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

(11) **EP 3 783 736 A1**

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

(43) Date of publication:
24.02.2021 Bulletin 2021/08

(21) Application number: **19788616.1**

(22) Date of filing: **15.04.2019**

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

(86) International application number:
PCT/JP2019/016074

(87) International publication number:
WO 2019/203170 (24.10.2019 Gazette 2019/43)

(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: **20.04.2018 JP 2018081499**

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

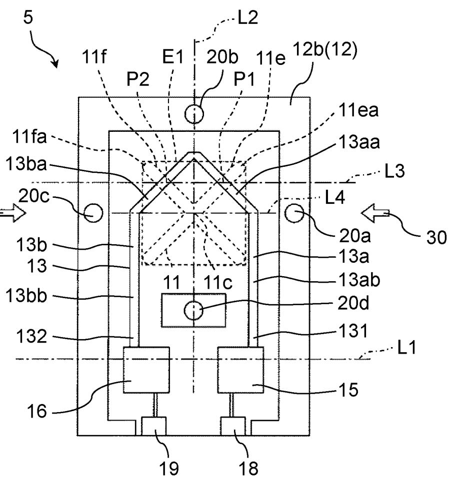
(72) Inventors:
- **KUBO Masayuki**
  Osaka 540-6207 (JP)
- **YOSHINO Koji**
  Osaka 540-6207 (JP)
- **SADAHIRA Masafumi**
  Osaka 540-6207 (JP)
- **NAKAMURA Hideki**
  Osaka 540-6207 (JP)

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

(54) **DIRECTIONAL COUPLER AND MICROWAVE HEATING DEVICE PROVIDED WITH SAME**

(57) A directional coupler includes: an opening having a first and a second elongated hole, mutually-crossing at a position without intersecting a waveguide's axis in plan-view; and a coupling line having a first and a second transmission line that respectively include a first and a second intersecting-line portion. The first intersecting-line portion extends, from one end of the axis, away from the axis as approaching a perpendicular line, and intersects the first hole at a position farther away from the axis than the opening-cross portion is, the perpendicular line being orthogonal to the axis and passing through the opening-cross portion at which the first hole and the second hole intersect each other, in plan-view. The second intersecting-line portion extends, from another end of the axis, away from the axis as approaching the perpendicular-line, and intersects the second hole at a position farther away from the axis than the opening-cross portion is, in plan-view. The first and second transmission lines are mutually coupled at out of an opening-located region, in plan-view.

FIG. 4



EP 3 783 736 A1

Description

TECHNICAL FIELD

[0001] The present disclosure relates to directional couplers which each detect the power level of a microwave propagating through a waveguide, and microwave heaters provided with the directional couplers.

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 separately and individually detects a traveling wave and a reflected wave which each propagate through a waveguide.

[0003] As a conventional directional coupler, for example, the directional coupler described in Patent Literature 1 is 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 failing to intersect the tube axis of the waveguide, and 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 so as to face each other with a central portion of the opening being interposed between them, and 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 wave emitted from the opening fed by the traveling wave, is opposite to that of a circularly polarized wave emitted from the opening fed by the reflected wave. By utilizing such a difference in rotation direction between the circularly polarized microwaves, the traveling wave and the reflected wave can be separately and individually detected.

Citation List

Patent Literature

[0005] PTL 1: Japanese Patent No. 6176540

SUMMARY OF THE INVENTION

[0006] The conventional directional coupler described above, however, still has room for improvement in view of achieving higher accuracy in separately detecting traveling waves and reflecting waves.

[0007] Therefore, an object of the present disclosure is to provide a directional coupler capable of separately detecting traveling waves and reflecting waves with high accuracy, and to provide a microwave heating device equipped with the directional coupler.

[0008] A directional coupler according to an aspect of the present disclosure includes: an opening disposed in a wall surface of a waveguide, and a coupling line disposed outside the waveguide, and separately detects a traveling wave and a reflecting wave which both propagate through the waveguide.

[0009] The opening includes a first elongated hole and a second elongated hole which cross each other and are disposed at a position that fails to intersect the tube axis of the waveguide, in a plan view. The coupling line includes: a first transmission line, and a second transmission line.

[0010] The first transmission line includes a first intersecting-line portion. The first intersecting-line portion extends, from one end of the tube axis, away from the tube axis as approaching a perpendicular line, and intersects the first elongated hole at a position farther away from the tube axis than the opening-cross portion is, the perpendicular line being orthogonal to the tube axis and passing through the opening-cross portion at which the first elongated hole and the second elongated hole intersect each other, in a plan view.

