(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 930 095 A1

(12) # EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
29.12.2021 Bulletin 2021/52

(21) Application number: **20758802.1**

(22) Date of filing: **13.02.2020**

(51) Int Cl.:
H01P 5/18 *(2006.01)* ***H05B 6/70*** *(2006.01)*

(86) International application number:
PCT/JP2020/005511

(87) International publication number:
WO 2020/170923 (27.08.2020 Gazette 2020/35)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **22.02.2019 JP 2019029955**

(71) Applicant: **Panasonic Intellectual Property Management Co., Ltd.**
Osaka-shi, Osaka 540-6207 (JP)

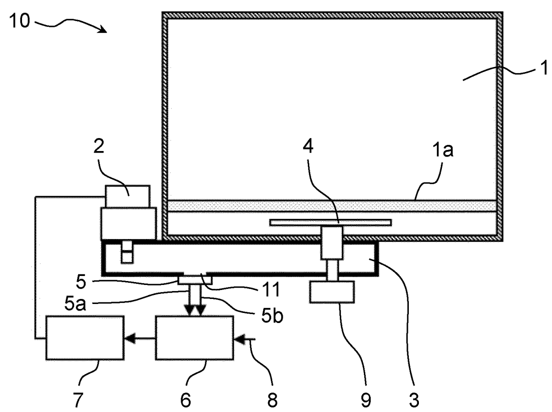
(72) Inventors:
- **KUBO, Masayuki**
  Osaka-shi, Osaka 540-6207 (JP)
- **YOSHINO, Koji**
  Osaka-shi, Osaka 540-6207 (JP)
- **SADAHIRA, Masafumi**
  Osaka-shi, Osaka 540-6207 (JP)
- **NAKAMURA, Hideki**
  Osaka-shi, Osaka 540-6207 (JP)

(74) Representative: **SSM Sandmair Patentanwälte Rechtsanwalt Partnerschaft mbB**
Joseph-Wild-Straße 20
81829 München (DE)

(54) **MICROWAVE HEATING DEVICE**

(57) A microwave heating device according to the present disclosure includes: a heating chamber to accommodate a heating target object, a microwave generating unit, a waveguide, an opening, and a reflected-wave detection unit. The microwave generating unit generates a microwave. The waveguide transmits, to the heating chamber, the microwave generated by the microwave generating unit. The opening is disposed in a wall surface of the waveguide, and extracts a part of a microwave from the waveguide. The reflected-wave detection unit detects a part of a reflected wave being a microwave propagating from the heating chamber toward the microwave generating unit, with the part of the reflected wave having been extracted through the opening. The reflected-wave detection unit is disposed within a range from the opening to a distance equal to 1/2 of the maximum opening length of the opening.

FIG. 1



Printed by Jouve, 75001 PARIS (FR)

Description

TECHNICAL FIELD

[0001] The present disclosure relates to microwave heating devices which each detect the power level of a microwave propagating through a waveguide.

BACKGROUND ART

[0002] A directional coupler is known as a device intended to detect the power level of a microwave propagating through a waveguide. The directional coupler separates and individually detects an incident wave and a reflected wave which both propagate through the waveguide.

[0003] Conventionally, for example, a directional coupler described in Patent Literature 1 has been known. The directional coupler described in Patent Literature 1 is provided with an opening disposed in a wall surface of a waveguide, and a coupling line disposed on the outside of the waveguide. The opening is disposed at a position not to intersect the tube axis of the waveguide in a plan view, and is configured to emit circularly polarized microwaves. The coupling line includes a first transmission line and a second transmission line which each intersect the opening in a plan view. The first transmission line and the second transmission line are disposed to face each other with a central portion of the opening being interposed between them, and are coupled to each other at a position out of the region vertically above the opening.

[0004] With the directional coupler according to Patent Literature 1, the rotation direction of a circularly polarized microwave emitted from the opening fed by an incident wave, is opposite to that of a circularly polarized microwave emitted from the opening fed by a reflected wave. By utilizing such a difference in rotation direction between the circularly polarized microwaves, the incident wave and the reflected wave can be separately detected.

Citation List

Patent Literature

[0005] PTL 1: Japanese Patent No. 6176540

SUMMARY OF THE INVENTION

[0006] The conventional microwave detection unit described above, however, still has room for improvement in view of achieving higher accuracy in separately detecting incident waves and reflected waves.

[0007] Therefore, an object of the present disclosure is to provide a microwave heating device capable of separately detecting, with higher accuracy, incident waves and reflected waves which both propagate through a waveguide.

[0008] A microwave heating device according to an aspect of the present disclosure includes: a heating chamber to accommodate a heating target object, a microwave generating unit, a waveguide, an opening, and a reflected-wave detection unit. The microwave generating unit generates a microwave. The waveguide transmits, to the heating chamber, the microwave generated by the microwave generating unit. The opening is disposed in a wall surface of the waveguide, and extracts a part of a microwave from the waveguide. The reflected-wave detection unit detects a part of a reflected wave being a microwave propagating from the heating chamber toward the microwave generating unit, with the part of the reflected wave having been extracted through the opening. The reflected-wave detection unit is disposed within a range from the opening to a distance equal to 1/2 of the maximum opening length of the opening.

[0009] In accordance with the aspect, it is possible to separately detect, with higher accuracy, an incident wave and a reflected wave propagating the waveguide.

BRIEF DESCRIPTION OF DRAWINGS

[0010]

FIG. 1 is a schematic view illustrating a configuration of a microwave heating device according to an embodiment of the present disclosure.
FIG. 2 is a perspective view of a microwave detection unit according to the embodiment.
FIG. 3 is a perspective view of the microwave detection unit according to the embodiment, in the state in which a printed circuit board has been removed.
FIG. 4 is a plan view of a waveguide according to the embodiment.

FIG. 5 is a circuit configuration diagram of the printed circuit board mounted on the microwave detection unit according to the embodiment.
FIG. 6 is a diagram for illustrating the principle that a cross opening emits a circularly polarized microwave.
FIG. 7 is a diagram for illustrating the direction and amount of a microwave that propagates through a microstrip line and varies with a lapse of time.
FIG. 8 is a diagram for illustrating the direction and amount of a microwave that propagates through the microstrip line and varies with a lapse of time.
FIG. 9A is a plan view showing an example of a first modification of a coupling line.
FIG. 9B is a plan view showing an example of a second modification of the coupling line.
FIG. 9C is a plan view showing an example of a third modification of the coupling line.
FIG. 9D is a plan view showing an example of a fourth modification of the coupling line.
FIG. 9E is a plan view showing an example of a fifth modification of the coupling line.
FIG. 9F is a plan view showing an example of a sixth modification of the coupling line.
FIG. 10 is a diagram schematically illustrating a positional relationship between the microwave detection unit and the opening.
FIG. 11 is a graph showing a relation between detection accuracy and the distance from the microwave detection unit to the opening.

DESCRIPTION OF EMBODIMENTS

[0011] The inventors have earnestly studied how to separately detect, with higher accuracy, incident waves and reflected waves which both propagate through a waveguide, and have obtained the following findings.
[0012] A microwave generated by a microwave generating unit is transmitted, via a waveguide, to a heating chamber as an incident wave. A part of the microwave transmitted to the heating chamber is absorbed by a heating target object while the rest of it returns from the heating chamber as a reflected wave via the waveguide.
[0013] In order to extract the reflected wave that is propagating the waveguide, an opening is disposed in a wall surface of the waveguide. A reflected-wave detection unit detects the reflected wave extracted through from the opening.
[0014] The inventors have obtained the finding that, in such detection, a distance between the opening and the reflected-wave detection unit that faces the opening has a great influence on the detection accuracy of the reflected wave. The present inventors have obtained the further finding, as to a distance between the opening and the reflected-wave detection unit, that the distance which can bring about accurate detection has a relation to the maximum opening length of the opening.
[0015] On the basis of these new findings, the inventors have found the following inventions.
[0016] A microwave heating device according to a first aspect of the present disclosure includes: a heating chamber to accommodate a heating target object, a microwave generating unit, a waveguide, an opening, and a reflected-wave detection unit.
[0017] The microwave generating unit generates a microwave. The waveguide transmits, to the heating chamber, the microwave generated by the microwave generating unit. The opening is disposed in a wall surface of the waveguide, and extracts a part of a microwave from the waveguide. The reflected-wave detection unit detects a part of a reflected wave being a microwave propagating from the heating chamber toward the microwave generating unit, with the part of the reflected wave having been extracted through the opening. The reflected-wave detection unit is disposed within a range from the opening to a distance equal to 1/2 of the maximum opening length of the opening.
[0018] A microwave heating device according to a second aspect of the present disclosure is the microwave heating device according to the first aspect, in which
the reflected-wave detection unit is disposed so as to fail to be in contact with the opening.
[0019] A microwave heating device according to a third aspect of the present disclosure is the microwave heating device according to the first aspect, the device further including an incident-wave detection unit to detect a part of an incident wave that is a microwave propagating from the microwave generating unit toward the heating chamber.
[0020] A microwave heating device according to a fourth aspect of the present disclosure is the microwave heating device according to the first aspect, in which

the incident-wave detection unit and the reflected-wave detection unit share a coupling line that faces the opening and has one end and the other end;
the incident-wave detection unit extracts the incident wave from the one end of the coupling line; and
the reflected-wave detection unit extracts the reflected wave from the other end of the coupling line.

[0021] A microwave heating device according to a fifth aspect of the present disclosure is the microwave heating device according to the first aspect, in which the opening includes: a first elongated hole; and a second elongated hole, with the first elongated hole and the second elongated hole crossing each other and being disposed at a position failing to cross the tube axis of the waveguide in a plan view; and

the coupling line includes: a first transmission line; and a second transmission line.

[0022] The first transmission line includes a first intersecting-line portion. The first intersecting-line portion is configured, in a plan view, to: extend, from one end of the tube axis, away from the tube axis as approaching a perpendicular line orthogonal to the tube axis, with the perpendicular line passing through an opening-cross portion at which the first elongated hole and the second elongated hole cross each other; and intersect the first elongated hole at a position farther away from the tube axis than the opening-cross portion.

[0023] The second transmission line includes a second intersecting-line portion. The second intersecting-line portion is configured, in a plan view, to: extend, from another end of the tube axis, away from the tube axis as approaching the perpendicular line; and intersect the second elongated hole at a position farther away from the tube axis than the opening-cross portion.

[0024] One end of the first transmission line is coupled to one end of the second transmission line at a position out of a region, in a plan view, in which the opening is disposed.

[0025] Hereinafter, descriptions will be made regarding a microwave heating device according to an embodiment of the present disclosure, with reference to the drawings.

[0026] FIG. 1 is a schematic view illustrating a configuration of microwave heating device 10 according to an embodiment of the present disclosure. FIG. 2 is a perspective view of microwave detection unit 5 according to the embodiment. FIG. 3 is a perspective view of microwave detection unit 5, in the state in which printed circuit board 12 has been removed. FIG. 4 is a plan view of waveguide 3. FIG. 5 is a circuit configuration diagram of printed circuit board 12 mounted on microwave detection unit 5 shown in FIG. 1.

[0027] As shown in FIG. 1, microwave heating device 10 includes: heating chamber 1, microwave generating unit 2, waveguide 3, microwave emitting part 4, microwave detection unit 5, controller 6, drive power supply 7, and motor 9.

[0028] Heating chamber 1 accommodates a heating target object. Microwave generating unit 2 generates a microwave. Waveguide 3 causes the microwave generated by microwave generating unit 2 to propagate. Microwave emitting part 4 is disposed below bottom surface 1a of heating chamber 1, and emits the microwave, which has propagated through waveguide 3, to heating chamber 1.

