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(54) **COMPOSITE RESONATOR AND ASSEMBLY**

(57) A composite resonator includes a first resonator (14) extending in a first plane direction, a second resonator (16) spaced apart from the first resonator (14) in a first direction and extending in the first plane direction, a third resonator (22) located between the first resonator (14) and the second resonator (16) in the first direction and configured to magnetically or capacitively connect to or electrically connect to each of the first resonator (14) and the second resonator (16), and a reference conductor (18) extending in the first plane direction, located between the first resonator (14) and the second resonator (16) in the first direction, and serving as a potential reference of the first resonator (14) and the second resonator (16). The reference conductor (18) surrounds at least a part of the third resonator (22) in the first plane direction.

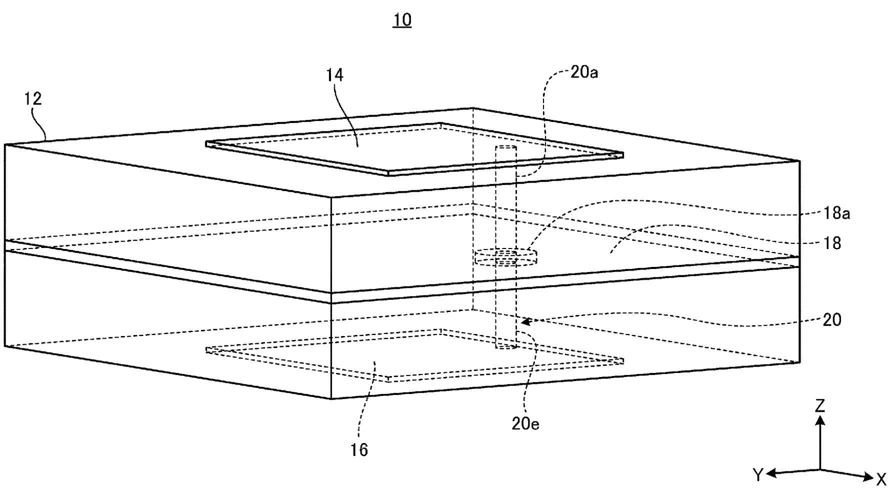

FIG. 2

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to a composite resonator and an assembly.

BACKGROUND OF INVENTION

[0002] A known technique involves controlling electromagnetic waves without using a dielectric lens. For example, Patent Document 1 describes a technique of refracting radio waves by changing parameters of respective elements in a structure including an array of resonator elements.

CITATION LIST

PATENT LITERATURE

[0003] Patent Document 1: JP 2015-231182 A

SUMMARY

SUMMARY OF THE INVENTION

[0004] In the resonator elements described in Patent Document 1, even when the parameters of respective elements are changed, a maximum amount of change in phase is 180°. There is a need to provide a resonator element which can form an assembly having a high degree of design freedom.

[0005] An objective of the present disclosure is to provide a composite resonator and an assembly that can be made with a high degree of design freedom.

SOLUTION TO PROBLEM

[0006] In the present disclosure, a composite resonator includes a first resonator extending in a first plane direction, a second resonator spaced apart from the first resonator in a first direction and extending in the first plane direction, a third resonator located between the first resonator and the second resonator in the first direction and configured to magnetically or capacitively connect to or electrically connect to each of the first resonator and the second resonator, and a reference conductor extending in the first plane direction, located between the first resonator and the second resonator in the first direction, and serving as a potential reference of the first resonator and the second resonator, and the reference conductor surrounds at least a part of the third resonator in the first plane direction.

[0007] An assembly according to the present disclosure includes a plurality of the composite resonators according to the present disclosure, in which the plurality of composite resonators are arranged in the first plane direction.

ADVANTAGEOUS EFFECT

[0008] According to the present disclosure, a composite resonator which can form an assembly having a high degree of design freedom can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

FIG. 1 is a diagram illustrating an overview of an assembly according to each embodiment.
FIG. 2 is a diagram schematically illustrating a configuration example of a unit structure according to a first embodiment.
FIG. 3 is a graph showing frequency characteristics of the unit structure according to the first embodiment.
FIG. 4 is a graph showing an amount of change in phase of the unit structure according to the first embodiment.
FIG. 5 is a diagram schematically illustrating a configuration example of a unit structure according to a second embodiment.
FIG. 6 is a graph showing frequency characteristics of a unit structure according to a second embodiment.
FIG. 7 is a graph showing an amount of change in phase of the unit structure according to the second embodiment.
FIG. 8 is a diagram schematically illustrating a configuration example of a unit structure according to a third embodiment.
FIG. 9 is a graph showing frequency characteristics of the unit structure according to the third embodiment.
FIG. 10 is a graph showing frequency characteristics of the unit structure according to the third embodiment.
FIG. 11 is a diagram illustrating a configuration of a unit structure according to a fourth embodiment.
FIG. 12 is a graph showing frequency characteristics of the unit structure according to the fourth embodiment.
FIG. 13 is a graph showing an amount of change in phase of the unit structure according to the fourth embodiment.
FIG. 14 is a graph showing frequency characteristics of the unit structure according to a variation of the fourth embodiment.
FIG. 15 is a graph showing an amount of change in phase of the unit structure according to the variation of the fourth embodiment.

DESCRIPTION OF EMBODIMENTS

[0010] Embodiments of the present disclosure will be described in detail with reference to the drawings. The embodiments described below do not limit the present disclosure.

[0011] In the following description, an XYZ orthogonal coordinate system is set, and the positional relationship between respective portions will be described by referring to the XYZ orthogonal coordinate system. A direction parallel to an X-axis in a horizontal plane is defined as an X-axis direction, a direction parallel to a Y-axis orthogonal to the X-axis in the horizontal plane is defined as a Y-axis direction, and a direction parallel to a Z-axis orthogonal to the horizontal plane is defined as a Z-axis direction. A plane including the X-axis and the Y-axis is appropriately referred to as an XY plane, a plane including the X-axis and the Z-axis is appropriately referred to as an XZ plane, and a plane including the Y-axis and the Z-axis is appropriately referred to as a YZ plane. The XY plane is parallel to the horizontal plane. The XY plane, the XZ plane, and the YZ plane are orthogonal to each other.

Overview

[0012] FIG. 1 illustrates an assembly in which a plurality of composite resonators are periodically arranged. In the assembly, the plurality of composite resonators periodically arranged function as an assembly. For example, the assembly functions as a spatial filter plate for a plane wave. For example, the assembly functions as a radio wave refraction plate by generating a phase difference in the plurality of composite resonators.

[0013] As illustrated in FIG. 1, an assembly 1 includes a plurality of unit structures 10 and a substrate 12.

[0014] The plurality of unit structures 10 are arranged in an XY plane direction. The XY plane direction may also be referred to as a first plane direction. That is, the plurality of unit structures 10 are arranged two-dimensionally. Each of the plurality of unit structures 10 has a resonance structure. The structure of the unit structure 10 will be described later. The unit structure 10 may be referred to as a composite resonator. The substrate 12 may be, for example, a dielectric substrate made of a dielectric body. The assembly 1 is made by two-dimensionally arranging the plurality of unit structures 10 having the resonance structure on the substrate 12 made of the dielectric body.

[0015] In the present disclosure, the assembly can be made by arranging the composite resonators of the following embodiments as illustrated in FIG. 1.

First Embodiment

Configuration of Unit Structure

[0016] A configuration example of the unit structure according to a first embodiment will be described with reference to FIG. 2. FIG. 2 is a diagram schematically illustrating the configuration example of the unit structure according to the first embodiment.

[0017] As illustrated in FIG. 2, the unit structure 10 includes a first resonator 14, a second resonator 16, a reference conductor 18, and a connection line path 20.

[0018] The first resonator 14 may be arranged on the substrate 12, extending on the XY plane. The first resonator 14 may be made of a conductor. The first resonator 14 may be, for example, a patch conductor formed in a rectangular shape. In the example illustrated in FIG. 2, the first resonator 14 is illustrated as the rectangular patch conductor, but the present disclosure is not limited thereto. The first resonator 14 may have, for example, a linear shape, a circular shape, a loop shape, or a polygonal shape other than a rectangular shape. That is, the shape of the first resonator 14 may be arbitrarily changed according to the design. The first resonator 14 resonates by an electromagnetic wave received from the +Z-axis direction.

[0019] The first resonator 14 radiates an electromagnetic wave during resonance. The first resonator 14 radiates the electromagnetic wave to the +Z-axis direction side during resonance.

[0020] The second resonator 16 may be arranged on the substrate 12 to extend on the XY plane at a position away from the first resonator 14 in the Z-axis direction. The second resonator 16 may be, for example, a patch conductor formed in a rectangular shape. In the example illustrated in FIG. 2, the second resonator 16 is illustrated as the rectangular patch conductor, but the present disclosure is not limited thereto. The second resonator 16 may have, for example, a linear shape, a circular shape, a loop shape, or a polygonal shape other than a rectangular shape. That is, the shape of the second resonator 16 may be arbitrarily changed according to the design. The shape of the second resonator 16 may be the same as or different from the shape of the first resonator 14. The area of the second resonator 16 may be the same as or different from the area of the first resonator 14.

[0021] The second resonator 16 radiates an electromagnetic wave during resonance. The second resonator 16, for example, radiates the electromagnetic wave to the -Z-axis direction side. The second resonator 16 radiates the electromagnetic wave to the -Z-axis direction side during resonance. The second resonator 16 resonates by receiving the electromagnetic wave from the -Z-axis direction.

[0022] The second resonator 16 may resonate at a phase different from that of the first resonator 14. The second resonator 16 may resonate in a direction different from the resonance direction of the first resonator 14 in the XY plane direction. For example, when the first resonator 14 resonates in the X-axis direction, the second resonator 16 may resonate in the Y-axis direction. The resonance direction of the second resonator 16 may change with time in the XY plane direction corresponding to a change with time in the resonance direction of the first resonator 14. The second resonator 16 may radiate the electromagnetic wave received by the first resonator 14 with a first frequency band thereof attenuated.

[0023] The reference conductor 18 may be arranged between the first resonator 14 and the second resonator 16 in the substrate 12. The reference conductor 18 may be, for example, at the center between the first resonator 14 and the second resonator 16 in the substrate 12, but the present disclosure is not limited thereto. For example, the reference conductor 18 may be at a position where the distance from the reference conductor 18 to the first resonator 14 differs from the distance from the reference conductor 18 to the second resonator 16. The reference conductor 18 has a through-hole 18a through which the connection line path 20 extends. The reference conductor 18 surrounds at least a part of the connection line path 20.