[0011] The second transmission line includes a second intersecting-line portion. The second intersecting-line portion extends, from another end of the tube axis, away from the tube axis as approaching the perpendicular line, and intersects the second elongated hole at a position farther away from the tube axis than the opening-cross portion is, in a plan view.

[0012] One end of the first transmission line is coupled to one end of the second transmission line at a position, in a plan view, out of a region in which the opening is disposed.

[0013] The directional coupler according to the aspect is capable of separately detecting a traveling wave and a reflecting wave with higher accuracy.

BRIEF DESCRIPTION OF DRAWINGS

[0014]

FIG. 1 is a perspective view of a directional coupler according to an embodiment of the present disclosure.
FIG. 2 is a perspective view of the directional coupler according to the embodiment, in the state in which a printed circuit board has been removed.
FIG. 3 is a plan view of a waveguide according to the embodiment.
FIG. 4 is a circuit configuration diagram of the printed circuit board mounted on the directional coupler according to the embodiment.
FIG. 5 is a diagram for illustrating the principle that a cross opening emits a circularly polarized microwave.
FIG. 6 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. 7 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. 8A is a plan view showing an example of a first modification of the microstrip line.
FIG. 8B is a plan view showing an example of a second modification of the microstrip line.
FIG. 8C is a plan view showing an example of a third modification of the microstrip line.
FIG. 8D is a plan view showing an example of a fourth modification of the microstrip line.
FIG. 8E is a plan view showing an example of a fifth modification of the microstrip line.
FIG. 8F is a plan view showing an example of a sixth modification of the microstrip line.
FIG. 9 is a schematic view of a microwave heating device according to an embodiment.

DESCRIPTION OF EMBODIMENTS

[0015] The present inventors have earnestly studied how to separately detect traveling waves and reflected waves with higher accuracy, and have obtained the following findings.

[0016] In a conventional directional coupler, a coupling line is configured as one line by coupling, at right angles, a plurality of lines parallel to the tube axis in a plan view to a plurality of lines perpendicular to the tube axis in a plan view. With this configuration, the influence of impedance of a load that is coupled to a waveguide is reduced, which allows accurate separation between a traveling wave and a reflected wave.

[0017] The present inventors have obtained the following finding: A magnetic field concentrates where the coupling line is bent at a right angle (or an acute angle), which impedes the flowing of electric current (microwave) in the coupling line, leading to an influence on the separation between a traveling wave and a reflected wave. The present inventors have found that the conventional directional coupler includes many bent portions at each of which the coupling line is bent at a right angle, and that these portions have great influences on the separation between a traveling wave and a reflected wave. The present inventors have found that the impeding of flowing of the electric current in the coupling line is reduced by keeping such bent portions of the coupling line away from a region in the vertical direction of the opening where influence of the magnetic field is strong.

[0018] On the basis of these findings, the present inventors have found the following inventions. The present inventors have confirmed that these inventions improve the directivity (the degree of separation between a traveling wave and a reflected wave) by 5 dB or more (approximately 3 times or more) as compared with that of the conventional directional coupler.

[0019] A directional coupler according to a first aspect of the present disclosure includes an opening disposed in a wall surface of a waveguide, and an coupling line disposed outside the waveguide, for separately detecting a traveling wave and a reflected wave that propagate through the waveguide.

[0020] The opening includes a first elongated hole and a second elongated hole that, in a plan view, cross each other and are disposed at a position that fails to intersect the tube axis of the waveguide. The coupling line includes a first transmission line and a second transmission line.

[0021] The first transmission line includes a first intersecting-line portion. The first intersecting-line portion is configured, in a plan view, to: pass from one end of the tube axis through an opening-cross portion where the first elongated hole and the second elongated hole cross each other, extend away from the tube axis as approaching a perpendicular line orthogonal to the tube axis, and intersect the first elongated hole at a position farther away from the tube axis than the opening-cross portion is.

[0022] 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 so as to be 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 is.

[0023] One end of the first transmission line is coupled to one end of the second transmission line at a position out of the region of the opening, in a plan view.

[0024] In the directional coupler according to a second aspect of the present disclosure, in addition to the first aspect, the first transmission line and the second transmission line are coupled to each other at a position that is out of a rectangular region circumscribing the opening and that is farther away from the tube axis than the rectangular region, in a plan view.