[0029] Microwave detection unit 5 is a directional coupler which is disposed to cover cross opening 11 disposed in waveguide 3. Through from cross opening 11, a part of the microwave propagating inside waveguide 3 is extracted.

[0030] Microwave detection unit 5 detects detection signal 5a in accordance with an incident wave that has propagated from microwave generating unit 2 through inside waveguide 3 toward microwave emitting part 4 and is extracted through from cross opening 11. Microwave detection unit 5 detects detection signal 5b in accordance with a reflected wave that has propagated from microwave emitting part 4 through inside waveguide 3 toward microwave generating unit 2 and is extracted through from cross opening 11. Details of waveguide 3, microwave detection unit 5, and cross opening 11 will be described later.

[0031] Controller 6 receives signal 8 in addition to detection signals 5a and 5b. Signal 8 includes signals regarding: heating conditions that are set by means of an input unit (not shown) of microwave heating device 10, and the weight and vapor-amount of the heating target object that are detected with sensors (not shown).

[0032] Controller 6 controls drive power supply 7 and motor 9 in accordance with detection signals 5a and 5b and signal 8. Drive power supply 7 supplies, to microwave generating unit 2, electric power for generating microwaves. Motor 9 rotates microwave emitting part 4. In this way, microwave heating device 10 heats the heating target object accommodated in heating chamber 1, by means of the microwave supplied to heating chamber 1.

[0033] As shown in FIGS. 2 and 3, microwave detection unit 5 is disposed on a wall surface of waveguide 3 that transmits microwaves. Waveguide 3 is a rectangular waveguide. The cross section, orthogonal to tube axis L1, of waveguide 3 has a rectangular shape. Tube axis L1 is the center axis of waveguide 3, in the direction of the width.

[0034] Microwave detection unit 5 includes cross opening 11, printed circuit board 12, and support part 14. Cross opening 11 is an X-shaped opening disposed in a wide plane (Wide Plane) 3a of waveguide 3. Printed circuit board 12 is disposed outside waveguide 3 so as to face cross opening 11. Support part 14 supports printed circuit board 12 on an outer surface of waveguide 3.

[0035] As shown in FIG. 4, cross opening 11 is disposed at a position not to intersect tube axis L1 of waveguide 3, in a plan view. Opening-center portion 11c of cross opening 11 is disposed away from tube axis L1 of waveguide 3 by dimension D1 in a plan view. Dimension D1 is equal to, for example, 1/4 of the width of waveguide 3. Cross opening 11 emits microwaves propagating inside waveguide 3, as circularly polarized microwaves, toward printed circuit board 12.

[0036] The opening shape of cross opening 11 is determined in accordance with conditions including: the width and height of waveguide 3, the power levels and frequency bands of microwaves propagating through waveguide 3, and the power levels of circularly polarized microwaves emitted from cross opening 11.

[0037] For example, in the case where the width and height of waveguide 3 are respectively 100 mm and 30 mm, the wall thickness of waveguide 3 is 0.6 mm, the maximum power level of the microwave propagating through waveguide 3 is 1000 W, the frequency band is 2450 MHz, and the maximum power level of the circularly polarized microwave emitted from cross opening 11 is approximately 10 mW, length 11w and width 11d of cross opening 11 are set to 20 mm and 2 mm, respectively.

[0038] As shown in FIG. 5, cross opening 11 includes: first elongated hole 11e and second elongated hole 11f which cross each other. Opening-center portion 11c of cross opening 11 coincides with an opening-cross portion where first elongated hole 11e crosses second elongated hole 11f. Cross opening 11 is formed to have line symmetry with respect to perpendicular line L2. Perpendicular line L2 is orthogonal to tube axis L1, and passes through opening-center portion 11c.

[0039] In the present embodiment, first elongated hole 11e and second elongated hole 11f cross each other at an angle of 90 degrees. However, the present disclosure is not limited to this. First elongated hole 11e and second elongated hole 11f may cross each other at an angle of either 60 degrees or 120 degrees.

[0040] In the case where opening-center portion 11c of cross opening 11 is disposed at a position at which the opening-center portion is superposed on tube axis L1 in a plan view, the electric field reciprocates along the transmission direction of the microwave, without rotating. In this case, cross opening 11 emits a linearly polarized microwave.

[0041] In the case where opening-center portion 11c is even slightly out of tube axis L1, the electric field will rotate. Further, in the case where opening-center portion 11c is close to tube axis L1 (as dimension D1 is closer to 0 [zero] mm), a distorted rotating electric field is generated. In this case, cross opening 11 emits an elliptically polarized microwave.

[0042] According to the present embodiment, dimension D1 is set equal to approximately 1/4 of the width of waveguide 3. In this case, a substantially-perfect circular rotating electric field is generated. Cross opening 11 emits a substantially-perfect circularly polarized microwave. This allows the rotation direction of the circularly polarized microwave to be more distinct. As a result, the incident wave and the reflected wave can be separately detected with high accuracy.

[0043] Printed circuit board 12 has board rear surface 12b facing cross opening 11, and board front surface 12a opposite to board rear surface 12b. Board front surface 12a includes copper foil (not shown), an example of a microwave reflecting member, that is formed to cover the whole of board front surface 12a. It is the copper foil that prevents the circularly polarized microwaves emitted from cross opening 11 from penetrating through printed circuit board 12.

[0044] As shown in FIG. 5, microstrip line 13, an example of a coupling line, is disposed on board rear surface 12b. Microstrip line 13 is configured with a transmission line with a characteristic impedance of approximately 50 Ω, for example. Microstrip line 13 is disposed to surround opening-center portion 11c of cross opening 11.

[0045] Hereinafter, effective length λ_{re} of microstrip line 13 will be described. Effective length λ_{re} of microstrip line 13 is expressed as the following equation, where "w" is the width of microstrip line 13, "h" is the thickness of printed circuit board 12, "c" is the velocity of light, "f' is the frequency of an electromagnetic wave, and "ε_r" is the relative permittivity of the printed circuit board. Effective length λ_{re} equals the wavelength of an electromagnetic wave propagating through microstrip line 13.

[Equation 1]

$$\lambda_{re} = \frac{c}{f \cdot \sqrt{\varepsilon_{re}}}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \frac{1}{\sqrt{(1 + 10h/w)}}$$

[0046] Specifically, microstrip line 13 includes: first transmission line 13a and second transmission line 13b. First transmission line 13a has first straight-line portion 13aa which is an example of a first intersecting-line portion. First straight-line portion 13aa intersects first elongated hole 11e at a position farther away from tube axis L1 than opening-center portion 11c, in a plan view. First straight-line portion 13aa extends away from tube axis L1 as approaching perpendicular line L2.

[0047] Second transmission line 13b has second straight-line portion 13ba which is an example of a second intersecting-line portion. Second straight-line portion 13ba intersects second elongated hole 11f at a position farther away from tube axis L1 than opening-center portion 11c, in a plan view. Second straight-line portion 13ba extends away from tube axis L1 as approaching perpendicular line L2. First straight-line portion 13aa and second straight-line portion 13ba are disposed to have line symmetry with respect to perpendicular line L2.

[0048] First transmission line 13a and second transmission line 13b are coupled to each other at a position that is outside rectangular region E1 and is farther away from tube axis L1 than rectangular region E1, in a plan view. First straight-line portion 13aa intersects first elongated hole 11e at a position that is closer to opening-end portion 11ea than opening-center portion 11c, in a plan view.

[0049] First straight-line portion 13aa is orthogonal to first elongated hole 11e in a plan view. Second straight-line portion 13ba intersects second elongated hole 11f at a position that is closer to opening-end portion 11fa than opening-center portion 11c, in a plan view. Second straight-line portion 13ba is orthogonal to second elongated hole 11f in a plan view.

[0050] One end of first transmission line 13a and one end of second transmission line 13b are coupled to each other at outside the region that is superposed on cross opening 11, in a plan view. One end of first straight-line portion 13aa is coupled to one end of second straight-line portion 13ba at outside rectangular region E1 that circumscribes cross opening 11.

[0051] First coupling point P1 is a point where first straight-line portion 13aa and first elongated hole 11e intersect each other in a plan view. Second coupling point P2 is a point where second straight-line portion 13ba and second elongated hole 11f intersect each other in a plan view. A straight line that connects first coupling point P1 and second coupling point P2 is defined as virtual straight line L3. In the present embodiment, the sum of a line distance of first transmission line 13a further away from tube axis L1 than virtual straight line L3 and a line distance of second transmission line 13b further away from tube axis L1 than virtual straight line L3, is set equal to 1/4 of effective length λ_{re}.

[0052] In a plan view, a line that passes through opening-center portion 11c and is parallel to tube axis L1 is defined as parallel line L4. In the present embodiment, the sum of a line distance of first transmission line 13a further away from tube axis L1 than parallel line L4 and a line distance of second transmission line 13b further away from tube axis L1 than parallel line L4, is set equal to 1/2 of effective length λ_{re}.

[0053] First transmission line 13a includes third straight-line portion 13ab that couples the other end of first straight-line portion 13aa to first output part 131. First straight-line portion 13aa and third straight-line portion 13ab are coupled to each other so as to make an obtuse angle (e.g. 135 degrees).

[0054] Second transmission line 13b includes fourth straight-line portion 13bb that couples the other end of second straight-line portion 13ba to second output part 132. Second straight-line portion 13ba and fourth straight-line portion 13bb are coupled to each other so as to make an obtuse angle (e.g. 135 degrees). Third straight-line portion 13ab and fourth straight-line portion 13bb are disposed in parallel with perpendicular line L2.

[0055] First output part 131 and second output part 132 are disposed outside support part 14 (see FIGS. 2 and 3) in a plan view. To first output part 131, first detector circuit 15 is coupled. First detector circuit 15 detects the level of a microwave signal, and outputs the detected level of the microwave signal as a control signal. To second output part 132, second detector circuit 16 is coupled. Second detector circuit 16 outputs the detected level of the microwave signal as a control signal.

[0056] In the present embodiment, each of first detector circuit 15 and second detector circuit 16 includes a smoothing circuit (not shown) that is configured to include a chip resistor and a Schottky diode. First detector circuit 15 rectifies a microwave signal fed from first output part 131, and converts the rectified microwave signal into a direct-current voltage. The thus-converted direct-current voltage is fed to first detection output part 18.

[0057] Likewise, second detector circuit 16 rectifies a microwave signal fed from second output part 132, and converts the rectified microwave signal into a direct-current voltage. The thus-converted direct-current voltage is fed to second detection output part 19.

[0058] Printed circuit board 12 includes four holes (holes 20a, 20b, 20c, and 20d) for attaching printed circuit board 12 to waveguide 3. On board rear surface 12b, copper foil for serving as a ground is formed at portions around holes 20a, 20b, 20c, and 20d. The portions on which the copper foil is formed have the same voltage as board front surface 12a.

[0059] Printed circuit board 12 is fixed to waveguide 3, with screws 201a, 201b, 201c, and 201d (see FIG. 2) being screwed through respective holes 20a, 20b, 20c, and 20d into support part 14.

[0060] As shown in FIG. 3, support part 14 is provided with screw portions 202a, 202b, 202c, and 202d into which screws 201a, 201b, 201c, and 201d are screwed, respectively. Screw portions 202a, 202b, 202c, and 202d are formed in a flange part disposed in support part 14.

[0061] Support part 14 has conductivity, and is disposed to surround cross opening 11 in a plan view. Support part 14 functions as a shield that prevents circularly polarized microwaves emitted from cross opening 11 from leaking out of support part 14.