[0024] The connection line path 20 may be made of a conductor. The connection line path 20 is located between the first resonator 14 and the second resonator 16 in the Z-axis direction. The Z-axis direction may also be referred to as a first direction, for example. The connection line path 20 may be connected to each of the first resonator 14 and the second resonator 16. Although the connection line path 20 passes through the through-hole 18a, the connection line path 20 is not in contact with the reference conductor 18. The connection line path 20 may be magnetically or capacitively connected to each of the first resonator 14 and the second resonator 16, for example. For example, the connection line path 20 may be electrically connected to each of the first resonator 14 and the second resonator 16. The connection line path 20 is connected to a side of the first resonator 14 parallel to the X-axis direction and is connected to a side of the second resonator 16 parallel to the X-axis direction. The connection line path 20 may be a path parallel to the Z-axis direction. The connection line path 20 may be a third resonator.

[0025] The unit structure 10 magnetically or capacitively connects the first resonator 14 and the second resonator 16 or electrically connects them to be combined. By combining the three resonators, the unit structure 10 transmits a high frequency excited by an electromagnetic wave incident on the first resonator 14 through the composite resonator. The unit structure 10 may have any one or more functions of a phase shift, a band-pass filter, a high-pass filter, and a low-pass filter depending on the transmission characteristics of the unit structure.

[0026] The unit structure 10 changes the phase of the electromagnetic wave incident on the first resonator 14 and radiates the electromagnetic wave from the second resonator 16. The amount of change in phase changes depending on the length of the connection line path 20. The amount of change in phase also changes depending on the area of the first resonator 14 or the second resonator 16.

[0027] Frequency characteristics of the unit structure according to the first embodiment will be described with reference to FIG. 3. FIG. 3 is a graph showing the frequency characteristics of the unit structure according to the first embodiment.

[0028] In FIG. 3, the horizontal axis represents the frequency [Giga Hertz (GHz)] and the vertical axis represents the gain [deci Bel (dB)]. FIG. 3 shows a graph G1 and a graph G2. The graph G1 shows a transmission coefficient. The graph G2 shows a reflection coefficient. The graph G1 shows that insertion loss in a region from around 21.00 GHz to around 28.00 GHz is -3dB or more and transmission characteristics are satisfactory. The graph G2 shows that the reflection coefficient in the region from around 21.00 GHz to around 28.00 GHz is low. That is, the unit structure 10 illustrated in FIG. 1 has satisfactory transmission characteristics over a wide range from around 21.00 GHz to around 28.00 GHz.

[0029] The amount of change in phase of the unit structure according to the first embodiment will be described with reference to FIG. 4. FIG 4 is a graph showing the amount of change in phase of the unit structure according to the first embodiment.

[0030] In FIG. 4, the horizontal axis represents the frequency [GHz] and the vertical axis represents the amount of change in phase [deg]. FIG. 4 shows a graph G3. The graph G3 shows the amount of shift in phase of the electromagnetic wave when the electromagnetic wave incident on the first resonator 14 is radiated from the second resonator 16. For example, when the electromagnetic wave having a frequency around 22.00 GHz is incident on the first resonator 14, the unit structure 10 shifts the phase of the electromagnetic wave by about - 38°and radiates the electromagnetic wave from the second resonator 16. For example, when the electromagnetic wave having a frequency around 24.00 GHz is incident on the first resonator 14, the unit structure 10 shifts the phase of the electromagnetic wave by about - 130°and radiates the electromagnetic wave from the second resonator 16. For example, when the electromagnetic wave having a frequency in around 28.00 GHz is incident on the first resonator 14, the unit structure 10 shifts the phase of the electromagnetic wave by about 135°and radiates the electromagnetic wave from the second resonator 16. The unit structure 10 can be used as a spatial filter. The unit structure 10 can obtain a desired phase difference between the elements by shifting a design value of a center frequency of the spatial filter.

[0031] The unit structures 10 are arranged in the assembly 1, and thus the electromagnetic wave transmitted through the assembly 1 is shifted. For example, the electromagnetic wave passing through the assembly 1 is shifted by about 22° at a frequency of 22.00 GHz. For example, the electromagnetic wave passing through the assembly 1 is shifted by about -130° at a frequency of 24.00 GHz. For example, the electromagnetic wave passing through the assembly 1 is shifted by about 135° at a frequency of 28 GHz.

Second Embodiment

Configuration of Unit Structure

[0032] A configuration example of a unit structure according to a second embodiment will be described with reference to FIG. 5. FIG. 5 is a diagram schematically illustrating the configuration example of the unit structure according to the second embodiment.

[0033] As illustrated in FIG. 5, a unit structure 10A differs from the unit structure 10 illustrated in FIG. 2 in that the connection line path 20 is not a linear path parallel to the Z-axis direction. Specifically, the connection line path 20 of the unit structure 10A differs from the unit structure 10 illustrated in FIG. 2 in that the connection line path 20 includes a first path portion 20a, a second path portion 20b, a third path portion 20c, a fourth path portion 20d, and a fifth path portion 20e.

[0034] The first path portion 20a may be a path parallel to the Z-axis direction and including one end connected to the first resonator 14 and the other end located between the first resonator 14 and the reference conductor 18. The second path portion 20b may be a path parallel to the XY plane and including one end connected to the other end of the first path portion 20a and the other end located between the first resonator 14 and the reference conductor 18. The third path portion 20c may be a path parallel to the Z-axis direction and including one end connected to the other end of the second path portion 20b and the other end located between the second resonator 16 and the reference conductor 18. The third path portion 20c passes through the through-hole 18a of the reference conductor 18. The third path portion 20c is not in contact with the reference conductor 18. The fourth path portion 20d may be a path parallel to the XY plane and including one end connected to the other end of the third path portion 20c and the other end located between the second resonator 16 and the reference conductor 18. The fifth path portion 20e may be a path parallel to the Z-axis direction and including one end connected to the fourth path portion 20d and the other end connected to the fifth path portion 20e.

[0035] In FIG. 5, the connection line path 20 has been described as including the five paths from the first path portion 20a to the fifth path portion 20e, but this is merely an example and does not limit the present disclosure. The number of paths included in the connection line path 20 may be more or less than five. The plurality of path portions may also be referred to as sub-resonators. For example, the connection line path 20 may have a bent portion being bent in a curved shape.

[0036] The unit structure 10A changes the phase of the electromagnetic wave incident on the first resonator 14 and radiates the electromagnetic wave from the second resonator 16. The amount of change in phase changes depending on the length of the connection line path 20. The amount of change in phase also changes depending on the area of the first resonator 14 or the second resonator 16.

[0037] Frequency characteristics of the unit structure according to the second embodiment will be described with reference to FIG. 6. FIG. 6 is a graph showing frequency characteristics of the unit structure according to the second embodiment.

[0038] In FIG. 6, the horizontal axis represents the frequency [GHz] and the vertical axis represents the gain [dB]. FIG. 6 shows a graph G4 and a graph G5. The graph G4 shows a transmission coefficient. The graph G5 shows a reflection coefficient. The graph G4 shows that insertion loss in a region from around 22.00 GHz to around 31.40 GHz is -3dB or more and transmission characteristics are satisfactory. The graph G5 shows that the reflection coefficient in the region from around 22.00 GHz to around 31.40 GHz is low. That is, the unit structure 10A illustrated in FIG. 5 has satisfactory transmission characteristics over a wide range from around 22.00 GHz to around 31.40 GHz.

[0039] An amount of change in phase of the unit structure according to the second embodiment will be described with reference to FIG. 7. FIG. 7 is a graph showing the amount of change in phase of the unit structure according to the second embodiment.

[0040] In FIG. 7, the horizontal axis represents the frequency [GHz] and the vertical axis represents the amount of change in phase [deg]. FIG. 7 shows a graph G6. The graph G6 shows the amount of shift in phase of the electromagnetic wave when the electromagnetic wave incident on the first resonator 14 is radiated from the second resonator 16. For example, when the electromagnetic wave having a frequency around 22.00 GHz is incident on the first resonator 14, the unit structure 10A shifts the phase of the electromagnetic wave by about - 65°and radiates the electromagnetic wave from the second resonator 16. For example, when the electromagnetic wave having a frequency in around 24.00 GHz is incident on the first resonator 14, the unit structure 10 shifts the phase of the electromagnetic wave by about - 140°and radiates the electromagnetic wave from the second resonator 16. For example, when the electromagnetic wave having a frequency in around 28.00GHz is incident on the first resonator 14, the unit structure 10 shifts the phase of the electromagnetic wave by about 1 10°and radiates the electromagnetic wave from the second resonator 16. That is, the unit structure 10A can be used as a spatial filter changing the phase of the electromagnetic wave changing the phase of the electromagnetic wave.

[0041] The unit structures 10A are arranged in the assembly 1, and thus the electromagnetic wave transmitted through the assembly 1 is shifted. For example, the electromagnetic wave passing through the assembly 1 is shifted by about -65° at a frequency of 22.00 GHz. For example, the electromagnetic wave passing through the assembly 1 is shifted by about -140° at a frequency of 24.00 GHz. For example, the electromagnetic wave passing through the assembly 1 is shifted by about 110° at a frequency of 28.00 GHz.

[0042] The unit structure 10 can obtain a desired phase difference between the elements by arranging the elements having shifted design value of the center frequency of the spatial filter. When the unit structure 10 and the unit structure 10A are arranged side by side in the assembly 1, a difference between phases in which electromagnetic waves transmitted through the unit structures 10 and 10A, respectively, are shifted is generated. For example, at the frequency 22.00 GHz, the phases of electromagnetic waves transmitted through the two unit structures 10 and 10A are shifted by about 22° and about -65°, respectively, and the phase difference is 85°. For example, at a frequency of 24.00 GHz, the phases of electromagnetic waves transmitted through the two unit structures 10 and 10A are shifted by about -130° and about -140°, respectively, and the phase difference is 10°. For example, at a frequency of 28.00 GHz, the phases of electromagnetic waves transmitted through the two unit structures 10 and 10A are shifted by about 135° and about 110°, respectively, and the phase difference is 25°.

Third Embodiment

Configuration of Unit Structure

[0043] A configuration example of the unit structure according to a third embodiment will be described with reference to FIG. 8. FIG. 8 is a diagram schematically illustrating the configuration example of the unit structure according to the third embodiment.

[0044] As illustrated in FIG. 8, a unit structure 10B differs from the unit structure 10 illustrated in FIG. 2 in that the unit structure 10B includes a connection line path 20A and a connection line path 20B.

[0045] In the unit structure 10B, the reference conductor 18 includes a through-hole 18a and a through-hole 18b. The through-hole 18a is a through-hole through which the connection line path 20A passes. The through-hole 18b is a through-hole through which the connection line path 20B passes.

[0046] The connection line path 20A may be made of a conductor. The connection line path 20A is located between the first resonator 14 and the second resonator 16 in the Z-axis direction. The connection line path 20A is connected to each of the first resonator 14 and the second resonator 16. Specifically, the connection line path 20A has one end connected to a side of the first resonator 14 parallel to the Y-axis direction and the other end connected to a side of the second resonator 16 parallel to the Y-axis direction. Although the connection line path 20A passes through the through-hole 18a, the connection line path 20A is not in contact with the reference conductor 18.