[0025] In the directional coupler according to a third aspect of the present disclosure, in addition to the first aspect, at least one of the first intersecting-line portion and the second intersecting-line portion intersects a corresponding one of the first elongated hole and the second elongated hole at a position closer to an opening-end portion of the opening than the opening-cross portion is, in a plan view.

[0026] In the directional coupler according to a fourth aspect of the present disclosure, in addition to the first aspect, at least one of the first intersecting-line portion and the second intersecting-line portion is orthogonal to a corresponding one of the first elongated hole and the second elongated hole, in a plan view.

[0027] In the directional coupler according to a fifth aspect of the present disclosure, in addition to the first aspect, the coupling line includes a plurality of straight-line portions that includes the first intersecting-line portion and the second intersecting-line portion. Of the plurality of straight-line portions, two straight-line portions adjacent to each other are coupled so as to make an obtuse angle.

[0028] In the directional coupler according to a sixth aspect of the present disclosure, in addition to the fifth aspect, the plurality of straight-line portions includes: a straight-line portion coupling the other end of the first intersecting-line portion to a first output part, and a straight-line portion coupling the second intersecting-line portion to a second output part.

[0029] In the directional coupler according to a seventh aspect of the present disclosure, in addition to the first aspect, the first intersecting-line portion intersects the first elongated hole at a first coupling point, and the second intersecting-line portion intersects the second elongated hole at a second coupling point, with a virtual line passing through the first coupling point and the second coupling point. In a plan view, the sum of a line distance of the first transmission line locating further away from the tube axis than the virtual line and a line distance of the second transmission line locating further away from the tube axis than the virtual line, is set equal to 1/4 of an effective length.

[0030] In the directional coupler according to an eighth aspect of the present disclosure, in addition to the first aspect, in a plan view, the sum of a line distance of the first transmission line locating further away from the tube axis than a parallel line that passes through the opening-cross portion and parallels the tube axis and a line distance of the second transmission line locating further away from the tube axis than the parallel line, is set equal to 1/2 of an effective length.

[0031] A microwave heating device according to a ninth aspect of the present disclosure includes a directional coupler according to the first aspect.

[0032] Hereinafter, descriptions will be made regarding a directional coupler according to an embodiment of the present disclosure, and a microwave heating device including the directional coupler, with reference to the drawings.

[0033] FIG. 1 is a perspective view of directional coupler 5 according to an embodiment of the present disclosure. FIG. 2 is a perspective view of directional coupler 5 in the state in which printed circuit board 12 has been removed. FIG. 3 is a plan view of waveguide 3. FIG. 4 is a circuit configuration diagram of printed circuit board 12 mounted on directional coupler 5.

[0034] As shown in FIGS. 1 to 3, directional coupler 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.

[0035] Directional coupler 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.

[0036] As shown in FIG. 3, cross opening 11 is disposed at a position failing 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, for example, 1/4 of the width of waveguide 3. Cross opening 11 emits microwaves propagating through waveguide 3, as circularly polarized microwaves, toward printed circuit board 12.

[0037] 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.

[0038] 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.

[0039] As shown in FIG. 4, 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.

[0040] In the 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.

[0041] In the case where opening-center portion 11c of cross opening 11 is disposed at a position at which it 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.

[0042] In the case where opening-center portion 11c is even slightly out of tube axis L1, the electric field will rotate. However, 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.

[0043] According to the embodiment, dimension D1 is set equal to approximately 1/4 of the width of waveguide 3. In this case, an substantially-perfect circular rotating electric field is generated. Cross opening 11 emits an substantially-perfect circularly polarized microwave. This allows the rotation direction of the circularly polarized microwave to be more distinct. As a result, the traveling wave and the reflected wave can be separately detected with high accuracy.

[0044] 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 a 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 passing through printed circuit board 12.

[0045] As shown in FIG. 4, 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 so as to surround opening-center portion 11c of cross opening 11.

[0046] 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]

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

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

[0047] 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.

[0048] 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.

[0049] 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.

[0050] 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.

[0051] 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.

[0052] 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}.

[0053] 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}.

[0054] 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).

[0055] 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.

[0056] First output part 131 and second output part 132 are disposed outside support part 14 (see FIGS. 1 and 2) 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 detects the level of a microwave signal, and outputs the detected level of the microwave signal as a control signal.

[0057] In the present embodiment, each of first detector circuit 15 and second detector circuit 16 includes a smoothing circuit (not shown) that is configured including 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 unit 18.

[0058] 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.