[0062] Support part 14 is provided with groove 141 and groove 142 through which both third straight-line portion 13ab and fourth straight-line portion 13bb of microstrip line 13 pass, respectively. With this configuration, both first output part 131 and second output part 132 of microstrip line 13 are allowed to be disposed outside support part 14. Grooves 141 and 142 function as extraction parts for extracting the microwave signals, which propagate through microstrip line 13, to the outside of support part 14. Grooves 141 and 142 can be formed by recessing the flange part of support part 14 so as to be away from printed circuit board 12.

[0063] In FIGS. 2 and 3, illustrated are connector 18a and connector 19a that are respectively coupled to first detection output part 18 and second detection output part 19 shown in FIG. 5.

[0064] Next, the operation and action of microwave detection unit 5 will be described.

[0065] First, with reference to FIG. 6, a description will be made regarding the principle that a circularly polarized microwave is emitted from cross opening 11. In FIG. 6, magnetic field distribution 3d that appears inside waveguide 3 is illustrated by concentric ellipses depicted with the dotted lines. The directions of magnetic fields in magnetic field distribution 3d are indicated by the arrows. Magnetic field distribution 3d travels through inside waveguide 3 in transmission direction A1 of the microwave with a lapse of time.

[0066] At time t = t0 shown in (a) of FIG. 6, magnetic field distribution 3d is formed. At this time, the magnetic field indicated by broken line arrow B1 excites first elongated hole 11e of cross opening 11. At time t = t0 + t1 shown in (b) of FIG. 6, the magnetic field indicated by broken line arrow B2 excites second elongated hole 11f of cross opening 11.

[0067] At time t = t0 + T/2 (where T is the period of the in-tube wavelength of the microwave) shown in (a) of FIG. 6, the magnetic field indicated by broken line arrow B3 excites first elongated hole 11e of cross opening 11. At time t = t0 + T/2 + t1 shown in (d) of FIG. 6, the magnetic field indicated by broken line arrow B4 excites second elongated hole 11f of cross opening 11. At time t = t0 + T, as in the case at t = t0, the magnetic field indicated by broken line arrow B1 excites first elongated hole 11e of cross opening 11.

[0068] By repeating these states sequentially, a circularly polarized microwave that rotates counterclockwise (in rotation direction 32 of the microwave) is emitted from cross opening 11 to the outside of waveguide 3.

[0069] Here, assuming that the microwave propagating along arrow 30 shown in FIG. 4 is an incident wave and that the microwave propagating along arrow 31 is a reflected wave, the incident wave then travels in the same direction as transmission direction A1 shown in FIG. 6. This causes, as described above, the circularly polarized microwave that rotates counterclockwise to be emitted from cross opening 11 to the outside of waveguide 3.

[0070] On the other hand, the reflected wave propagates in the direction opposite to transmission direction A1 shown in FIG. 6. This causes the circularly polarized microwave that rotates clockwise to be emitted from cross opening 11 to the outside of waveguide 3.

[0071] The circularly polarized microwave emitted to the outside of the waveguide 3 is coupled to microstrip line 13 that faces cross opening 11. Microstrip line 13 outputs, to first output prat 131, most of the microwave that is fed by the incident wave propagating along arrow 30 and is emitted from cross opening 11.

[0072] On the other hand, microstrip line 13 outputs, to second output prat 132, most of the microwave that is fed by the reflected wave that propagates along arrow 31 and is emitted from cross opening 11.

[0073] That is, microwave detection unit 5 functions as both an incident-wave detection unit to detect incident waves and a reflected-wave detection unit to detect reflected waves, in which both units share microstrip line 13 being a coupling line facing cross opening 11.

[0074] This configuration allows microwave detection unit 5 to separately detect the incident waves and reflected waves with high accuracy. This will be described in detail with reference to FIG. 7.

[0075] FIG. 7 is a diagram for illustrating the direction and amount of a microwave that propagates through microstrip line 13 and varies with a lapse of time. There is a gap between microstrip line 13 and cross opening 11. In general, the time required for a microwave to arrive at microstrip line 13 is delayed by the time during which the microwave propagates across the gap. However, for convenience, it is assumed that there is no time delay here.

[0076] Here, regions in each of which cross opening 11 intersects microstrip line 13 in a plan view are referred to as coupling regions. First coupling point P1 locates at an approximate center of the coupling region in which first elongated hole 11e intersects microstrip line 13. Second coupling point P2 locates at an approximate center of the coupling region in which second elongated hole 11f intersects microstrip line 13.

[0077] In FIG. 7, the amount (observed as an electric current that flows due to interlinkage of a magnetic field) of the microwave propagating through microstrip line 13 is represented by the thickness of the solid line arrow. That is, when the amount of the microwave propagating through microstrip line 13 is large, it is indicated by the thick line; when the amount of the microwave propagating through microstrip line 13 is small, it is indicated by the thin line.

[0078] At time t = t0 shown in (a) of FIG. 7, the magnetic field indicated by broken line arrow B1 excites first elongated hole 11e of cross opening 11, and a microwave indicated by thick solid line arrow M1 is generated at first coupling point P1. This microwave propagates through microstrip line 13 toward second coupling point P2.

[0079] At time t = t0 + t1 shown in (b) of FIG. 7, the magnetic field indicated by broken line arrow B2 excites second elongated hole 11f of cross opening 11, and a microwave indicated by thick solid line arrow M2 is generated at second coupling point P2.

[0080] In the case where the effective propagation time of the microwave between first coupling point P1 and second coupling point P2 through microstrip line 13 is set to time t1, the microwave generated at first coupling point P1 at the time shown in (a) of FIG. 7 propagates to second coupling point P2 at the time shown in (b) of FIG. 7. That is, at the time shown in (b) of FIG. 7, both the microwave indicated by solid line arrow M1 and the microwave indicated by solid line arrow M2 occur at second coupling point P2.

[0081] Accordingly, the two microwaves are added and propagate through microstrip line 13 toward second output part 132, and are then fed to second output part 132 after a lapse of a predetermined time. In the present embodiment, in order to set the effective propagation time described above equal to time t1, the sum of a line distance of first transmission line 13a further away from tube axis L1 than virtual straight line L3 and a line distance of second transmission line 13b further away from tube axis L1 than virtual straight line L3, is set equal to 1/4 of effective length λ_{re}. This configuration allows easy designing of microstrip line 13.

[0082] At time t = t0 + T/2 shown in (c) of FIG. 7, the magnetic field indicated by broken line arrow B3 excites first elongated hole 11e of cross opening 11, and a microwave indicated by thin solid line arrow M3 is generated at first coupling point P1. This microwave propagates through microstrip line 13 toward first output part 131, and is fed to first output part 131 after a lapse of a predetermined time.

[0083] The reason why the thickness of solid line arrow M3 is made thinner than that of solid line arrow M1 is as follows: From cross opening 11, a circularly polarized microwave that rotates counterclockwise (in rotation direction 32 of the microwave) is emitted as described above.

[0084] At the time shown in (a) of FIG. 7, the microwave generated at first coupling point P1 indicated by solid line arrow M1 propagates in a direction substantially the same as the rotation direction of the microwave emitted from cross opening 11. For this reason, the energy of the microwave indicated by solid line arrow M1 is not reduced.

[0085] In contrast, at the time shown in (c) of FIG. 7, the microwave generated at first coupling point P1 indicated by solid line arrow M3 propagates in a direction substantially opposite to the rotation direction of the microwave emitted from cross opening 11. For this reason, the energy of the combined microwave is reduced. Accordingly, the amount of the microwave indicated by solid line arrow M3 is smaller than the amount of the microwave indicated by solid line arrow M1.

[0086] At time t = t0 + T/2 + t1 shown in (d) of FIG. 7, the magnetic field indicated by broken line arrow B4 excites second elongated hole 11f of cross opening 11, and a microwave indicated by thin solid line arrow M4 is generated at second coupling point P2. This microwave propagates toward first coupling point P1. The reason why the thickness of solid line arrow M4 is made thin is the same as the reason why the thickness of solid line arrow M3 is made thin as described above.

[0087] At time t = t0 + T, as in the case at time t = t0 shown in (a) of FIG. 7, the magnetic field indicated by broken line arrow B1 excites first elongated hole 11e of cross opening 11. In this case, although having not been described in the case at the time shown in (a) of FIG. 7, there exists a microwave indicated by thin solid line arrow M4 on microstrip line 13.

[0088] The microwave indicated by thin solid line arrow M4 propagates to first coupling point P1 at time t = t0 + T (that is, t = t0). The microwave indicated by thin solid line arrow M4 propagates in the direction opposite to the microwave indicated by thick solid line arrow M1. Therefore, the microwave indicated by solid line arrow M4 is canceled and disappears, and is not fed to first output part 131.

[0089] Strictly speaking, the amount of the microwave propagating from first coupling point P1 at time t = t0 is equal to the amount (M1 - M4) that is obtained by subtracting the amount of the microwave indicated by thin solid line arrow M4 from the amount of the microwave indicated by thick solid line arrow M1. Accordingly, the amount of the microwave fed to second output part 132 is equal to the amount (M1 + M2 - M4) that is obtained by adding the amount of the microwave indicated by thick solid line arrow M2 to the amount of the microwave propagating from second coupling point P2.

[0090] In consideration of this, the amount (M1 + M2 - M4) of the microwave fed to second output part 132 is much larger than the amount (M3) of the microwave fed to first output part 131. Therefore, microstrip line 13 outputs, to second output prat 132, most of the microwave rotating counterclockwise that is fed by the reflected wave propagating along arrow 31 and is emitted from cross opening 11. On the other hand, microstrip line 13 outputs, to first output prat 131, most of the microwave rotating clockwise that is fed by the incident wave propagating along arrow 30 and is emitted from cross opening 11.

[0091] The amount of the microwave emitted from cross opening 11 with respect to the amount of the microwave propagating through waveguide 3 is determined by the shapes and dimensions of waveguide 3 and cross opening 11. For example, in the case where the shapes and dimensions are set to ones described above, the amount of the microwave emitted from cross opening 11 is approximately 1/100000 (approximately -50 dB) times the amount of the microwave propagating through waveguide 3.

[0092] Next, a description will be made regarding the reason why, in the present embodiment, the sum of a line distance of first transmission line 13a further away from tube axis L1 than parallel line L4 and a line distance of second transmission line 13b further away from tube axis L1 than parallel line L4, is set equal to 1/2 of effective length λ_{re}.

[0093] FIG. 8 is a diagram for illustrating the direction and amount of a microwave that propagates through microstrip line 13 and varies with a lapse of time. In (a) to (d) of FIG. 8, the states of (a) to (d) of FIG. 7 after a lapse of time t1/2 are respectively illustrated.

[0094] Although the description is omitted above, magnetic field distribution 3d travels through inside waveguide 3 in transmission direction A1 of the microwave with a lapse of time. Therefore, as shown in (a) to (d) of FIG. 8, the magnetic fields indicated by broken line arrows B12, B23, B34, and B41 excite first elongated hole 11e and second elongated hole 11f. This causes circularly polarized microwaves emitted to the outside of waveguide 3 to be coupled to microstrip line 13.

[0095] Here, in a plan view, a region in which perpendicular line L2 and parallel line L4 intersect microstrip line 13 is referred to as a coupling region. Third coupling point P3 locates at an approximate center of the coupling region in which perpendicular line L2 intersects microstrip line 13. Fourth coupling point P4 locates at an approximate center of the coupling region in which parallel line L4 intersects first transmission line 13a. Fifth coupling point P5 locates at an approximate center of the coupling region in which parallel line L4 intersects second transmission line 13b.

[0096] At time t = t0 + t1/2 shown in (a) of FIG. 8, the magnetic field indicated by broken line arrow B12 excites cross opening 11, and a microwave indicated by thick solid line arrow M11 is generated at third coupling point P3. This microwave propagates through microstrip line 13 toward fifth coupling point P5.