[0047] The connection line path 20B may be made of a conductor. The connection line path 20B is located between the first resonator 14 and the second resonator 16 in the Z-axis direction. The connection line path 20B is connected to each of the first resonator 14 and the second resonator 16. Specifically, the connection line path 20B has one end connected to a side of the first resonator 14 parallel to the X-axis direction and the other end connected to a side of the second resonator 16 parallel to the X-axis direction. Although the connection line path 20B passes through the through-hole 18b, the connection line path 20B is not in contact with the reference conductor 18.

[0048] Frequency characteristics of the unit structure according to the third embodiment will be described with reference to FIGs. 9 and 10. FIGs. 9 and 10 are graphs showing the frequency characteristics of the unit structure according to the third embodiment.

[0049] In FIG. 9, the horizontal axis represents the frequency [GHz] and the vertical axis represents the gain [dB]. FIG. 9 shows a graph G7 and a graph G8. The graph G7 shows a transmission coefficient when the electromagnetic wave incident from the X-axis direction is radiated in the X-axis direction. The graph G88 shows a reflection coefficient. The graph G16 shows that insertion loss in a region from around 21.00 GHz to around 28.00 GHz is about -3 dB or more and transmission characteristics are satisfactory. The graph G8 shows that the reflection coefficient in the region from around 21.00 GHz to around 28.00 GHz is low. That is, the unit structure 10B illustrated in FIG. 8 has satisfactory transmission characteristics over a wide range from around 21.00 GHz to around 28.00 GHz.

[0050] In FIG. 10, the horizontal axis represents the frequency [GHz] and the vertical axis represents the gain [dB]. FIG. 10 shows a graph G9. The graph G9 shows a transmission coefficient when the electromagnetic wave incident from the X-axis direction is radiated in the Y-axis direction. As shown in the graph G9, in the transmission coefficient when the electromagnetic wave incident from the X-axis direction is radiated in the Y-axis direction, the insertion loss in a region from around 21.00 GHz to around 28.00 GHz is about -3 dB or more and transmission characteristics are satisfactory.

[0051] The unit structure 10B has satisfactory transmission coefficients of the electromagnetic wave from the X-axis direction to the X-axis direction and from the X-axis direction to the Y-axis direction. That is, the unit structure 10B functions as a spatial filter and has a polarizing function.

Fourth Embodiment

Configuration of Unit Structure

[0052] A configuration of the unit structure according to a fourth embodiment will be described with reference to FIG. 11. FIG. 11 is a diagram illustrating a configuration of the unit structure according to the fourth embodiment.

[0053] As illustrated in FIG. 11, a unit structure 10C includes the substrate 12 the first resonator 14, the second resonator 16, the reference conductor 18, the connection line path 20 and a third resonator 22. The unit structure 10C differs from the unit structure 10 illustrated in FIG. 2 in that the unit structure 10C includes the third resonator 22. In the unit structure 10C, the reference conductor 18 includes an opening portion 18c surrounding the third resonator 22.

[0054] The third resonator 22 may be located between the first resonator 14 and the second resonator 16 in the Z-axis direction. The third resonator 22 may be located within the opening portion 18c of the reference conductor 18. The third resonator 22 may be located within the opening portion 18c so as not to be in contact with the reference conductor 18. That is, the third resonator 22 is surrounded by the reference conductor 18. The third resonator 22 is capacitively connected to the reference conductor 18.

[0055] In the present embodiment, when a wavelength of a fundamental wave of an incoming electromagnetic wave is λ, a length of at least one side of the first resonator 14 is set to $\lambda/2$, a length of at least one side of the second resonator 16 is set to $\lambda/2$, and a length of at least one side of the third resonator 22 is set to $\lambda/4$.

[0056] Frequency characteristics of the unit structure according to the fourth embodiment will be described with reference to FIG. 12. FIG. 12 is a graph showing frequency characteristics of the unit structure according to the fourth embodiment.

[0057] In FIG. 12, the horizontal axis represents the frequency [GHz] and the vertical axis represents the gain [dB]. FIG. 12 shows a graph G10 and a graph G11. The graph G10 shows the transmission coefficient from the X-axis direction to the X-axis direction. The graph G11 shows the reflection coefficient of the electromagnetic wave incident in the X-axis direction. The graph G10 shows that the insertion loss in a region from around 18.00 GHz to around 28.00 GHz is -2 dB or more and transmission characteristics are satisfactory. The graph G11 shows that the reflection coefficient in the region from around 18.00 GHz to around 28.00 GHz is low. As shown in the graph G10, the unit structure 10C has a steep attenuation characteristic in a higher frequency band than in the unit structure 10 illustrated in FIG. 2. That is, the unit structure 10C illustrated in FIG. 11 has satisfactory transmission characteristics over a wide range from around 18.00 GHz to around 28.00 GHz.

[0058] An amount of change in phase of the unit structure according to the fourth embodiment will be described with reference to FIG. 13. FIG. 13 is a graph showing the amount of change in phase of the unit structure according to the fourth embodiment.

[0059] In FIG. 13, the horizontal axis represents the frequency [GHz] and the vertical axis represents the gain [dB]. FIG. 13 shows a graph G12. The graph G12 shows the amount of shift in phase of the electromagnetic wave when the electromagnetic wave incident on the first resonator 14 is radiated from the second resonator 16. For example, when the electromagnetic wave having a frequency around 18.00GHz is incident on the first resonator 14, the unit structure 10C shifts the phase of the electromagnetic wave by about -37°and radiates the electromagnetic wave from the second resonator 16. For example, when the electromagnetic wave having a frequency around 27.50 GHz is incident on the first resonator 14, the unit structure 10C shifts the phase of the electromagnetic wave by about -40°and radiates the electromagnetic wave from the second resonator 16. That is, even when a plurality of the resonators are provided as in the unit structure 10C, the incoming electromagnetic wave can be shifted.

Variation of Fourth Embodiment

[0060] In the unit structure 10C, by changing the designs of the first resonator 14, the second resonator 16, and the third resonator 22, the amount of change in phase and the frequency band in which the phase is changed can be changed.

[0061] Frequency characteristics of the unit structure according to a variation of the fourth embodiment will be described with reference to FIG. 14. FIG. 14 is a graph showing frequency characteristics of the unit structure according to a variation of the fourth embodiment.

[0062] In FIG. 14, the horizontal axis represents the frequency [GHz] and the vertical axis represents the gain [dB]. FIG. 14 shows a graph G13 and a graph G14. The graph G13 shows the transmission coefficient from the X-axis direction to the X-axis direction. The graph G13 shows the reflection coefficient of the electromagnetic wave incident in the X-axis direction. The graph G22 shows that the insertion loss in a region from around 21.00 GHz to around 28.00 GHz is -2 dB or more and transmission characteristics are satisfactory. The graph G13 shows that the reflection coefficient in the region from around 21.00 GHz to around 28.00 GHz is low. That is, the unit structure 10C illustrated in FIG. 11 has satisfactory transmission characteristics over a wide range from around 21.00 GHz to around 28.00 GHz.

[0063] An amount of change in phase of the unit structure according to a variation of the fourth embodiment will be described with reference to FIG. 15. FIG. 15 is a graph showing the amount of change in phase of the unit structure according to the variation of the fourth embodiment.

[0064] In FIG. 15, the horizontal axis represents the frequency [GHz] and the vertical axis represents the gain [dB]. FIG. 15 shows a graph G15. The graph G15 shows the amount of shift in phase of the electromagnetic wave when the electromagnetic wave incident on the first resonator 14 is radiated from the second resonator 16. For example, when the electromagnetic wave having a frequency around 21.00 GHz is incident on the first resonator 14, the unit structure 10C shifts the phase of the electromagnetic wave by about -55°and radiates the electromagnetic wave from the second resonator 16. For example, when the electromagnetic wave having a frequency around 27.50 GHz is incident on the first resonator 14, the unit structure 10C shifts the phase of the electromagnetic wave by about 117°and radiates the electromagnetic wave from the second resonator 16. That is, even when a plurality of the resonators are provided as in the unit structure 10C, the incoming electromagnetic wave can be shifted.

[0065] In the example illustrated in FIG. 11, the unit structure 10C includes three resonators, but the present disclosure is not limited thereto. In the present disclosure, the composite resonator may include three or more resonators. In the present disclosure, by increasing the number of resonators, a steeper attenuation characteristic can be provided in a high frequency band.

[0066] Embodiments of the present disclosure have been described above, but the present disclosure is not limited by the contents of the embodiments. Constituent elements described above include those that can be easily assumed by a person skilled in the art, those that are substantially identical to the constituent elements, and those within a so-called range of equivalency. The constituent elements described above can be combined as appropriate. Various omissions, substitutions, or modifications of the constituent elements can be made without departing from the spirit of the above-described embodiments.

REFERENCE SIGNS

[0067]

1 Assembly
10 Unit structure
12 Substrate
14 First resonator
16 Second resonator
18 Reference conductor
20 Connection line path
22 Third resonator

Claims

1. A composite resonator according the present disclosure comprising;

   a first resonator extending in a first plane direction;
   a second resonator spaced apart from the first resonator in a first direction and extending in the first plane direction;
   a third resonator located between the first resonator and the second resonator in the first direction and configured to magnetically or capacitively connect to or electrically connect to each of the first resonator and the second resonator; and
   a reference conductor extending in the first plane direction, located between the first resonator and the second resonator in the first direction, and serving as a potential reference of the first resonator and the second resonator, wherein
   the reference conductor surrounds at least a part of the third resonator in the first plane direction.

2. The composite resonator according to claim 1, wherein

   the third resonator comprises a plurality of sub-resonators, and
   the plurality of sub-resonators are configured to magnetically or capacitively connect to or electrically connect to at least any other sub-resonator.

3. The composite resonator according to claim 1 or 2, wherein
   the entirety of the third resonator is covered with the first resonator and the second resonator in the first direction.

4. The composite resonator according to any one of claims 1 to 3, wherein

   the reference conductor comprises a through-hole, and
   the third resonator is configured to magnetically or capacitively connect to or electrically connect to each of the first resonator and the second resonator through the through-hole.

5. The composite resonator according to any one of claims 1 to 4, wherein
   the first resonator is configured to resonate by receiving an electromagnetic wave from a forward direction of the first direction.

6. The composite resonator according to claim 5, wherein
   the second resonator is configured to radiate an electromagnetic wave during resonance.

7. The composite resonator according to any one of claims 1 to 6, wherein
   the second resonator is configured to radiate an electromagnetic wave in a reverse direction of the first direction during resonance.

8. The composite resonator according to any one of claims 1 to 7, wherein
   the second resonator is configured to resonate by receiving the electromagnetic wave from the reverse direction of the first direction.

9. The composite resonator according to any one of claims 1 to 8, wherein the first resonator is configured to radiate an electromagnetic wave during reso-

nance.

