherein
[0162] the extended line region is
[0163] formed with an extended line extending from each of the two reflection ends of the 90 degree hybrid circuit, and
[0164] the grounded line region is
[0165] formed with a grounded line that short circuits a terminal end of the extended line formed in the extended line region to the ground pattern.
(Supplementary Note 5)
[0166] The phase shifter according to supplementary note 4, wherein
[0167] the extended line having a line length corresponding to a desired phase shift amount is formed in the extended line region, and
[0168] the grounded line connecting the terminal end of the extended line formed in the extended line region and the ground pattern is formed in the grounded line region.
(Supplementary Note 6)
[0169] The phase shifter according to supplementary note 3, wherein an opening is formed in the line formation layer between the extended line region and the grounded line region.
(Supplementary Note 7)
[0170] The phase shifter according to supplementary note 4, wherein
[0171] the line formation layer is
[0172] separated in association with each of the plurality of heat generating elements arranged in an array form in an extending direction of the extended line.
(Supplementary Note 8)
[0173] The phase shifter according to supplementary note 4, wherein
[0174] the heat generation drive circuit that causes the heat generating element used for forming the extended line and the grounded line related to a conductor pattern related to a desired phase shift amount to generate heat is selected using a phase shift table in which the conductor pattern related to the phase shift amount is registered, and
[0175] the extended line and the grounded line related to the conductor pattern set by using the phase shift table are formed in the line formation layer.
(Supplementary Note 9)
[0176] The phase shifter according to supplementary note 1, wherein
[0177] the ground pattern is
[0178] formed with two grooves in which the variable stubs are disposed, and
[0179] the variable stub is

[0180] disposed in each of the two grooves formed in the ground pattern, and connected to each of the two reflection ends of the 90 degree hybrid circuit.
(Supplementary Note 10)
[0181] An antenna device comprising:
[0182] the phase shifter according to any one of supplementary notes 1 to 9, and
[0183] an antenna array in which a plurality of patch antennas are arrayed in a two-dimensional array form, wherein
[0184] the phase shifter is
[0185] disposed in association with each of the plurality of patch antennas.

Claims

1. A phase shifter comprising: a 90 degree hybrid circuit having two reflection ends; a variable stub having a line formation layer made of vanadium dioxide and extending from each of the two reflection ends, and a ground pattern formed with a groove in which the variable stub is disposed and connected to a side end of the variable stub disposed in the groove.
2. The phase shifter according to claim 1, wherein the variable stub includes a plurality of heat generating elements arranged in an array form along one surface of the line formation layer, and a heat generation drive circuit arranged in association with each of the plurality of heat generating elements, and wherein each of the plurality of heat generating elements is thermally connected to the line formation layer, and each of the plurality of heat generation drive circuits is configured to cause the heat generating element to generate heat to a temperature exceeding a phase transition temperature of vanadium dioxide contained in the line formation layer according to selection of the heat generating element.
3. The phase shifter according to claim 2, wherein the line formation layer includes an extended line region extending from each of the two reflection ends of the 90 degree hybrid circuit, and a grounded line region connecting the extended line region and the ground pattern.
4. The phase shifter according to claim 3, wherein the extended line region is formed with an extended line extending from each of the two reflection ends of the 90 degree hybrid circuit, and the grounded line region is formed with a grounded line that short circuits a terminal end of the extended line formed in the extended line region to the ground pattern.
5. The phase shifter according to claim 4, wherein the extended line having a line length corresponding to a desired phase shift amount is formed in the extended line region, and the grounded line connecting the terminal end of the extended line formed in the extended line region and the ground pattern is formed in the grounded line region.
6. The phase shifter according to claim 3, wherein an opening is formed in the line formation layer between the extended line region and the grounded line region.
7. The phase shifter according to claim 4, wherein the extended line region and the grounded line region are separated in the line formation layer, and the extended line region and the grounded line region are electrically connected by a plurality of connection members arranged in association with the heat generating elements adjacent to each other in a direction perpendicular to an extending direction.
8. The phase shifter according to claim 4, wherein the heat generation drive circuit that causes the heat generating element used for forming the extended line and the grounded line related to a conductor pattern related to a desired phase shift amount to generate heat is selected using a phase shift table in which the conductor pattern related to the phase shift amount is registered, and the extended line and the grounded line related to the conductor pattern set by using the phase shift table are formed in the line formation layer.
9. The phase shifter according to claim 1, wherein the ground pattern is formed with two grooves in which the variable stubs are disposed, and the variable stub is disposed in each of the two grooves

formed in the ground pattern, and connected to each of the two reflection ends of the 90 degree hybrid circuit.

10. An antenna device comprising: the phase shifter according to claim 1; and an antenna array in which a plurality of patch antennas are arrayed in a two-dimensional array form; wherein the phase shifter is disposed in association with each of the plurality of patch antennas.