[0097] At time t = t0 + t1 + t1/2 shown in (b) of FIG. 8, the magnetic field indicated by broken line arrow B23 excites cross opening 11. At fifth coupling point P5, a microwave indicated by thick solid line arrow M12a is generated. At fourth coupling point P4, a microwave indicated by thin solid line arrow M12b is generated. The reason why solid line arrow M12b is made thin is the same as the reason why solid line arrow M3 is made thin as described above.

[0098] In the case where the effective propagation time of the microwave between third coupling point P3 and fifth coupling point P5 through microstrip line 13 is set to time t1, the microwave generated at third coupling point P3 at the time shown in (a) of FIG. 8 propagates to fifth coupling point P5 at the time shown in (b) of FIG. 8. That is, at the time shown in (b) of FIG. 8, both the microwave indicated by thick solid line arrow M11 and the microwave indicated by thick solid line arrow M12a occur at fifth coupling point P5.

[0099] Accordingly, the two microwaves are added and propagate through microstrip line 13 toward second output part 132, thereby being fed to second output part 132 after a lapse of a predetermined time. In the present embodiment, in order to set the effective propagation time described above equal to time t1, the line distance of first transmission line 13a further away from tube axis L1 than parallel line L4 is set equal to 1/4 of effective length λ_{re}. The microwave generated at fourth coupling point P4 and indicated by thin solid line arrow M12b, propagates through microstrip line 13 toward first output part 131, and is fed to first output part 131 after a lapse of a predetermined time.

[0100] At time t = t0 + T/2 + t1/2 shown in (c) of FIG. 8, the magnetic field indicated by broken line arrow B34 excites cross opening 11. At third coupling point P3, a microwave indicated by thin solid line arrow M13b is generated. This microwave propagates through microstrip line 13 toward first output part 131. The reason why solid line arrow M13b is made thin is the same as the reason why solid line arrow M3 is made thin as described above.

[0101] At time t = t0 + T/2 + t1 + t1/2 shown in (d) of FIG. 8, the magnetic field indicated by broken line arrow B41 excites cross opening 11. At fifth coupling point P5, a microwave indicated by thin solid line arrow M14b is generated. At fourth coupling point P4, a microwave indicated by thick solid line arrow M14a is generated. The microwave indicated by thin solid line arrow M14b propagates through microstrip line 13 toward third coupling point P3. The reason why solid line arrow M14b is made thin is the same as the reason why solid line arrow M3 is made thin as described above.

[0102] The microwave indicated by thick solid line arrow M14a propagates through microstrip line 13 toward third coupling point P3. In the case where the effective propagation time of the microwave between third coupling point P3 and fourth coupling point P4 through microstrip line 13 is set to time t1, the microwave generated at third coupling point P3 at the time shown in (c) of FIG. 8 propagates to fourth coupling point P4 at the time shown in (d) of FIG. 8.

[0103] That is, at the time shown in (d) of FIG. 8, both the microwave indicated by thin solid line arrow M13b and the microwave indicated by thick solid line arrow M14a occur at fourth coupling point P4. In the present embodiment, in order to set the effective propagation time described above equal to time t1, the line distance of second transmission line 13b further away from tube axis L1 than parallel line L4 is set equal to 1/4 of effective length λ_{re}.

[0104] That is, the sum of a line distance of first transmission line 13a further away from tube axis L1 than parallel line L4 and a line distance of second transmission line 13b further away from tube axis L1 than parallel line L4, is set equal to 1/2 of effective length λ_{re}. The microwave indicated by thin solid line arrow M13b propagates in the direction opposite to the microwave indicated by thick solid line arrow M14a. Therefore, the microwave indicated by thin solid line arrow M13b is canceled and disappears, and is not fed to first output part 131.

[0105] At time t = t0 + T + t1/2, as in the case at time t = t0 + t1/2 shown in (a) of FIG. 8, the magnetic field indicated by broken line arrow B12 excites cross opening 11. In this case, although having not been described in the case at the time shown in (a) of FIG. 8, there exists a microwave indicated by thin solid line arrow M14b on microstrip line 13.

[0106] At time t = t0 + T + t1/2, the microwave indicated by thin solid line arrow M14b propagates to third coupling point P3. The microwave indicated by thin solid line arrow M14b propagates in the direction opposite to the microwaves indicated by thick solid line arrow M11 and thick solid line arrow M14a. Therefore, the microwave indicated by thin solid line arrow M14b is canceled and disappears, and is not fed to first output part 131.

[0107] Strictly speaking, at time t = t0 + t1/2, the amount of the microwave propagating from third coupling point P3 is equal to the amount (M11 + M14a - M14b) that is obtained by subtracting the amount of the microwave indicated by thin solid line arrow M14b from the amount of the microwaves indicated by thick solid line arrows M11 and M14a. Accordingly, the amount of the microwave fed to second output part 132 is equal to the amount (M11+ M12a + M14a -

M14b) that is obtained by adding the amount of the microwave indicated by thick solid line arrow M12a to the amount of the microwave propagating from third coupling point P3.

[0108] In consideration of this, the amount (M11+ M12a + M14a - M14b) of the microwave fed to second output part 132 is much larger than the amount (M12b) of the microwave fed to first output part 131. Therefore, microstrip line 13 outputs, to second output prat 132, most of the microwave rotating counterclockwise that is fed by the reflected wave propagating along arrow 31 and is emitted from cross opening 11. On the other hand, microstrip line 13 outputs, to first output prat 131, most of the microwave rotating clockwise that is fed by the incident wave propagating along arrow 30 and is emitted from cross opening 11.

[0109] Microwave detection unit 5 includes cross opening 11 that is disposed at a position not to intersect tube axis L1 of waveguide 3 in a plan view, and that emits circularly polarized microwaves. With this configuration, the rotation directions of the circularly polarized microwaves emitted from cross opening 11 are opposite to each other between the incident wave and the reflected wave. By utilizing such a difference in rotation direction between the circularly polarized microwaves, the incident wave and the reflected wave can be separately detected.

[0110] In microwave detection unit 5, first transmission line 13a includes first straight-line portion 13aa and second transmission line 13b includes second straight-line portion 13ba. With this configuration, the number of bent portions at each of which microstrip line 13 is bent can be reduced as compared with conventional ones. The need for bending microstrip line 13 at a right angle can be eliminated. It is possible to keep the bent portions, at each of which microstrip line 13 is bent, away from a region in the vertical direction of cross opening 11. This allows the incident wave and the reflected wave to be separately detected with higher accuracy.

[0111] In microwave detection unit 5, first transmission line 13a and second transmission line 13b are coupled to each other at a position, in a plan view, that is outside rectangular region E1 and is away from tube axis L1. This configuration allows the bent portions, at each of which microstrip line 13 is bent, to be separated farther away from the region in the vertical direction of cross opening 11. This allows both first straight-line portion 13aa and second straight-line portion 13ba to be made longer, thereby reducing the impeding of flowing of the electric current in microstrip line 13. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0112] In microwave detection unit 5, first straight-line portion 13aa intersects first elongated hole 11e at a position that is closer to opening-end portion 11ea than opening-center portion 11c, in a plan view. Second straight-line portion 13ba intersects second elongated hole 11f at a position that is closer to opening-end portion 11fa than opening-center portion 11c, in a plan view. In general, the magnetic field generated around opening-end portions 11ea and 11fa is stronger than that generated around opening-center portion 11c. This configuration allows the stronger magnetic field to be coupled to microstrip line 13. Thus, the amount of the electric current flowing in microstrip line 13 is larger. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0113] In microwave detection unit 5, first straight-line portion 13aa is orthogonal to first elongated hole 11e in a plan view. With this configuration, the transmission direction of the microwave indicated by solid line arrow M1 generated at first coupling point P1 is made identical, in direction, to rotation direction 32 of the microwave emitted from cross opening 11. This configuration results in a further increase in the amount of the microwave indicated by solid line arrow M1.

[0114] The transmission direction of the microwave indicated by solid line arrow M3 generated at first coupling point P1 is made opposite, in direction, to rotation direction 32 of the microwave emitted from cross opening 11. This configuration results in a further decrease in the amount of the microwave indicated by solid line arrow M3. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0115] In microwave detection unit 5, second straight-line portion 13ba is orthogonal to second elongated hole 11f in a plan view. With this configuration, the transmission direction of the microwave indicated by solid line arrow M2 generated at second coupling point P2 is made identical, in direction, to rotation direction 32 of the microwave emitted from cross opening 11. This configuration results in a further increase in the amount of the microwave indicated by solid line arrow M2.

[0116] The transmission direction of the microwave indicated by solid line arrow M4 generated at second coupling point P2 is made opposite, in direction, to rotation direction 32 of the microwave emitted from cross opening 11. This configuration results in a further decrease in the amount of the microwave indicated by solid line arrow M4. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0117] In microwave detection unit 5, microstrip line 13 includes: first straight-line portion 13aa, second straight-line portion 13ba, third straight-line portion 13ab, and fourth straight-line portion 13bb. First straight-line portion 13aa and third straight-line portion 13ab are adjacent to and coupled to each other so as to make an obtuse angle. Second straight-line portion 13ba and fourth straight-line portion 13bb are adjacent to and coupled to each other so as to make an obtuse angle.

[0118] With this configuration, the number of the bent portions at each of which microstrip line 13 is bent can be reduced. This allows a reduction in the impeding of flowing of the electric current in the coupling line. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0119] In microwave detection unit 5, the sum of a line distance of first transmission line 13a further away from tube axis L1 than virtual straight line L3 and a line distance of second transmission line 13b further away from tube axis L1 than virtual straight line L3, is set equal to 1/4 of effective length λ_{re}. With this configuration, the incident wave and the reflected wave can be separately detected with much higher accuracy. It is sufficient for the sum of line distances described above to be set equal to approximately 1/4 of effective length λ_{re}; the sum is not necessarily set strictly equal to 1/4 of effective length λ_{re}.

[0120] In microwave detection unit 5, the sum of a line distance of first transmission line 13a further away from tube axis L1 than parallel line L4 and a line distance of second transmission line 13b further away from tube axis L1 than parallel line L4, is set equal to 1/2 of effective length λ_{re}. With this configuration, the incident wave and the reflected wave can be separately detected with much higher accuracy. It is sufficient for the sum of line distances described above to be set equal to approximately 1/2 of effective length λ_{re}; the sum is not necessarily set strictly equal to 1/2 of effective length λ_{re}.

[0121] As shown in FIG. 5, in the present embodiment, one end of first transmission line 13a and one end of second transmission line 13b are coupled so as to make a right angle. However, the present disclosure is not limited to this. It is sufficient if one end of first transmission line 13a is coupled to one end of second transmission line 13b at a position out of the region of cross opening 11 in a plan view. In the region, there exists a large influence of the magnetic field.

[0122] FIGS. 9A to 9D are plan views respectively showing examples of first to sixth modifications of microstrip line 13. As shown in FIG. 9A, both first transmission line 13a and second transmission line 13b may be bent such that the coupling point between one end of first transmission line 13a and one end of second transmission line 13b is separated from opening-center portion 11c.

[0123] As shown in FIG. 9B, both first transmission line 13a and second transmission line 13b may be bent such that the coupling point between one end of first transmission line 13a and one end of second transmission line 13b becomes closer to opening-center portion 11c. As shown in FIG. 9C, first transmission line 13a and second transmission line 13b may be curved such that the coupling point between one end of first transmission line 13a and one end of second transmission line 13b becomes closer to opening-center portion 11c.