[0059] 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 foils each for serving as a ground are formed at portions around holes 20a, 20b, 20c, and 20d. The portions on which the copper foils are formed have the same voltage as that of board front surface 12a.

[0060] Printed circuit board 12 is fixed to waveguide 3, with screws 201a, 201b, 201c, and 201d (see FIG. 1) being screwed through respective holes 20a, 20b, 20c, and 20d into support part 14.

[0061] As shown in FIG. 2, 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.

[0062] Support part 14 has conductivity, and is disposed so as 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.

[0063] Support part 14 is provided with groove 141 and groove 142 through which 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 that 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.

[0064] In FIGS. 1 and 2, 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. 4.

[0065] Next, the operation and action of directional coupler 5 will be described.

[0066] First, with reference to FIG. 5, a description will be made regarding the principle that a circularly polarized microwave is emitted from cross opening 11. In FIG. 5, 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 Al of the microwave with a lapse of time.

[0067] At time t = t0 shown in (a) of FIG. 5, 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. 5, the magnetic field indicated by broken line arrow B2 excites second elongated hole 11f of cross opening 11.

[0068] At time t = t0 + T/2 (where T is the period of the in-tube wavelength of the microwave) shown in (c) of FIG. 5, 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. 5, 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.

[0069] 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.

[0070] Here, assuming that the microwave propagating along arrow 30 shown in FIG. 3 is a traveling wave and that the microwave propagating along arrow 31 is a reflected wave, the traveling wave then travels in the same direction as transmission direction Al shown in FIG. 5. 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.

[0071] On the other hand, the reflected wave propagates in the direction opposite to transmission direction Al shown in FIG. 5. This causes the circularly polarized microwave that rotates clockwise to be emitted from cross opening 11 to the outside of waveguide 3.

[0072] 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 traveling wave propagating along arrow 30 and is emitted from cross opening 11.

[0073] 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. This allows the traveling wave and the reflected wave to be separately detected with higher accuracy. Regarding this, a more detailed description is made with reference to FIG. 6.

[0074] FIG. 6 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.

[0075] Here, regions at 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.

[0076] In FIG. 6, 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 arrow; when the amount of the microwave propagating through microstrip line 13 is small, it is indicated by the thin arrow.

[0077] At time t = t0 shown in (a) of FIG. 6, 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. The microwave propagates through microstrip line 13 toward second coupling point P2.

[0078] 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, and a microwave indicated by thick solid line arrow M2 is generated at second coupling point P2.

[0079] 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. 6 propagates to second coupling point P2 at the time shown in (b) of FIG. 6. That is, at the time shown in (b) of FIG. 6, both the microwave indicated by solid line arrow M1 and the microwave indicated by solid line arrow M2 occur at second coupling point P2.

[0080] 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 tl, 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.

[0081] At time t = t0 + T/2 shown in (c) of FIG. 6, 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. The 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.

[0082] 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.

[0083] At the time shown in (a) of FIG. 6, 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.

[0084] In contrast, at the time shown in (c) of FIG. 6, 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.

[0085] 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, and a microwave indicated by thin solid line arrow M4 is generated at second coupling point P2. The microwave propagates toward first coupling point P1. The reason why the thickness of solid arrow M4 is made thin is the same as the reason why the thickness of solid arrow M3 is made thin as described above.

[0086] At time t = t0 + T, as in the case at time t = t0 shown in (a) of FIG. 6, 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. 6, there exists a microwave indicated by thin solid line arrow M4 on microstrip line 13.

[0087] The microwave indicated by thin solid arrow M4 propagates to first coupling point P1 at time t = t0 + T (that is, t = t0). The microwave indicated by thin solid arrow M4 propagates in the direction opposite to the microwave indicated by thick solid arrow M1. Therefore, the microwave indicated by solid arrow M4 is canceled and disappears, and is not fed to first output part 131.

[0088] 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 arrow M4 from the amount of the microwave indicated by thick solid 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 arrow M2 to the amount of the microwave propagating from second coupling point P2.

[0089] 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 traveling wave propagating along arrow 30 and is emitted from cross opening 11.

[0090] 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.

[0091] 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}.

[0092] 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. In (a) to (d) of FIG. 7, the states of (a) to (d) of FIG. 6 after a lapse of time t1/2 are respectively illustrated.

[0093] Although the description is omitted above, magnetic field distribution 3d travels through inside waveguide 3 in transmission direction Al of the microwave with a lapse of time. Therefore, as shown in (a) to (d) of FIG. 7, 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.