10. The composite resonator according to claim 9, wherein
the first resonator is configured to radiate the electromagnetic wave in the forward direction of the first direction during resonance.

11. The composite resonator according to any one of claims 8 to 10, wherein
the second resonator is configured to resonate at a phase different from a phase of the first resonator.

12. The composite resonator according to any one of claims 8 to 11, wherein
the second resonator is configured to resonate in an in-plane direction different from an in-plane direction of the first resonator in the first plane direction.

13. The composite resonator according to any one of claims 8 to 12, wherein
the resonance direction of the second resonator is configured to change with time in the first plane direction with respect to the resonance direction of the first resonator.

14. The composite resonator according to any one of claims 8 to 13, wherein
the second resonator is configured to radiate an electromagnetic wave received by the first resonator with a first frequency band being attenuated.

15. An assembly comprising:
a plurality of the composite resonators according to any one of claims 1 to 14, wherein the plurality of composite resonators are arranged in the first plane direction.

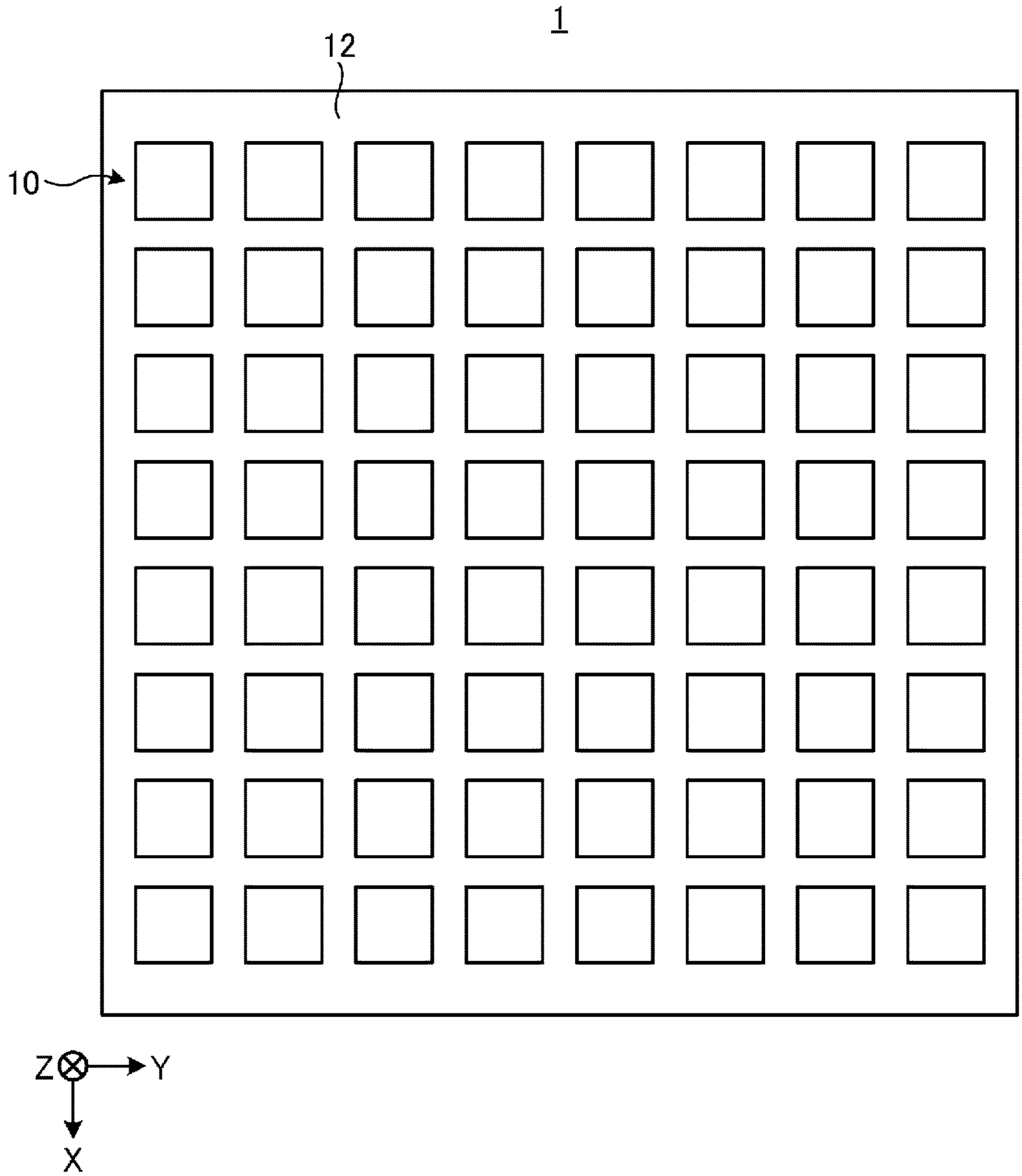


FIG. 1

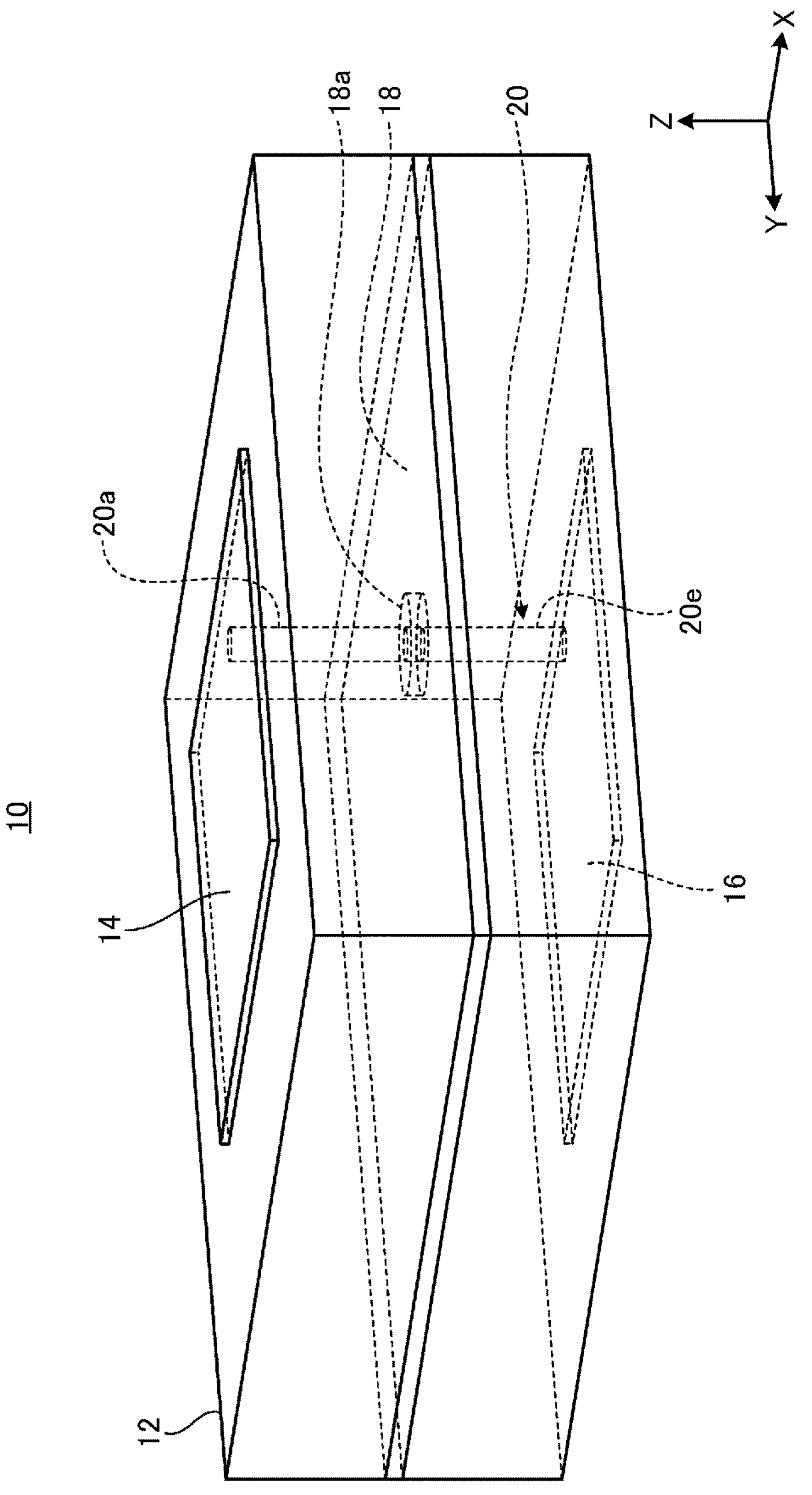
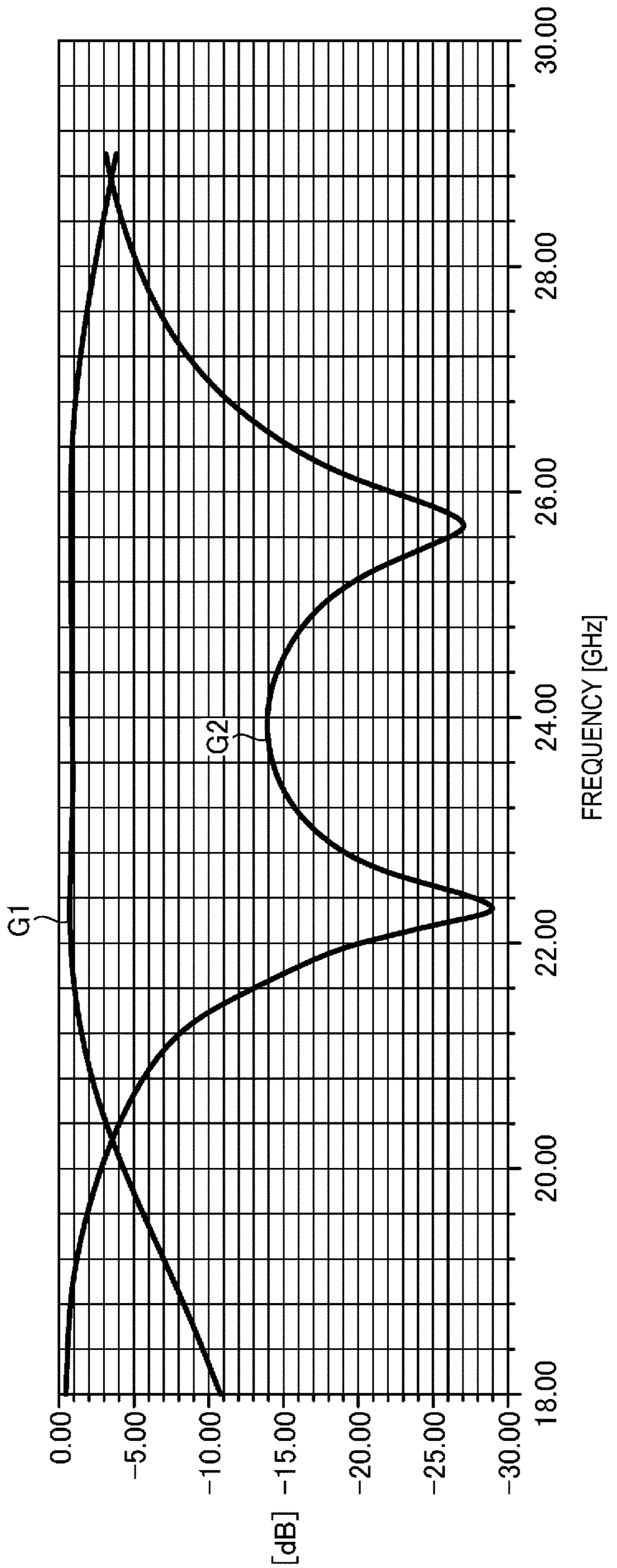