[0124] In the present embodiment, first straight-line portion 13aa and second straight-line portion 13ba respectively correspond to the first intersecting-line portion and the second intersecting-line portion. However, the present disclosure is not limited to this. As shown in FIG. 9D, the first intersecting-line portion and the second intersecting-line portion may be respectively circular-arc portion 13ac and circular-arc portion 13bc.

[0125] In the present embodiment, both third straight-line portion 13ab and fourth straight-line portion 13bb are parallel to perpendicular line L2. However, the present disclosure is not limited to this. As shown in FIG. 9E, both third straight-line portion 13ab and fourth straight-line portion 13bb may be parallel to parallel line L4.

[0126] In the present embodiment, first transmission line 13a and second transmission line 13b each include a plurality of the straight-line portions. However, the present disclosure is not limited to this. As shown in FIG. 9F, each of first transmission line 13a and second transmission line 13b may be configured with one straight-line portion.

[0127] In the present embodiment, cross opening 11 is formed to have line symmetry with respect to perpendicular line L2. Perpendicular line L2 is orthogonal to tube axis L1, and passes through opening-center portion 11c. However, the present disclosure is not limited to this. Cross opening 11 may not be formed to have line symmetry with respect to perpendicular line L2. For example, first elongated hole 11e and second elongated hole 11f may cross each other at a position out of each of their own center portions in the longitudinal direction. The length of first elongated hole 11e and the length of second elongated hole 11f may be different from each other.

[0128] In these cases, the opening-cross portion at which first elongated hole 11e and second elongated hole 11f cross each other is out of opening-center portion 11c. Cross opening 11 may be formed to have line symmetry with respect to a line that slightly inclines relative to perpendicular line L2, in a plan view.

[0129] FIG. 10 is a diagram schematically illustrating a positional relationship between microwave detection unit 5 and opening 33 in the present embodiment. In FIG. 10, opening 33 corresponds to cross opening 11 shown in FIG. 4. Maximum opening length D2 of opening 33 corresponds to length 11w of cross opening 11 shown in FIG. 4.

[0130] As shown in FIG. 10, the microwave extracted through from opening 33 is emitted approximately spherically from opening 33. In region HR from the center of opening 33 to a distance equal to a half of maximum opening length D2, the microwave emitted from opening 33 shows high intensity.

[0131] Therefore, microwave detection unit 5 is disposed such that distance D3 from opening 33 to microwave detection unit 5 is equal to not larger than 1/2 of maximum opening length D2. With this configuration, microwave detection unit 5 can efficiently detect microwaves. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0132] In the present embodiment, distance D3 is larger than 0 (zero). That is, microwave detection unit 5 is disposed such that microwave detection unit 5 is not in contact with waveguide 3. This allows microwave detection unit 5 to stably detect microwaves without causing sparks due to electric field concentration. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0133] In the present embodiment, connectors 18a and 19a (see FIGS. 2 and 3) and electronics components used in the detector circuits of microwave detection unit 5 are disposed in a plane that faces opening 33. In this case, if distance

D3 is too small, the wall surface of waveguide 3 will come into contact with the connectors or the electronics components of the detector circuits, resulting in a difficulty for microwave detection unit 5 to be disposed. For this reason, distance D3 is preferably not less than 1 mm.

[0134] FIG. 11 shows a relation between detection accuracy and distance D3 in the case where maximum opening length D2 is 24 mm, with such a relation having been obtained by using an electromagnetic field simulator.

[0135] The detection accuracy, in a directional coupler being a typical microwave detection unit, means directivity that represents the degree of signal separation between an incident wave and a reflected wave. The detection accuracy indicates an error component being contained in the detection signal, with the error component relating proportionately to the value of directivity. Therefore, the smaller the value of detection accuracy, the smaller the error component is, meaning that the directional coupler has higher performance.

[0136] As shown in FIG. 11, in the case where distance D3 is approximately 6 mm, i.e., equal to 1/4 of maximum opening length D2, the detection accuracy is highest. In order to accurately separate the incident wave and the reflected wave, it is sufficient if the error component is smaller than the detection signal even when the detection signal is at its minimum.

[0137] The detection signal being at its minimum value is one obtained for a reflected wave when the reflection becomes minimum. With a typical microwave heating device, the minimum value of the reflected wave is approximately -13 dB (5% of the input value). For this reason, the detection is possible without any problem as long as the detection accuracy indicates the error component being within up to -16 dB (2.5% of the input value), i.e. 1/2 of -13 dB, taking into account of a safety factor.

[0138] Therefore, the detection accuracy preferably is not larger than -16 dB. As shown in FIG. 11, distance D3 may be in a range approximately from 3 mm to 12 mm, i.e., in a range from 1/8 to 1/2 of maximum opening length D2. In this way, the incident wave and the reflected wave can be separately detected with higher accuracy.

INDUSTRIAL APPLICABILITY

[0139] The microwave detection units according to the present disclosure are applicable to microwave heating devices (for example, a microwave oven) for consumer or industrial use.

REFERENCE MARKS IN THE DRAWINGS

[0140]

1	heating chamber
1a	bottom surface
2	microwave generating unit
3	waveguide
3a	wide plane
3d	magnetic field distribution
4	microwave emitting part
5	microwave detection unit
5a, 5b	detection signal
6	controller
7	drive power supply
8	signal
9	motor
10	microwave heating device
11	cross opening
11c	opening-center portion
11d	width
11e	first elongated hole
11ea, 11fa	opening-end portion
11f	second elongated hole
11w	length
12	printed circuit board
12a	board front surface
12b	board rear surface
13	microstrip line
13a	first transmission line

13aa	first straight-line portion
13ab	third straight-line portion
13ac	circular-arc portion
13b	second transmission line
13ba	second straight-line portion
13bb	fourth straight-line portion
13bc	circular-arc portion
14	support part
15	first detector circuit
16	second detector circuit
18	first detection output part
18a, 19a	connector
19	second detection output part
20a	hole
30, 31	arrow
32	rotation direction
33	opening
131	first output part
132	second output part
141, 142	groove

Claims

1. A microwave heating device, comprising:

a heating chamber configured to accommodate a heating target object;
a microwave generating unit configured to generate a microwave;
a waveguide configured to transmit, to the heating chamber, the microwave generated by the microwave generating unit;
an opening disposed in the wall surface of the waveguide and configured to extract a part of the microwave from the waveguide; and
a reflected-wave detection unit configured to detect a part of a reflected wave being a microwave propagating from the heating chamber toward the microwave generating unit, the part of the reflected wave being extracted through the opening,
wherein the reflected-wave detection unit is disposed within a range from the opening to a distance equal to 1/2 of a maximum opening length of the opening.

2. The microwave heating device according to claim 1, wherein the reflected-wave detection unit is disposed apart from the opening.

3. The microwave heating device according to claim 1, further comprising
an incident-wave detection unit configured to detect a part of an incident wave being a microwave propagating from the microwave generating unit toward the heating chamber.

4. The microwave heating device according to claim 3,

wherein the incident-wave detection unit and the reflected-wave detection unit share a coupling line that faces the opening and has one end and the other end;
the incident-wave detection unit is configured to extract the incident wave from the one end of the coupling line; and
the reflected-wave detection unit is configured to extract the reflected wave from the other end of the coupling line.

5. The microwave heating device according to claim 1,

wherein the waveguide has a tube axis;
the opening includes:

a first elongated hole; and
a second elongated hole, the first elongated hole and the second elongated hole crossing each other at an opening-cross portion and being disposed at a position failing to cross the tube axis in a plan view;

the coupling line includes:

a first transmission line having one end; and
a second transmission line having one end;

the first transmission line includes
a first intersecting-line portion configured, in a plan view, to: extend, from one end of the tube axis, away from the tube axis as approaching a perpendicular line orthogonal to the tube axis, the perpendicular line passing through the opening-cross portion; and intersect the first elongated hole at a position farther away from the tube axis than the opening-cross portion;
the second transmission line includes
a second intersecting-line portion configured, in a plan view, to: extend, from another end of the tube axis, away from the tube axis as approaching the perpendicular line; and intersect the second elongated hole at a position farther away from the tube axis than the opening-cross portion; and
the one end of the first transmission line is coupled to the one end of the second transmission line at a position out of a region, in a plan view, in which the opening is disposed.