[0094] 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.

[0095] At time t = t0 + t1/2 shown in (a) of FIG. 7, 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. The microwave propagates through microstrip line 13 toward fifth coupling point P5.

[0096] At time t = t0 + t1 + t1/2 shown in (b) of FIG. 7, 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.

[0097] 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 tl, the microwave generated at third coupling point P3 at the time shown in (a) of FIG. 7 propagates to fifth coupling point P5 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 thick solid line arrow M11 and the microwave indicated by thick solid line arrow M12a occur at fifth coupling point P5.

[0098] 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.

[0099] At time t = t0 + T/2 + t1/2 shown in (c) of FIG. 7, 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. The 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.

[0100] At time t = t0 + T/2 + t1 + t1/2 shown in (d) of FIG. 7, 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.

[0101] 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 tl, the microwave generated at third coupling point P3 at the time shown in (c) of FIG. 7 propagates to fourth coupling point P4 at the time shown in (d) of FIG. 7.

[0102] That is, at the time shown in (d) of FIG. 7, 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 tl, 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}.

[0103] 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 arrow M13b propagates in the direction opposite to the microwave indicated by thick solid arrow M14a. Therefore, the microwave indicated by thin solid arrow M13b is canceled and disappears, and is not fed to first output part 131.

[0104] At time t = t0 + T + t1/2, as in the case at time t = t0 + t1/2 shown in (a) of FIG. 7, 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. 7, there exists a microwave indicated by thin solid line arrow M14b on microstrip line 13.

[0105] 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 arrow M14b propagates in the direction opposite to the microwaves indicated by thick solid arrow M11 and thick solid arrow M14a. Therefore, the microwave indicated by thin solid arrow M14b is canceled and disappears, and is not fed to first output part 131.

[0106] 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 arrow M14b from the amount of the microwaves indicated by thick solid 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 arrow M12a to the amount of the microwave propagating from third coupling point P3.

[0107] 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 traveling wave propagating along arrow 30 and is emitted from cross opening 11.

[0108] Directional coupler 5 includes cross opening 11 that is disposed at a position failing 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 traveling wave and the reflected wave. By utilizing such a difference in rotation direction between the circularly polarized microwaves, the traveling wave and the reflected wave can be separately detected.

[0109] With directional coupler 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 traveling wave and the reflected wave to be separately detected with higher accuracy.

[0110] With directional coupler 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 traveling wave and the reflected wave can be separately detected with much higher accuracy.

[0111] With directional coupler 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 a 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 traveling wave and the reflected wave can be separately detected with much higher accuracy.

[0112] With directional coupler 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.

[0113] 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 traveling wave and the reflected wave can be separately detected with much higher accuracy.

[0114] With directional coupler 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.

[0115] 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 traveling wave and the reflected wave can be separately detected with much higher accuracy.

[0116] With directional coupler 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.

[0117] 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 traveling wave and the reflected wave can be separately detected with much higher accuracy.

[0118] With directional coupler 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 traveling 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}.

[0119] With directional coupler 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 traveling 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}.

[0120] As shown in FIG. 4, 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.

[0121] FIGS. 8A to 8D are plan views respectively showing examples of first to sixth modifications of microstrip line 13. As shown in FIG. 8A, 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.

[0122] As shown in FIG. 8B, 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. 8C, 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.

[0123] 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. 8D, the first intersecting-line portion and the second intersecting-line portion may be respectively circular-arc portion 13ac and circular-arc portion 13bc.

[0124] 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. 8E, both third straight-line portion 13ab and fourth straight-line portion 13bb may be parallel to parallel line L4.

[0125] 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. 8F, each of first transmission line 13a and second transmission line 13b may be configured with one straight-line portion.

[0126] 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.

[0127] 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.

[0128] Hereinafter, with reference to FIG. 9, a description will be made regarding the configuration of microwave heating device 10 according to the present embodiment. As shown in FIG. 9, microwave heating device 10 includes: heating chamber 1, microwave generating unit 2, waveguide 3, and microwave emitting part 4.

[0129] 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. Directional coupler 5 is disposed on wide plane 3a (see FIGS. 1 and 2) of waveguide 3, between microwave generating unit 2 and microwave emitting part 4.