FIG. 2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−20.00
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−30.00
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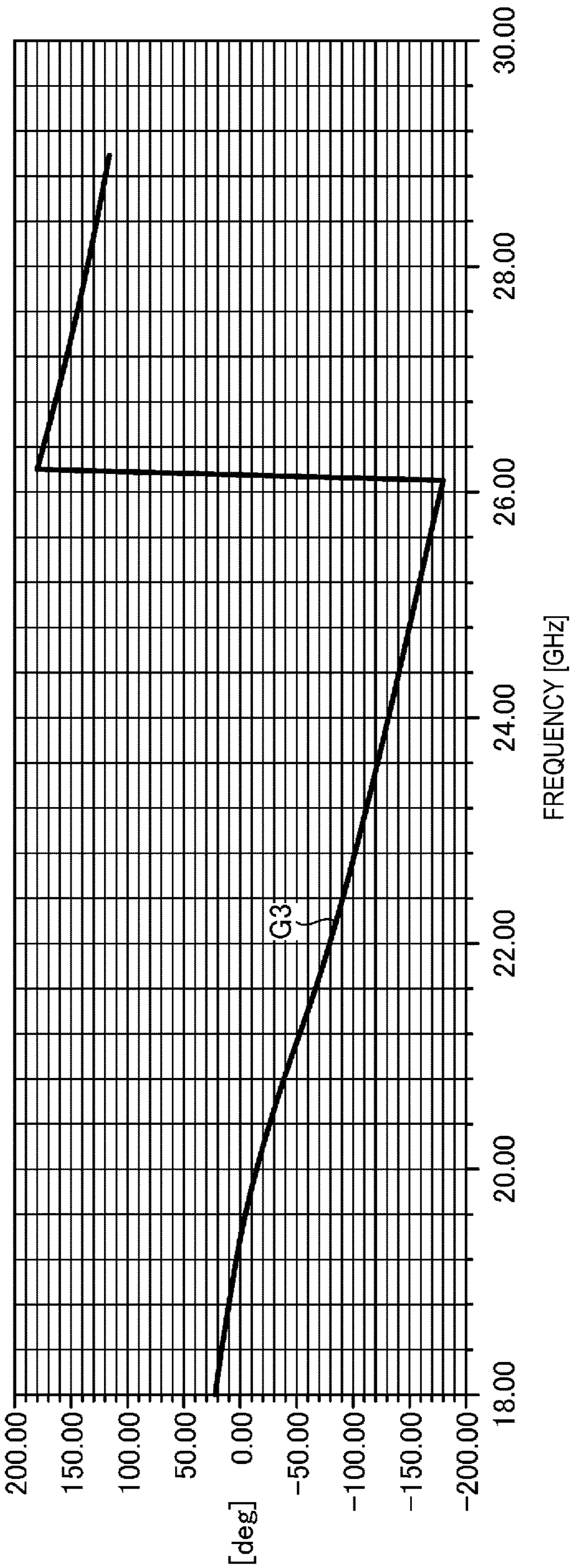
22.00
24.00
26.00
28.00
30.00
FREQUENCY [GHz]
G1
G2

FIG. 3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20.00
22.00
24.00
26.00
28.00
30.00
FREQUENCY [GHz]
G3

FIG. 4

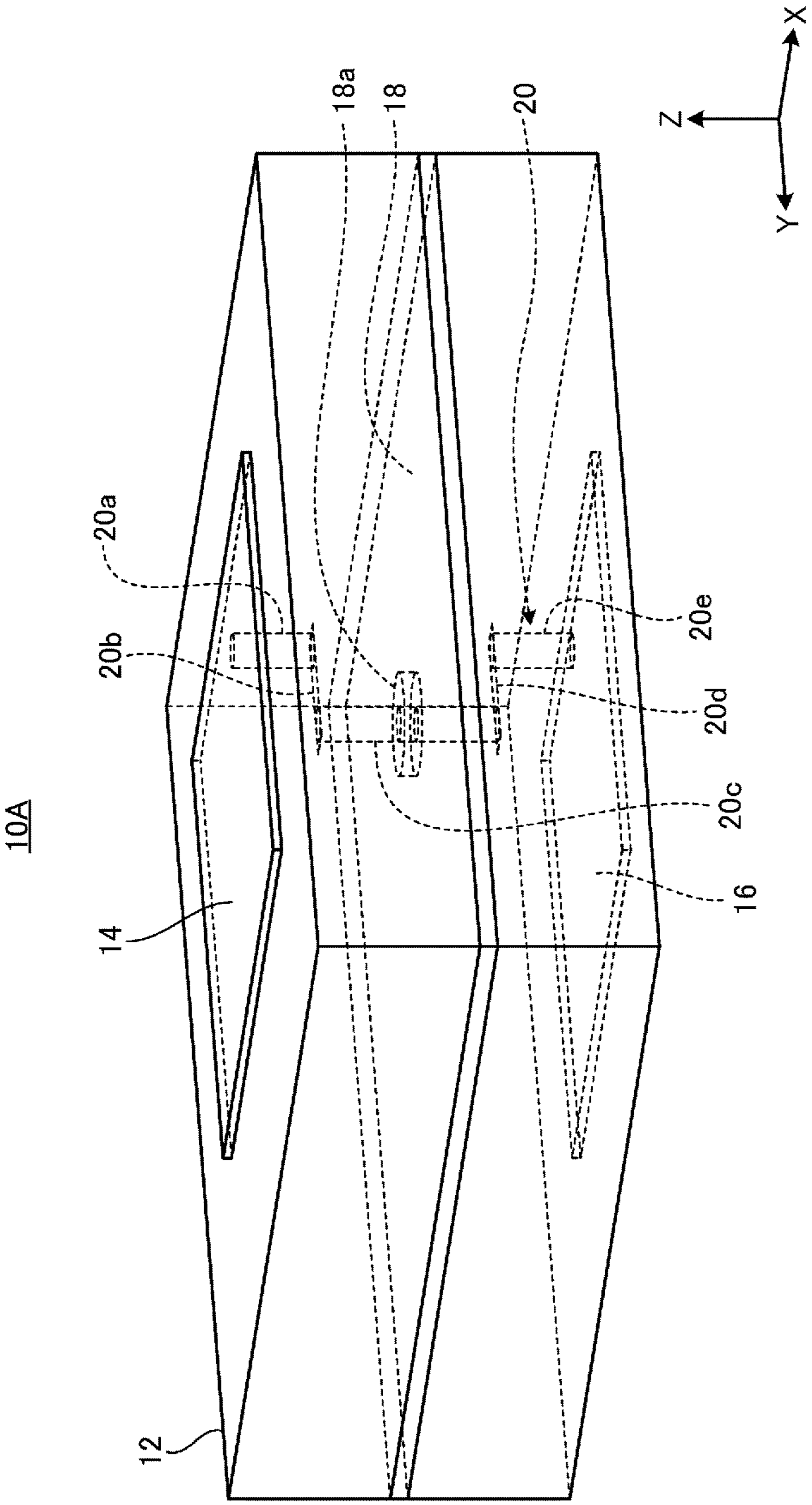
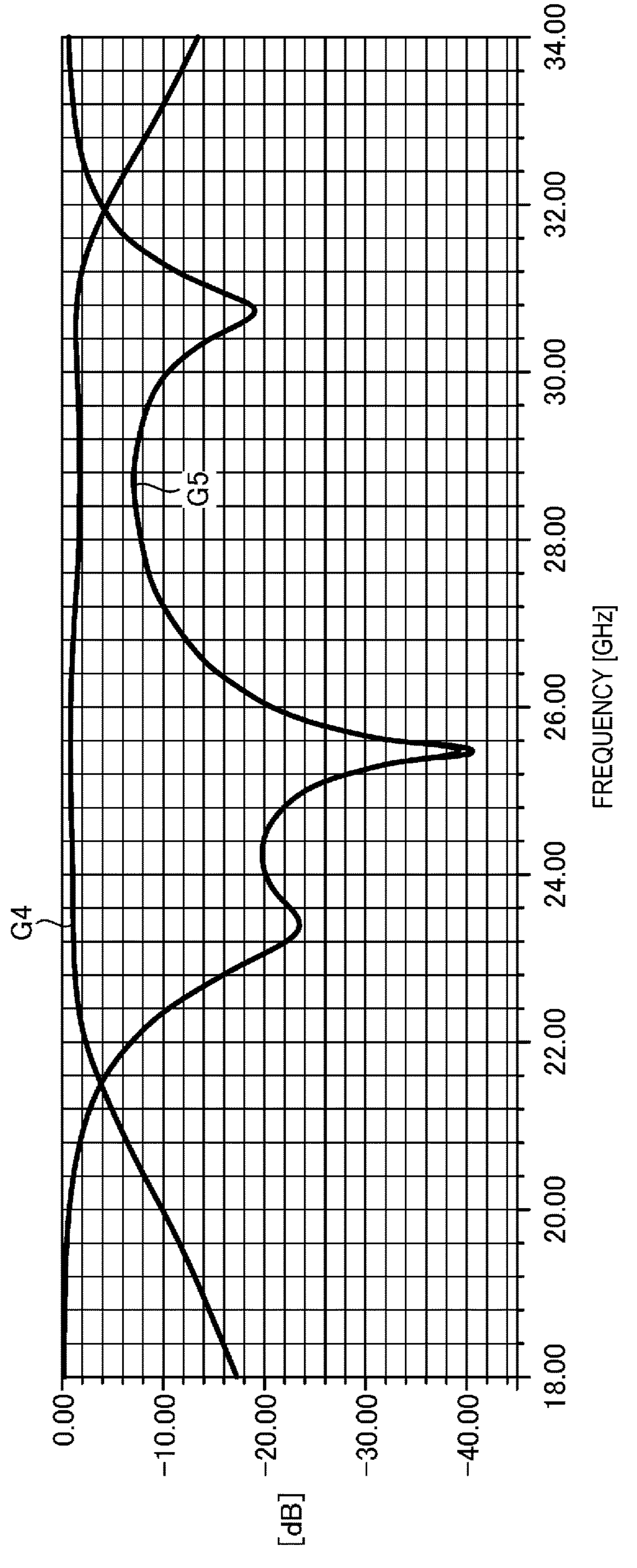