FIG. 1

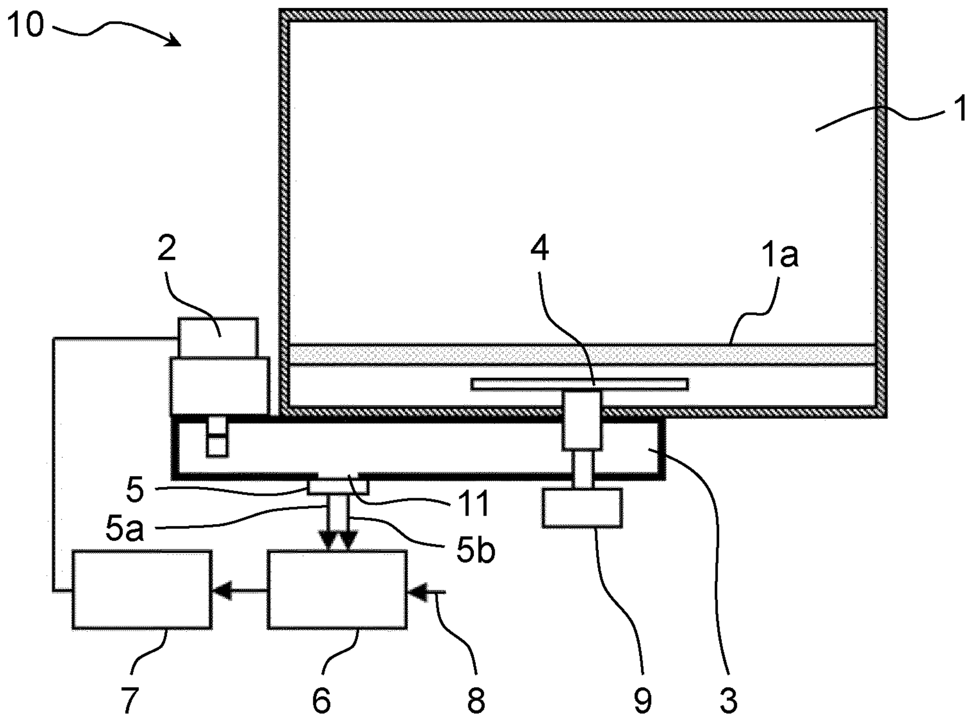


FIG. 2

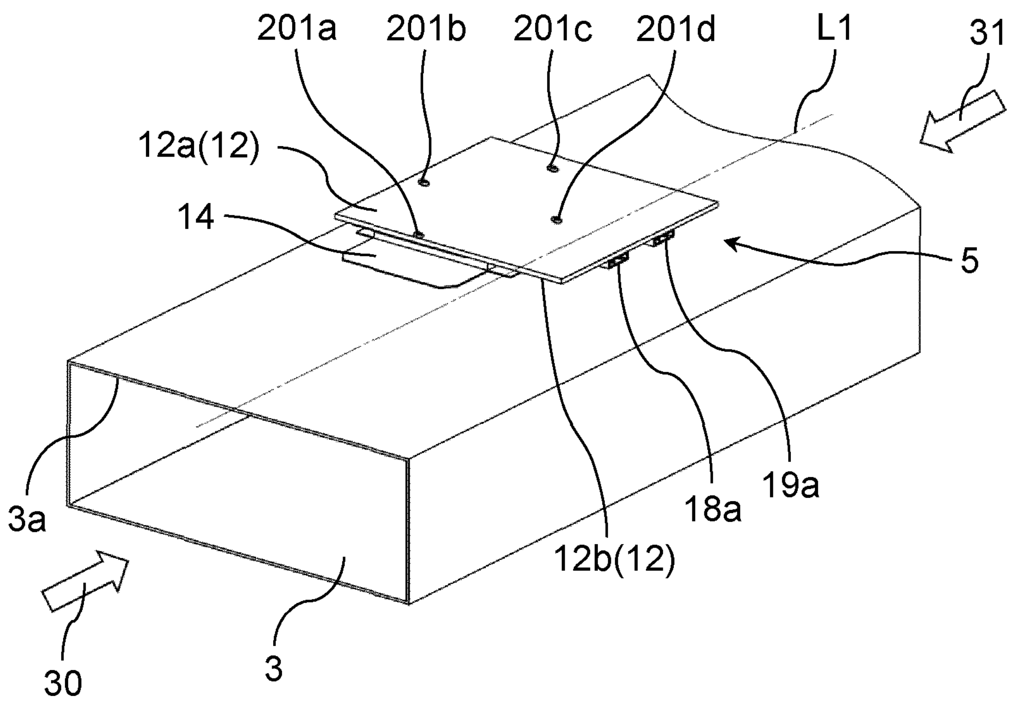

201a
201b
201c
201d
L1
31
12a(12)
14
5
18a
19a
12b(12)
3a
30
3

FIG. 3

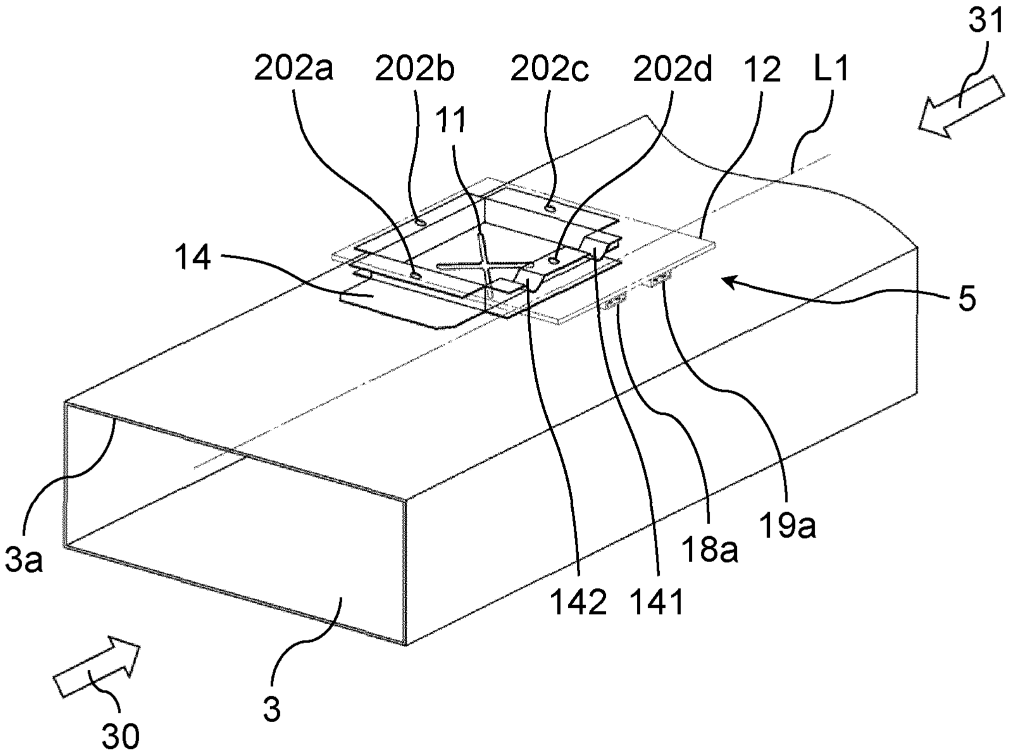

31
202a
202b
202c
202d
12
L1
11
14
5
3a
18a
19a
142
141
3
30

FIG. 4

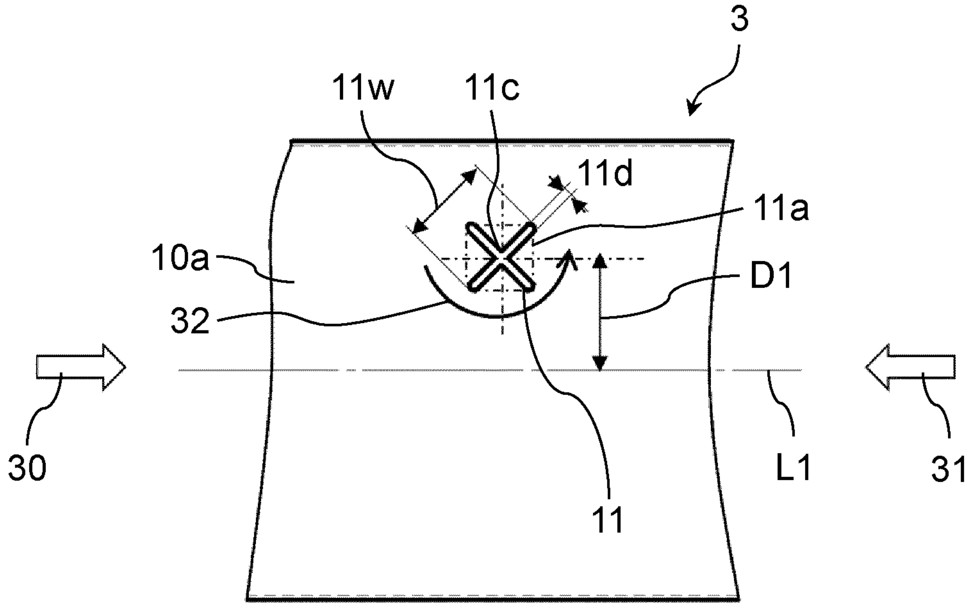


FIG. 5

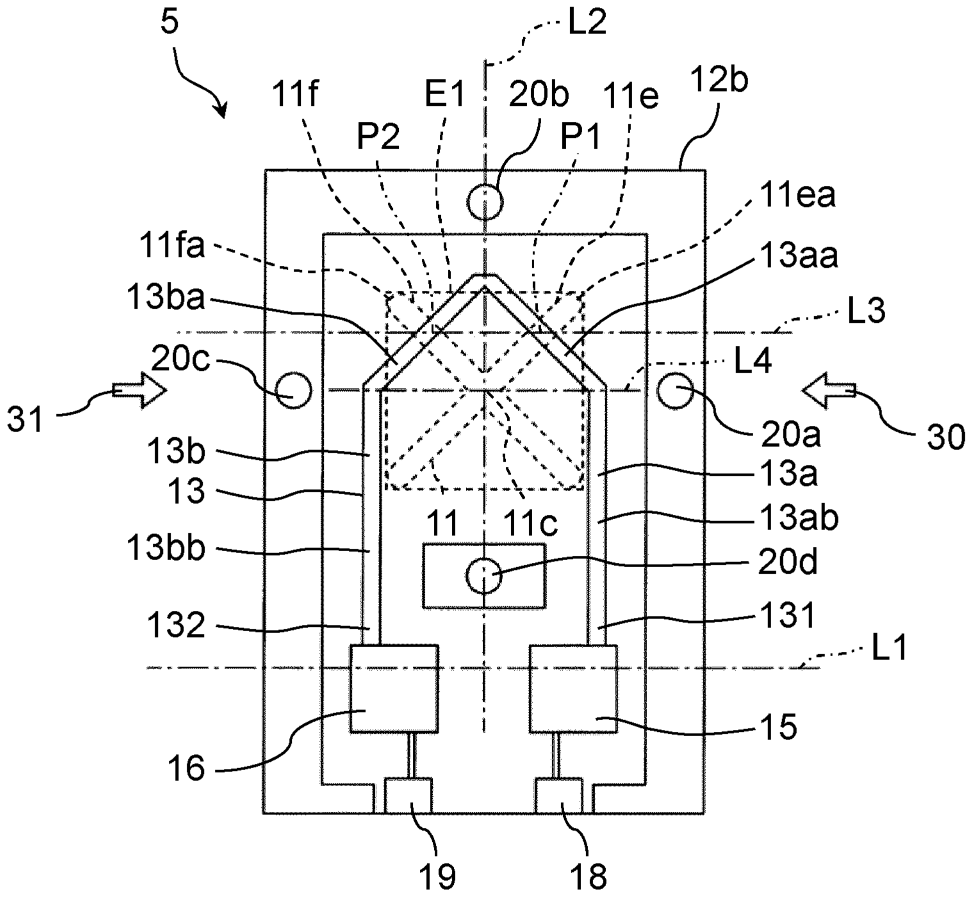

5
L2
11f
E1
20b
11e
12b
P2
P1
11ea
11fa
13aa
13ba
L3
20c
L4
31
20a
30
13b
13a
13
11
11c
13ab
13bb
20d
132
131
L1
16
15
19
18

FIG. 6

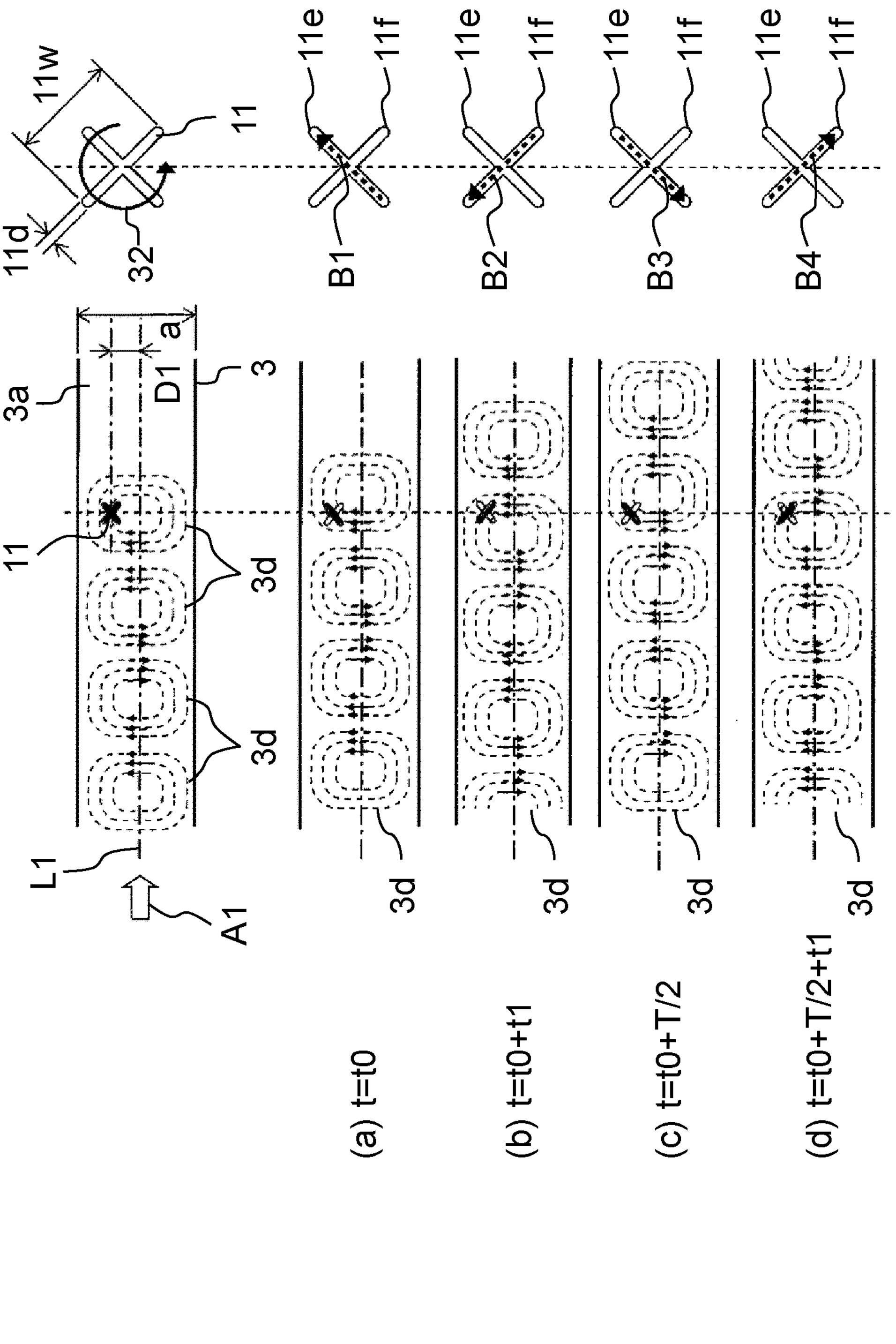

11w
11d
11
32
11e
11f
B1
B2
B3
B4
3a
D1
a
3
3d
L1
A1
(a) t=t0
(b) t=t0+t1
(c) t=t0+T/2
(d) t=t0+T/2+t1