[0130] Directional coupler 5 detects detection signal 5a in accordance with a traveling wave that propagates through waveguide 3 from microwave generating unit 2 toward microwave emitting part 4. Directional coupler 5 detects detection signal 5b in accordance with a reflected wave that propagates through waveguide 3 from microwave emitting part 4 toward microwave generating unit 2. Directional coupler 5 transmits detection signals 5a and 5b to controller 6.

[0131] Controller 6 receives signal 8 in addition to detection signals 5a and 5b. Signal 8 includes signals regarding: a heating condition that is 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). Controller 6 controls drive power supply 7 and motor 9 in accordance with signal 8 and detection signals 5a and 5b. 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.

[0132] As the heating target object is heated, the heating target object physically changes. In accordance with such physical changes, the amount of the reflected wave changes. Detecting of the changes in the amount of the reflected wave through use of directional coupler 5, allows microwave heating device 10 to grasp the progress of heating of the heating target object. Microwave heating device 10 can also grasp the changes in state of the inside of the heating target object, and the kind and amount of the heating target object. Therefore, the present embodiment can provide the highly convenient microwave heating device.

INDUSTRIAL APPLICABILITY

[0133] The directional couplers according to the present disclosure are applicable to microwave heating devices for consumer or industrial use.

REFERENCE MARKS IN THE DRAWINGS

[0134]

1	heating chamber
1a	bottom surface
2	microwave generating unit
3	waveguide
3a	wide plane
3d	magnetic field distribution
4	microwave emitting part
5	directional coupler
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, 13bc	circular-arc portion
13b	second transmission line
13ba	second straight-line portion
13bb	fourth straight-line 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	arrow
31	arrow
131	first output part
132	second output part
141, 142	groove
201a	screw
202a	screw portion
E1	rectangular region
L1	tube axis
L2	perpendicular line

L3	virtual straight line
L4	parallel line
P1	first coupling point
P2	second coupling point
P3	third coupling point
P4	fourth coupling point
P5	fifth coupling point

Claims

1. A directional coupler for separately detecting a travelling wave and a reflected wave that both propagate in a waveguide having a wall surface and a tube axis, the directional coupler comprising:

    an opening disposed in the wall surface of the waveguide and including:

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

    a coupling line disposed outside the waveguide and including:

        a first transmission line having one end and including
        a first intersecting-line portion; and
        a second transmission line having one end and including
        a second intersecting-line portion,

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

2. The directional coupler according to claim 1, wherein the first transmission line and the second transmission line are coupled to each other at a position that is outside a rectangular region circumscribing the opening and is farther away from the tube axis than the rectangular region, in a plan view.

3. The directional coupler according to claim 1,
    wherein the opening has an opening-end portion; and,
    in a plan view, at least one of the first intersecting-line portion and the second intersecting-line portion intersects a corresponding one of the first elongated hole and the second elongated hole at a position closer to the opening-end portion than the opening-cross portion is.

4. The directional coupler according to claim 1, wherein at least one of the first intersecting-line portion and the second intersecting-line portion is orthogonal to a corresponding one of the first elongated hole and the second elongated hole, in a plan view.

5. The directional coupler according to claim 1,
    wherein the coupling line includes
    a plurality of straight-line portions including:

        the first intersecting-line portion; and the second intersecting-line portion; and,

of the plurality of straight-line portions, two straight-line portions adjacent to each other are coupled so as to make an obtuse angle.

6. The directional coupler according to claim 5, wherein the plurality of straight-line portions includes:

a straight-line portion configured to couple another end of the first intersecting-line portion to a first output part; and
a straight-line portion configured to couple the second intersecting-line portion to a second output part.

7. The directional coupler according to claim 1,
wherein, in a plan view, the first intersecting-line portion intersects the first elongated hole at a first coupling point, and the second intersecting-line portion intersects the second elongated hole at a second coupling point, a virtual line passing through the first coupling point and the second coupling point; and
a sum of a line distance of the first transmission line locating further away from the tube axis than the virtual line and a line distance of the second transmission line locating further away from the tube axis than the virtual line is set equal to 1/4 of an effective length.

8. The directional coupler according to claim 1,
wherein, in a plan view, a parallel line passes through the opening-cross portion and parallels the tube axis; and
a sum of a line distance of the first transmission line locating further away from the tube axis than the parallel line and a line distance of the second transmission line locating further away from the tube axis than the parallel line is set equal to 1/2 of an effective length.