FIG. 5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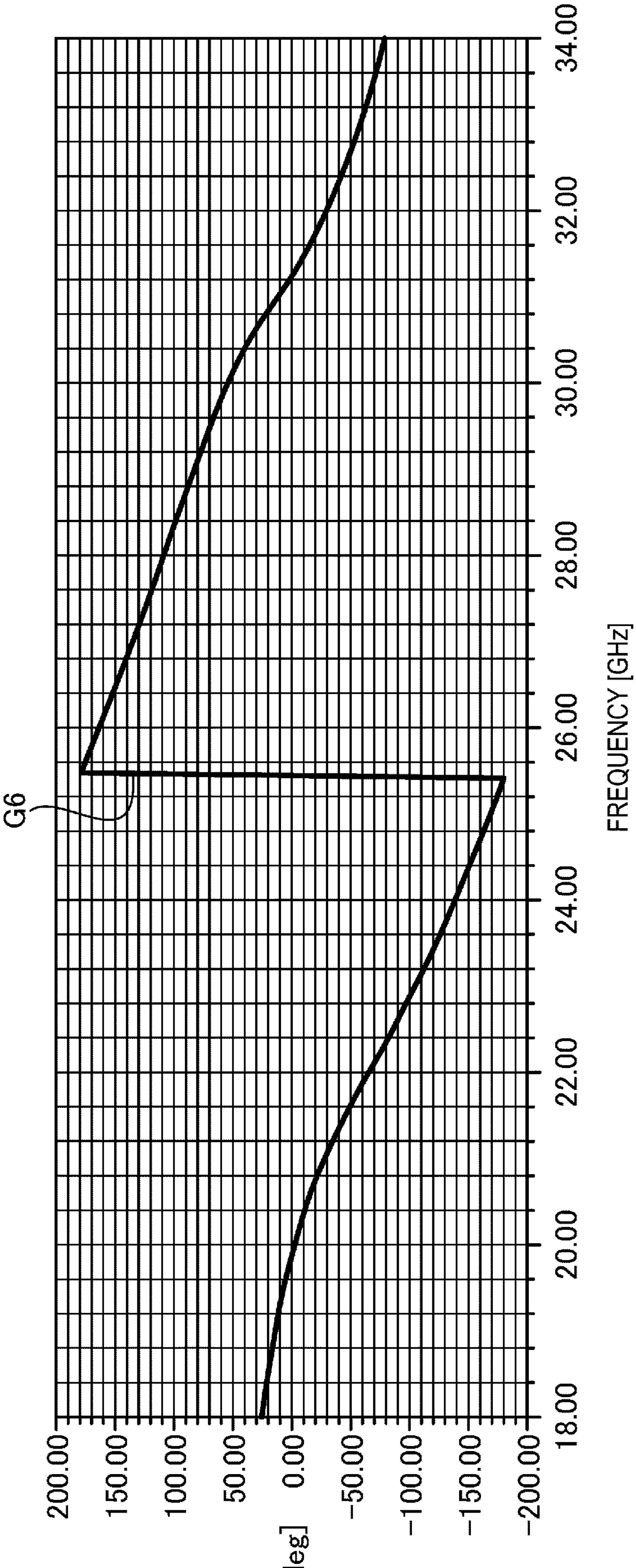
30.00
32.00
34.00
FREQUENCY [GHz]
G4
G5

FIG. 6


G6
[deg]
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−200.00
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20.00
22.00
24.00
26.00
28.00
30.00
32.00
34.00
FREQUENCY [GHz]

FIG. 7

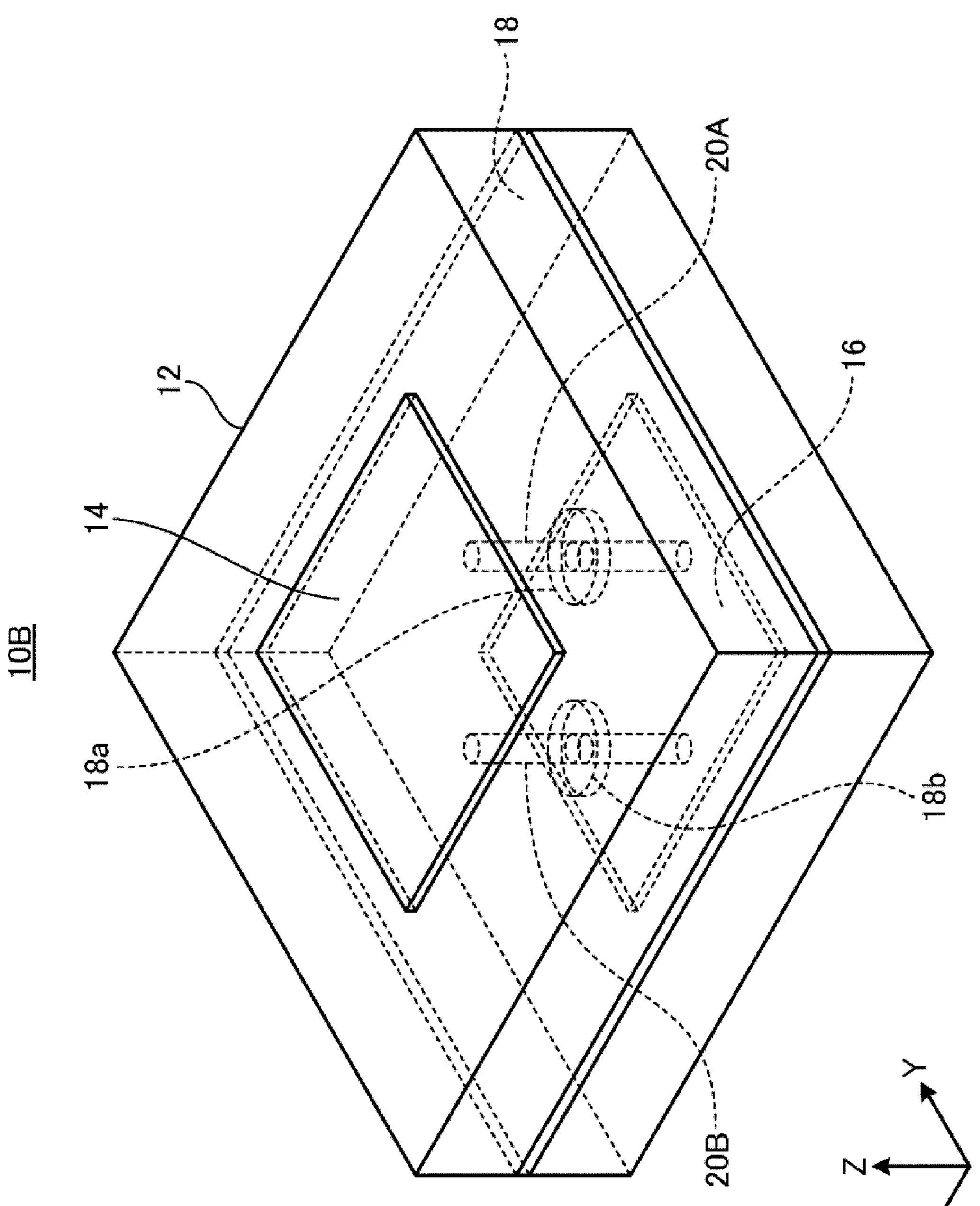
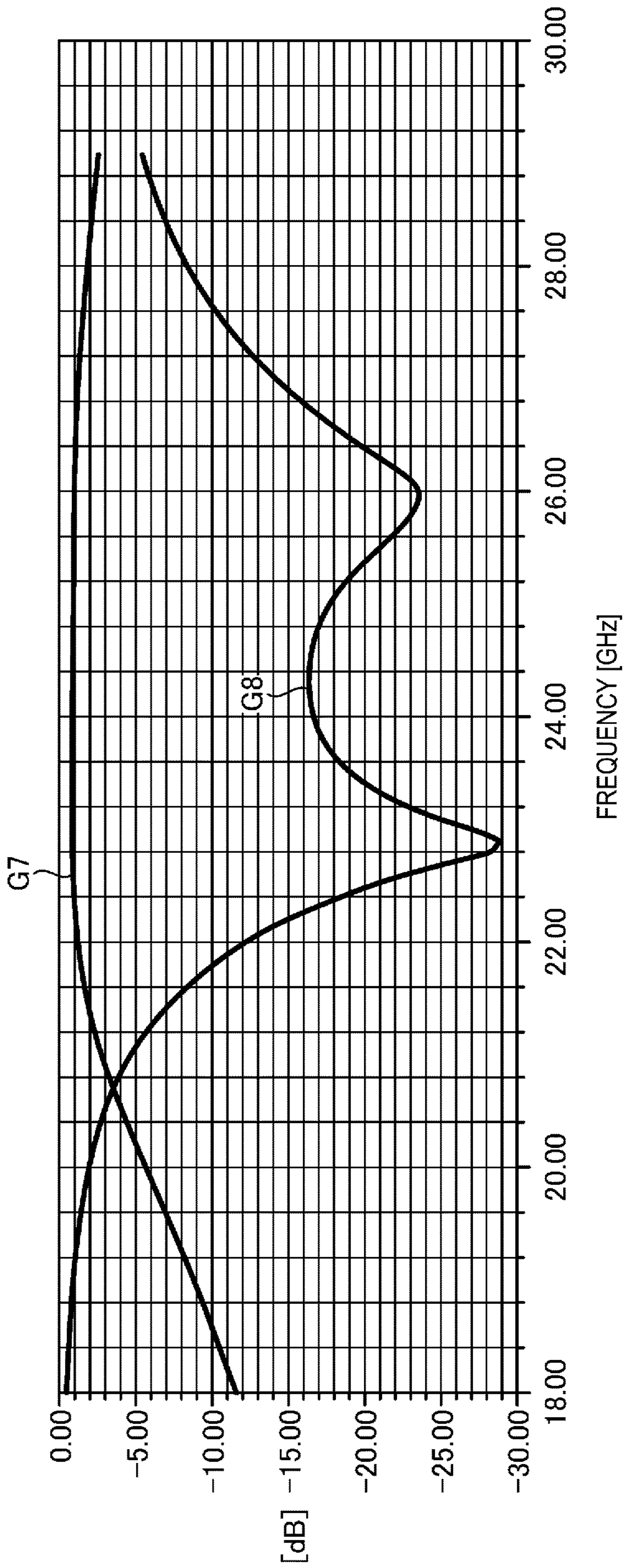