FIG. 7

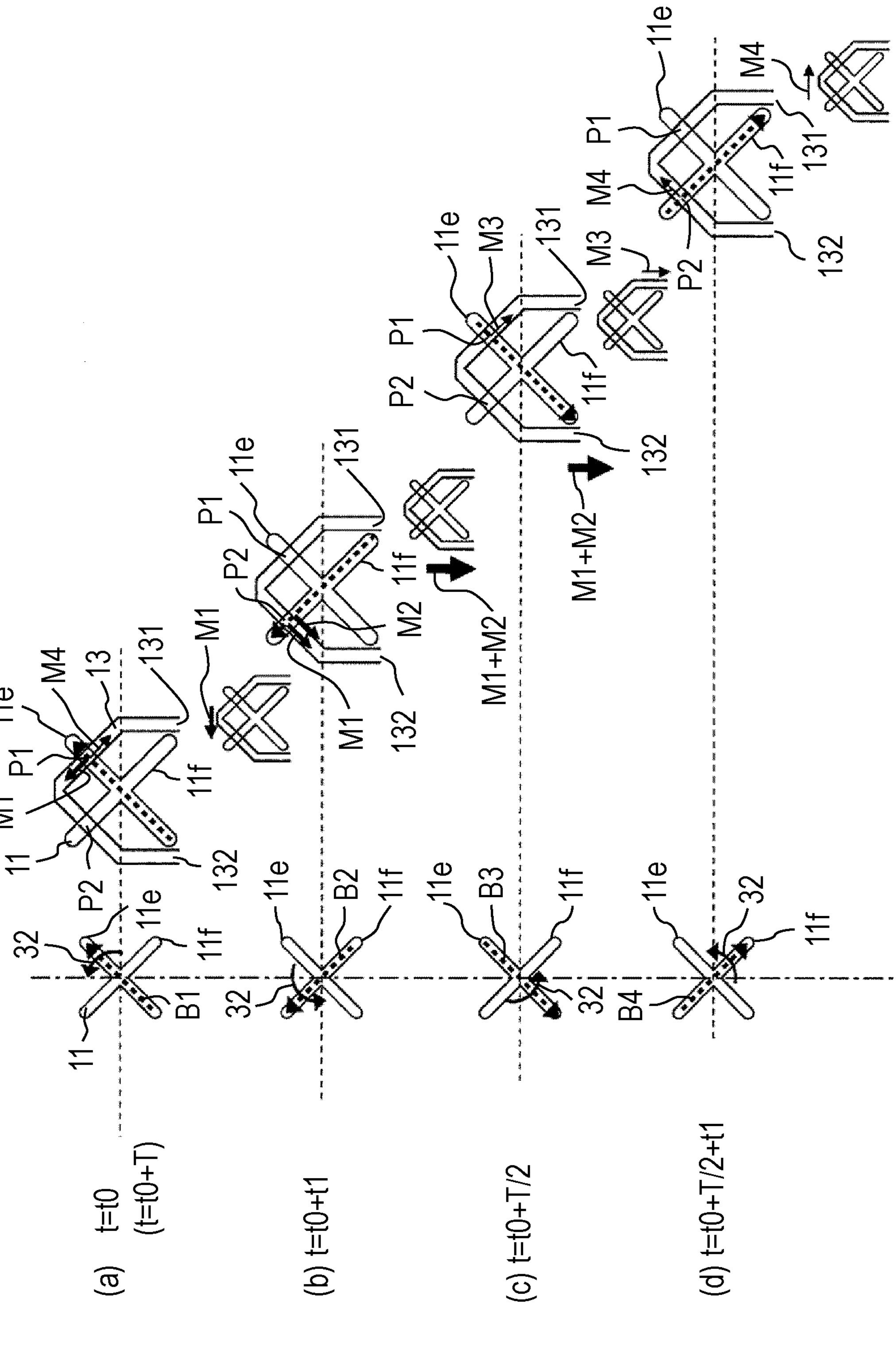

(a) t=t0
(t=t0+T)
(b) t=t0+t1
(c) t=t0+T/2
(d) t=t0+T/2+t1
11
11e
11f
13
131
132
32
B1
B2
B3
B4
P1
P2
M1
M2
M3
M4
M1+M2

FIG. 8

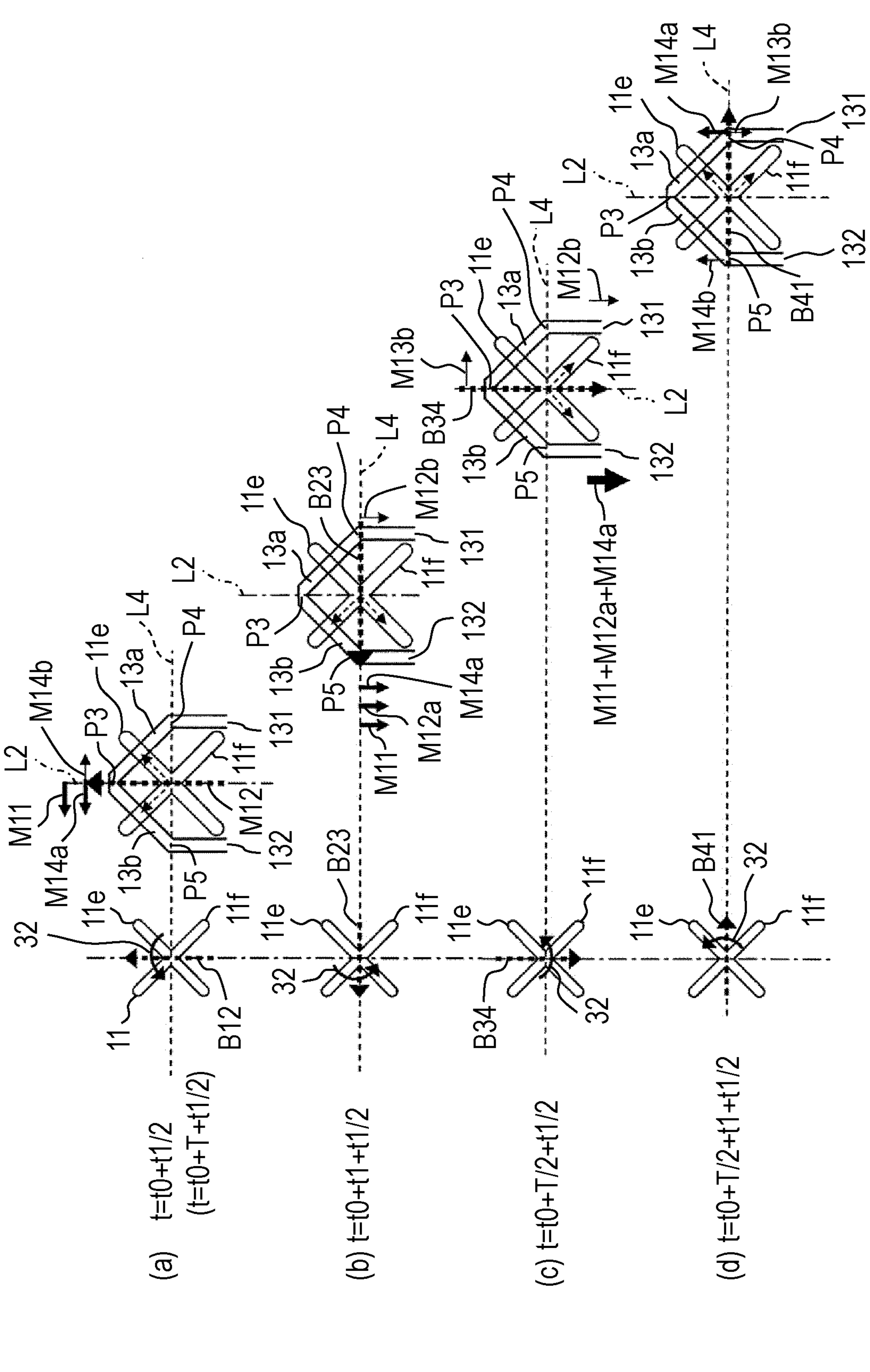

(a) t=t0+t1/2
(t=t0+T+t1/2)
(b) t=t0+t1+t1/2
(c) t=t0+T/2+t1/2
(d) t=t0+T/2+t1+t1/2
11
11e
11f
32
B12
B23
B34
B41
M11
M14a
M14b
L2
L4
P3
P4
P5
13a
13b
131
132
M12
M12a
M12b
M13b
M14a
M11+M12a+M14a