9. A microwave heating device, comprising a directional coupler according to claim 1.

FIG. 1

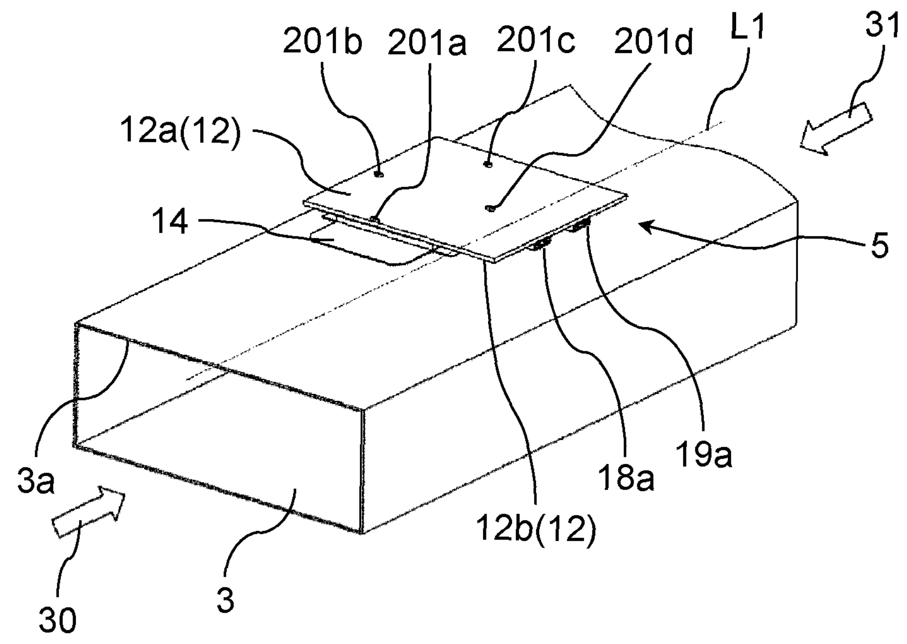

201b
201a
201c
201d
L1
31
12a(12)
14
5
3a
18a
19a
12b(12)
30
3

FIG. 2