FIG. 8


G7
G8
[dB]
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-20.00
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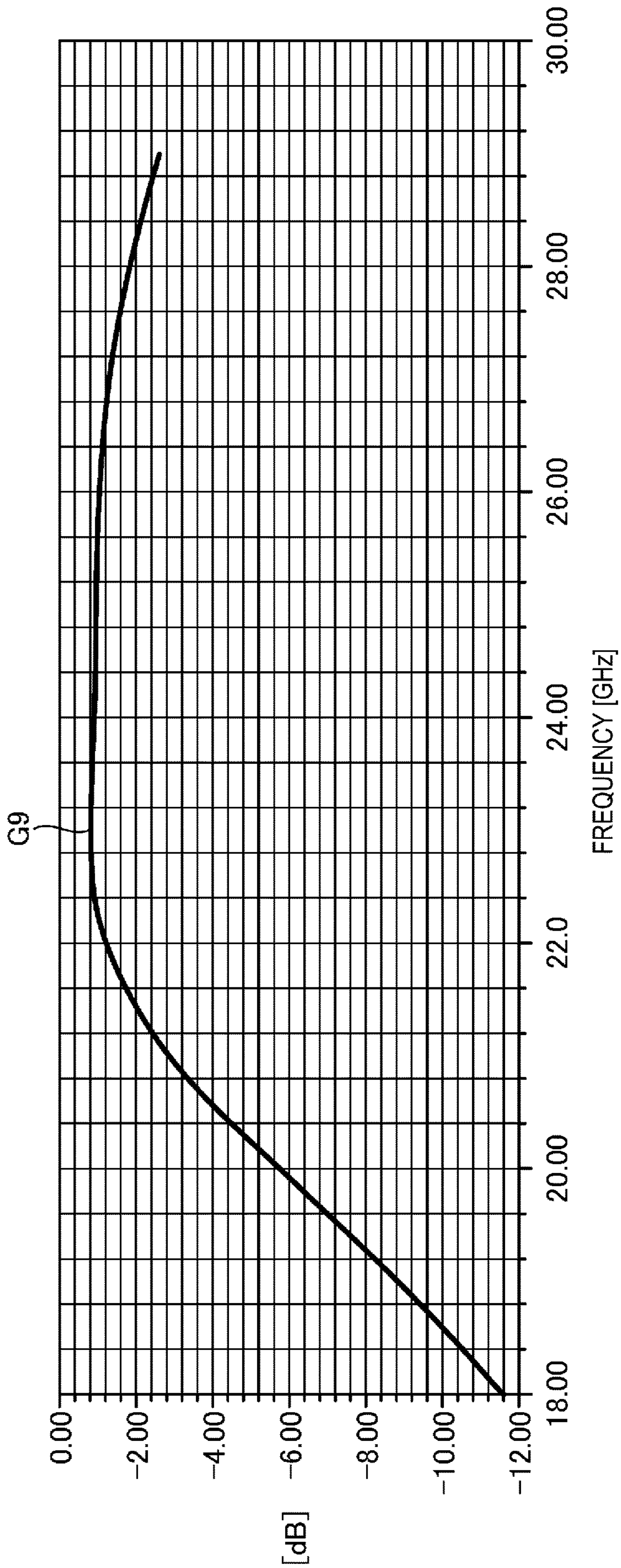
22.00
24.00
26.00
28.00
30.00
FREQUENCY [GHz]

FIG. 9


G9
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−10.00
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[dB]
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26.00
28.00
30.00
FREQUENCY [GHz]

FIG. 10

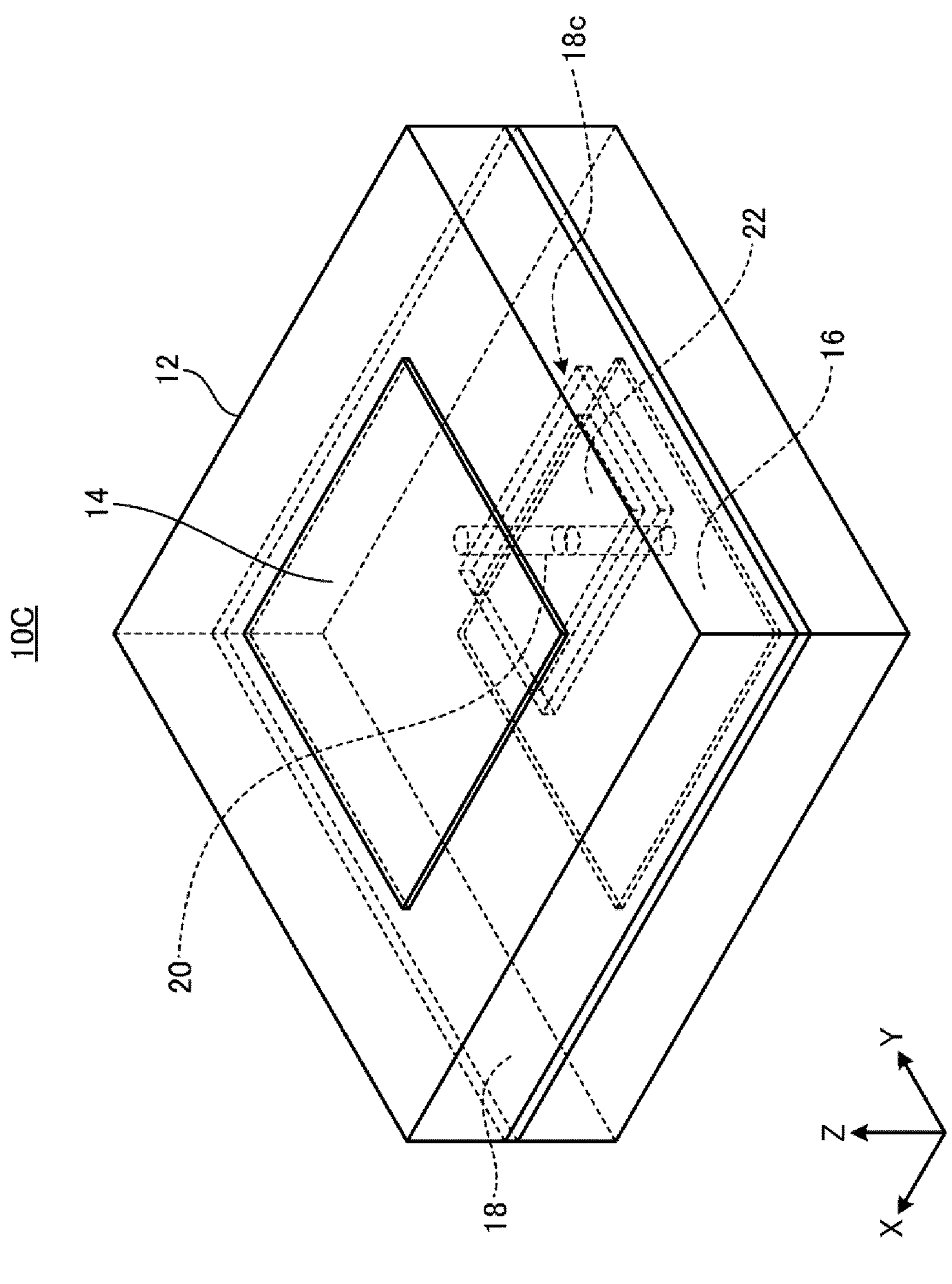
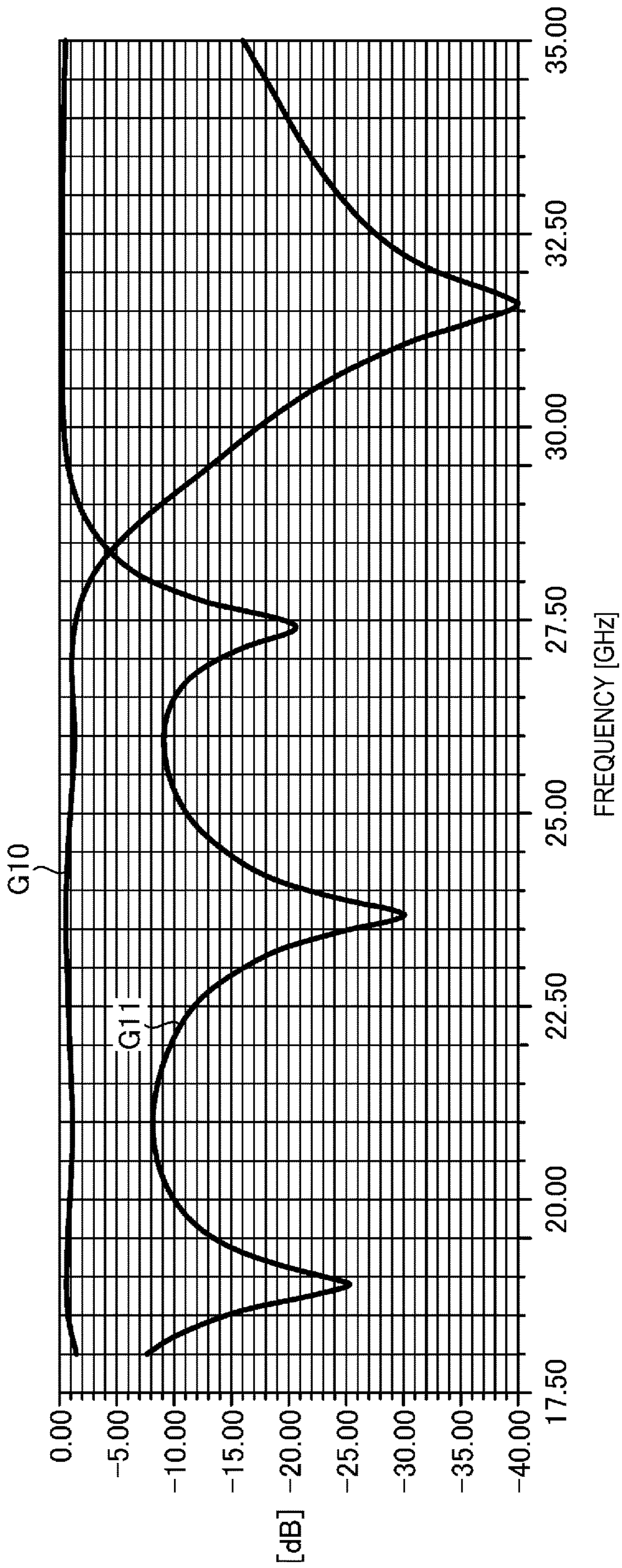