FIG. 9A

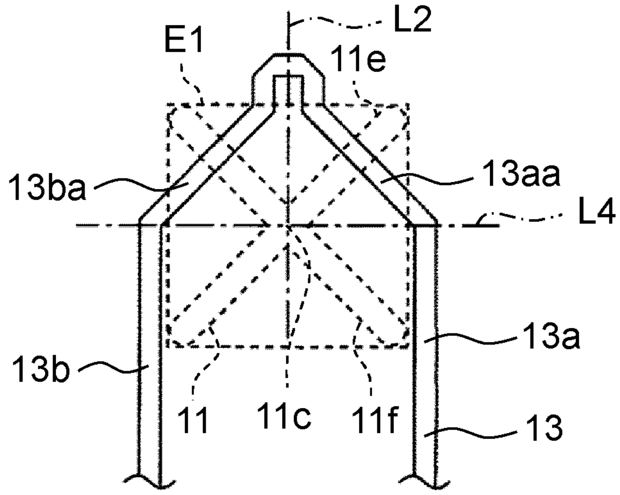


FIG. 9B

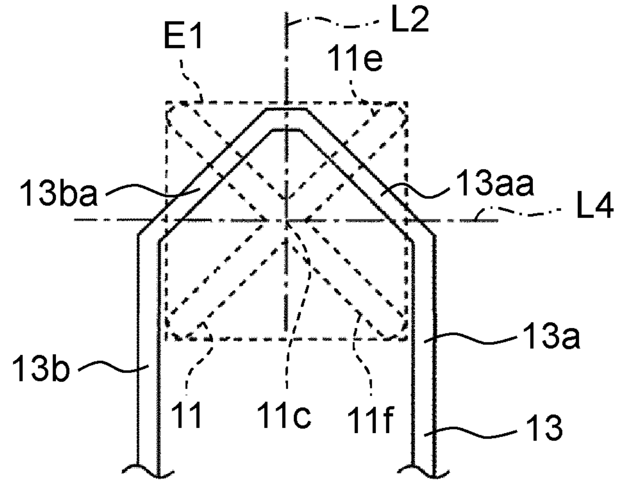


FIG. 9C

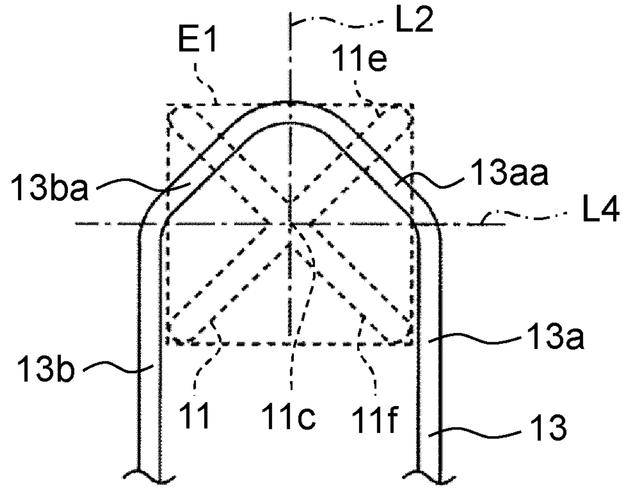


FIG. 9D

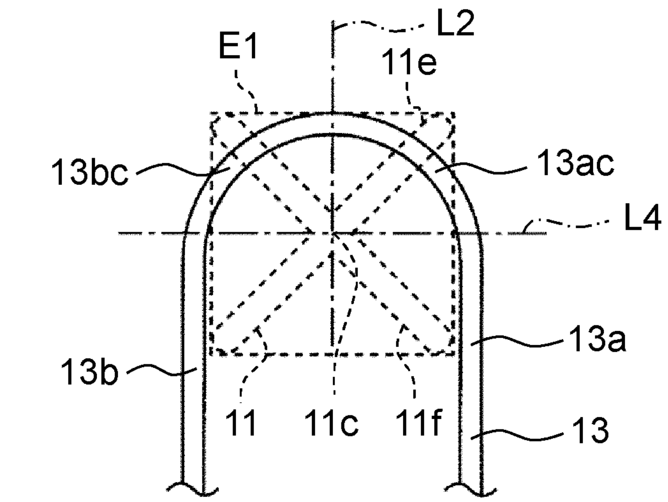


FIG. 9E

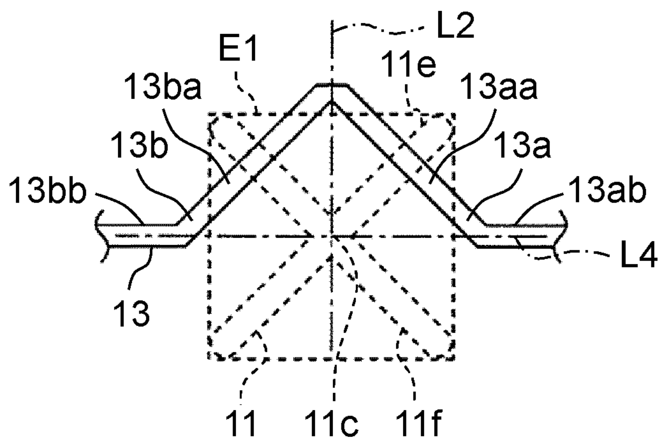


FIG. 9F

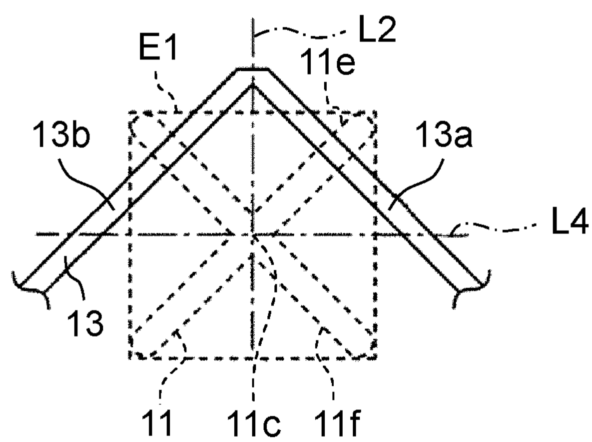


FIG. 10

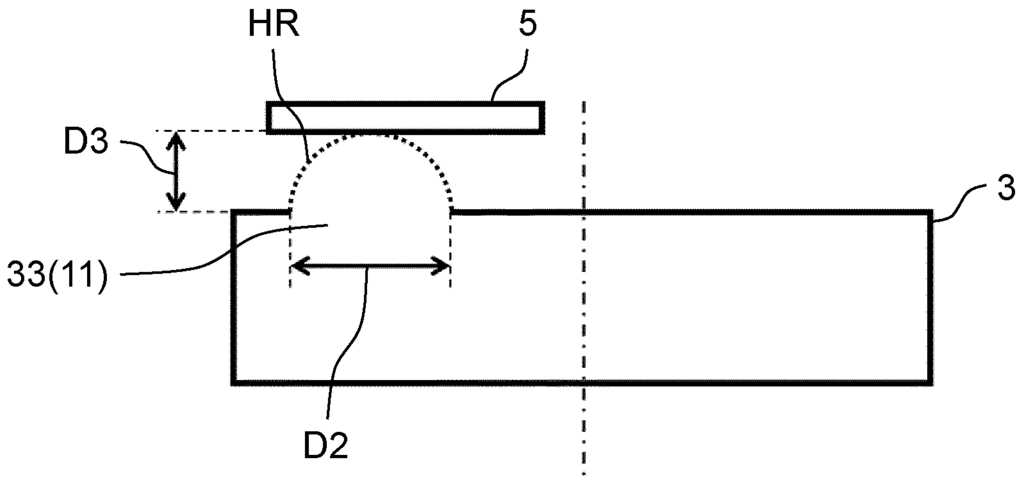
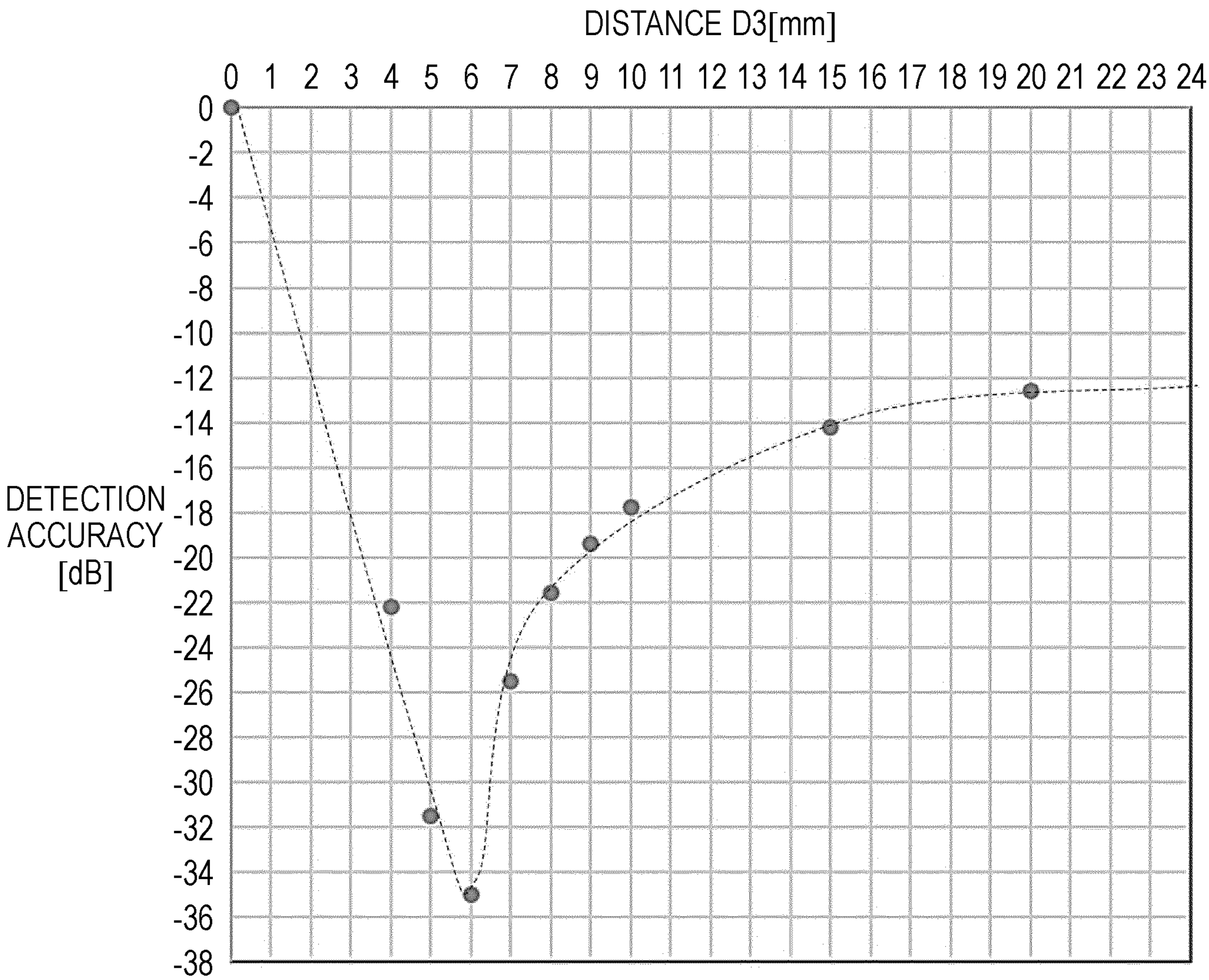


FIG. 11


DISTANCE D3[mm]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
DETECTION ACCURACY [dB]
0 -2 -4 -6 -8 -10 -12 -14 -16 -18 -20 -22 -24 -26 -28 -30 -32 -34 -36 -38

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2020/005511

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. H01P5/18(2006.01)i, H05B6/70(2006.01)i
FI: H05B6/70 Z, H01P5/18 F

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)
Int. Cl. H01P5/18, H05B6/70

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	1971-2020
Registered utility model specifications of Japan	1996-2020
Published registered utility model applications of Japan	1994-2020

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.
X A	WO 2017/164291 A1 (PANASONIC INTELLECTUAL PROPERTY MANAGEMENT CO., LTD.) 28 September 2017, paragraphs [0121]-[0175], fig. 1, 9-12	1-4 5
A	WO 2014/119333 A1 (PANASONIC INTELLECTUAL PROPERTY MANAGEMENT CO., LTD.) 07 August 2014, entire text, all drawings	1-5
A	JP 08-171985 A (HITACHI, LTD.) 02 July 1996, entire text, all drawings	1-5
A	US 2004/0046620 A1 (HUANG Wen-Liang) 11 March 2004, entire text, all drawings	1-5

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

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "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
03.04.2020	14.04.2020

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

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2020/005511

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, A	WO 2019/203170 A1 (PANASONIC INTELLECTUAL PROPERTY MANAGEMENT CO., LTD.) 24 October 2019, entire text, all drawings	1-5

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2020/005511

Patent Documents referred to in the Report	Publication Date	Patent Family	Publication Date
WO 2017/164291 A1	28.09.2017	US 2019/0090317 A1 paragraphs [0138]-[0191], fig. 1, 9-12 EP 3435736 A1	
WO 2014/119333 A1	07.08.2014	US 2015/0244055 A1 EP 2953204 A1	
JP 08-171985 A	02.07.1996	(Family: none)	
US 2004/0046620 A1	11.03.2004	(Family: none)	
WO 2019/203170 A1	24.10.2019	(Family: none)	

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

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 6176540 B **[0005]**