FIG. 11


G10
G11
[dB]
0.00
-5.00
-10.00
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-20.00
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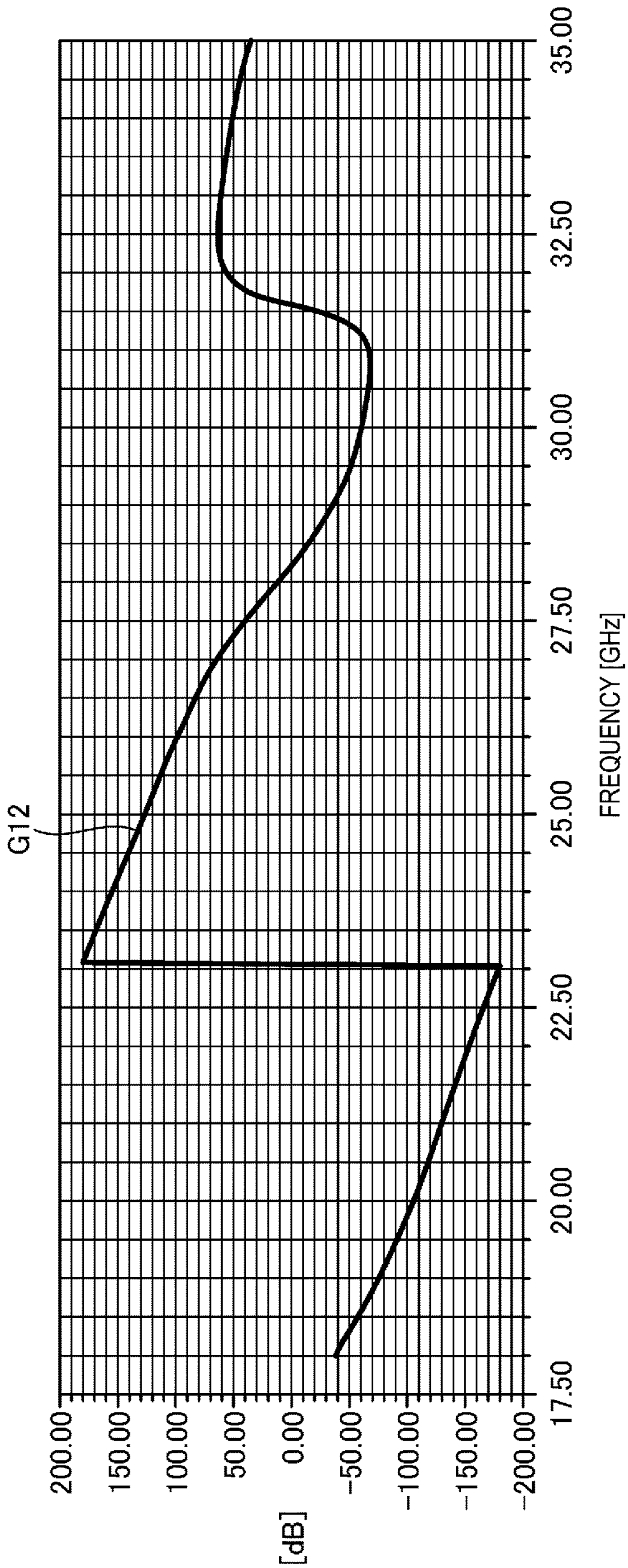
-30.00
-35.00
-40.00
17.50
20.00
22.50
25.00
27.50
30.00
32.50
35.00
FREQUENCY [GHz]

FIG. 12


G12
[dB]
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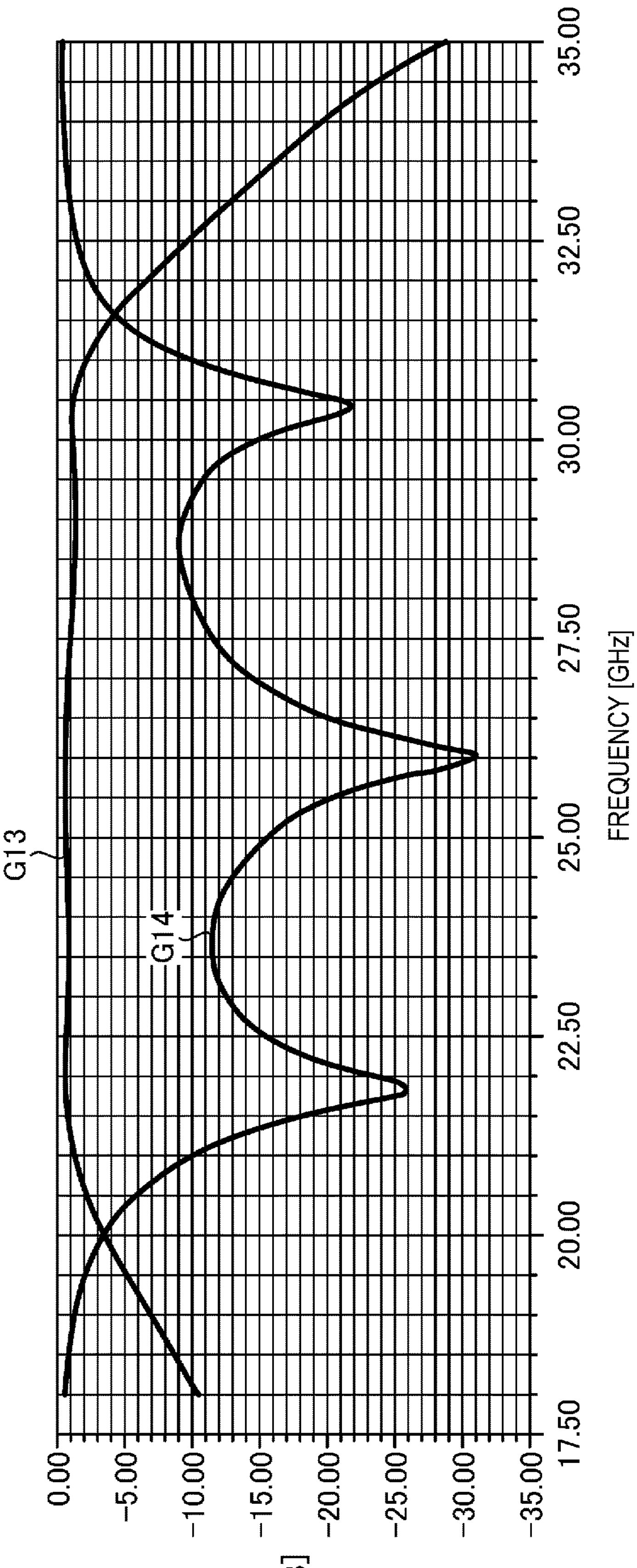
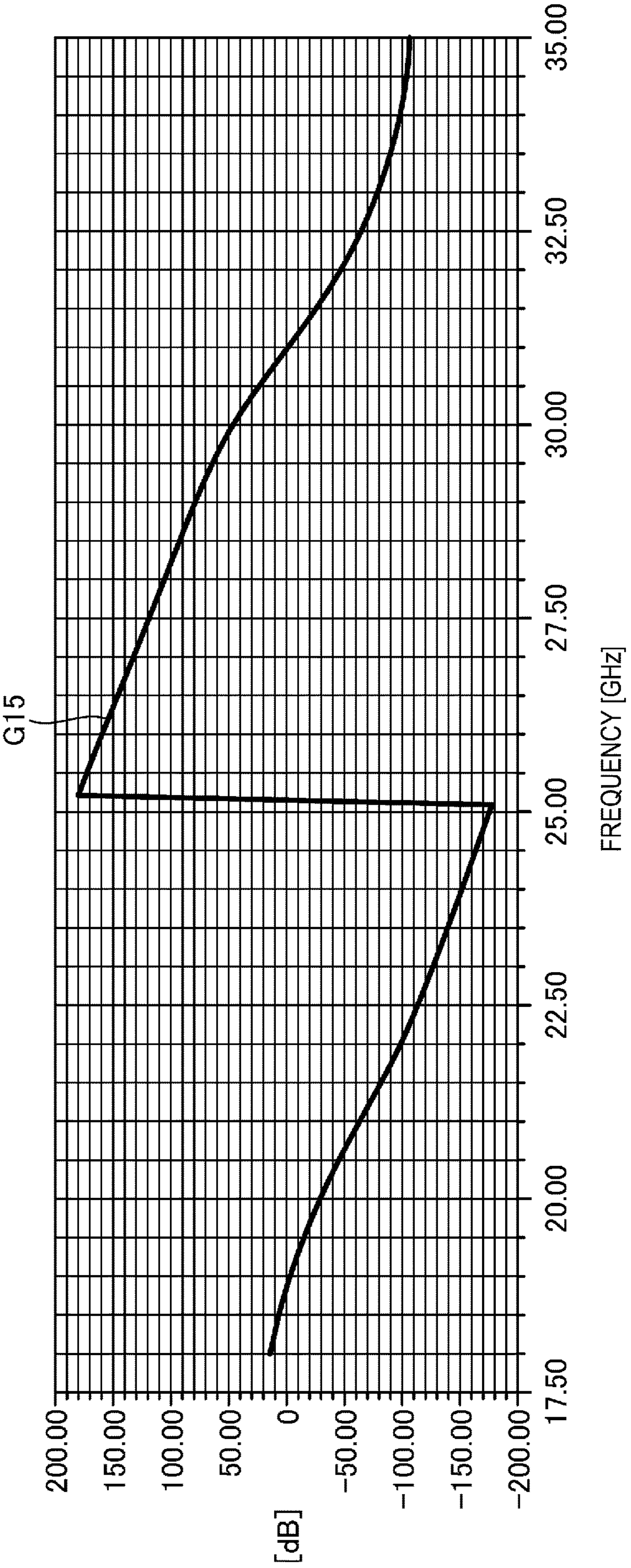
−50.00
−100.00
−150.00
−200.00
17.50
20.00
22.50
25.00
27.50
30.00
32.50
35.00
FREQUENCY [GHz]

FIG. 13



[dB]
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
17.50
20.00
22.50
25.00
27.50
30.00
32.50
35.00
FREQUENCY [GHz]
G13
G14

FIG. 14


G15
[dB]
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100.00
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−150.00
−200.00
17.50
20.00
22.50
25.00
27.50
30.00
32.50
35.00
FREQUENCY [GHz]

FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/045392

A. CLASSIFICATION OF SUBJECT MATTER

H01Q 15/12(2006.01)i; ***H01Q 15/14***(2006.01)i
FI: H01Q15/12; H01Q15/14 B

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01Q15/12; H01Q15/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2014-160947 A (UNIV IBARAKI) 04 September 2014 (2014-09-04) entire text, all drawings	1-15
A	WO 2015/161323 A1 (TRANSSIP, INC.) 22 October 2015 (2015-10-22) entire text, all drawings	1-15
A	US 2013/0207737 A1 (WELDON, Thomas, P., ADAMS, Ryan S., MIEHLE, Konrad) 15 August 2013 (2013-08-15) entire text, all drawings	1-15

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 February 2022	**08 March 2022**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/045392

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2014-160947 A	04 September 2014	(Family: none)	
WO 2015/161323 A1	22 October 2015	(Family: none)	
US 2013/0207737 A1	15 August 2013	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2015231182 A **[0003]**