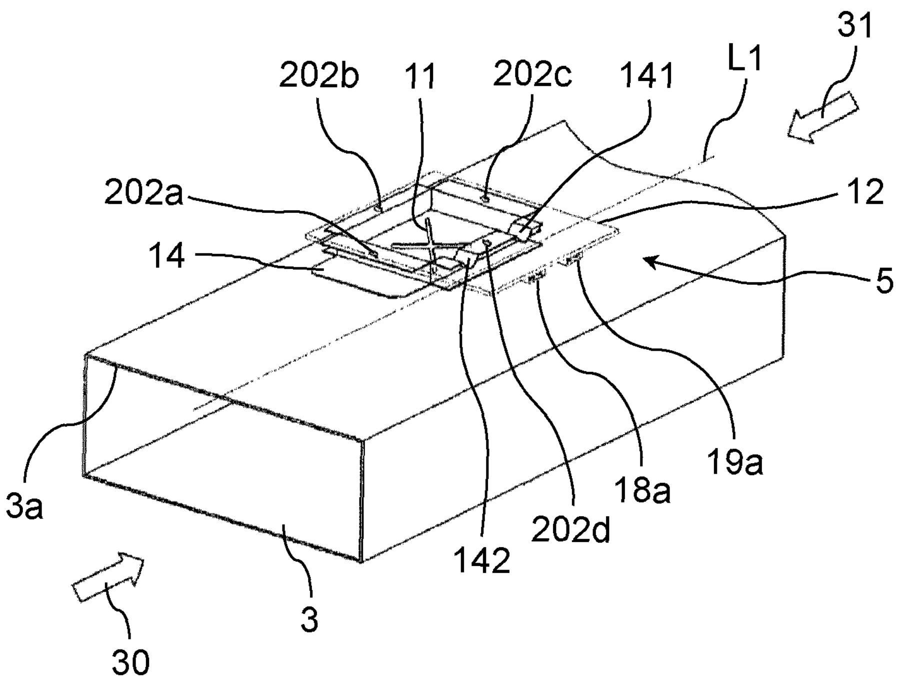

31
202b
11
202c
141
L1
202a
12
14
5
3a
19a
18a
202d
142
3
30

FIG. 3

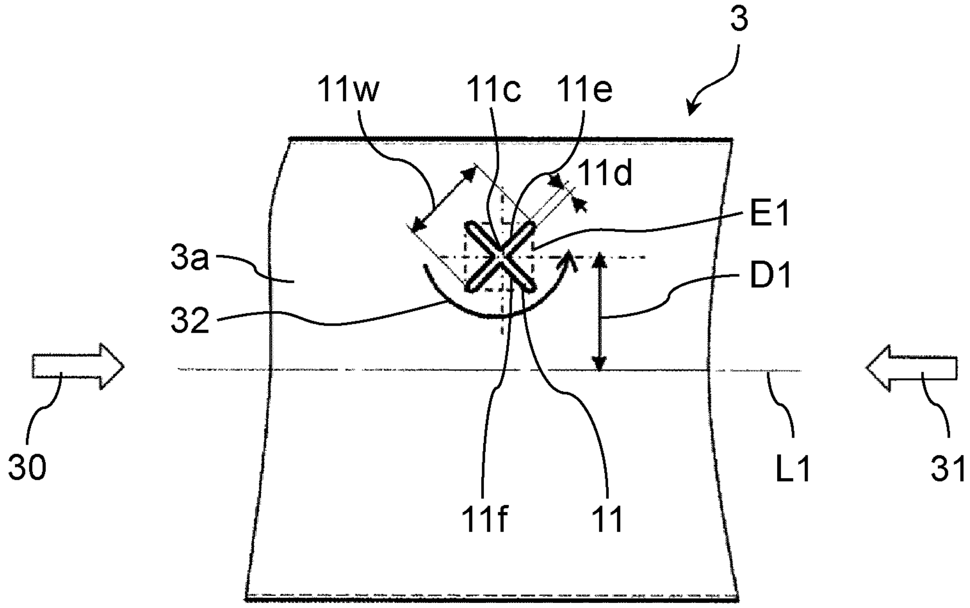


FIG. 4

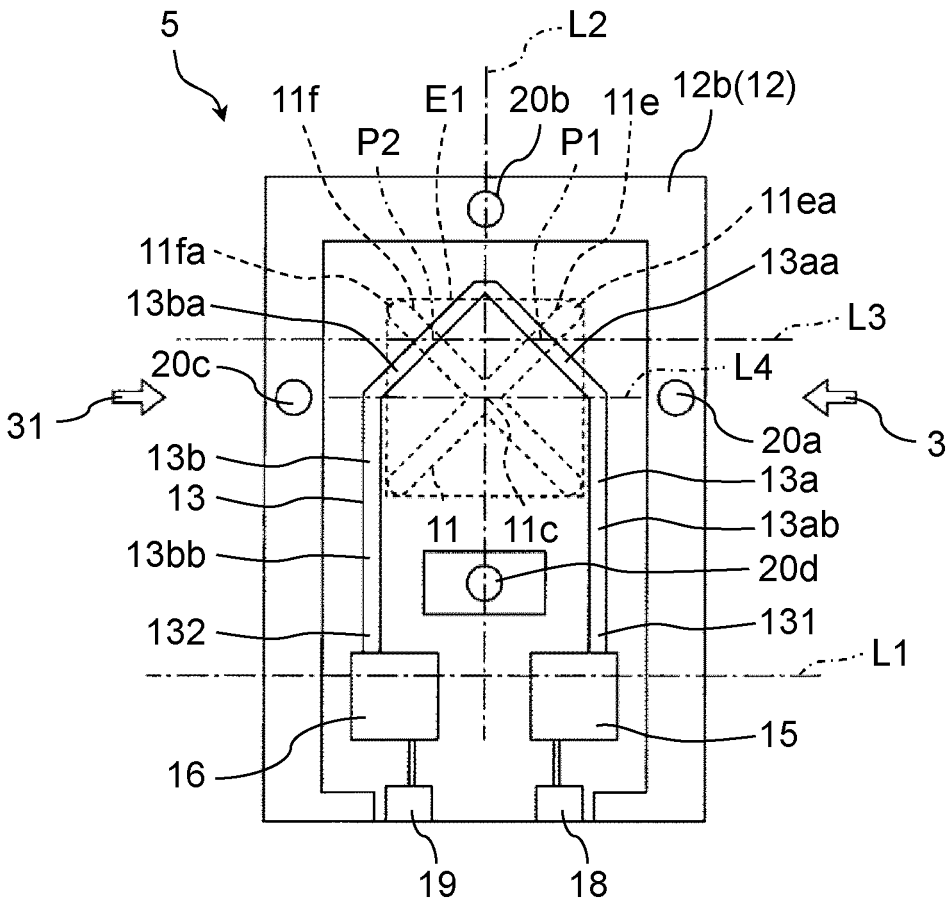
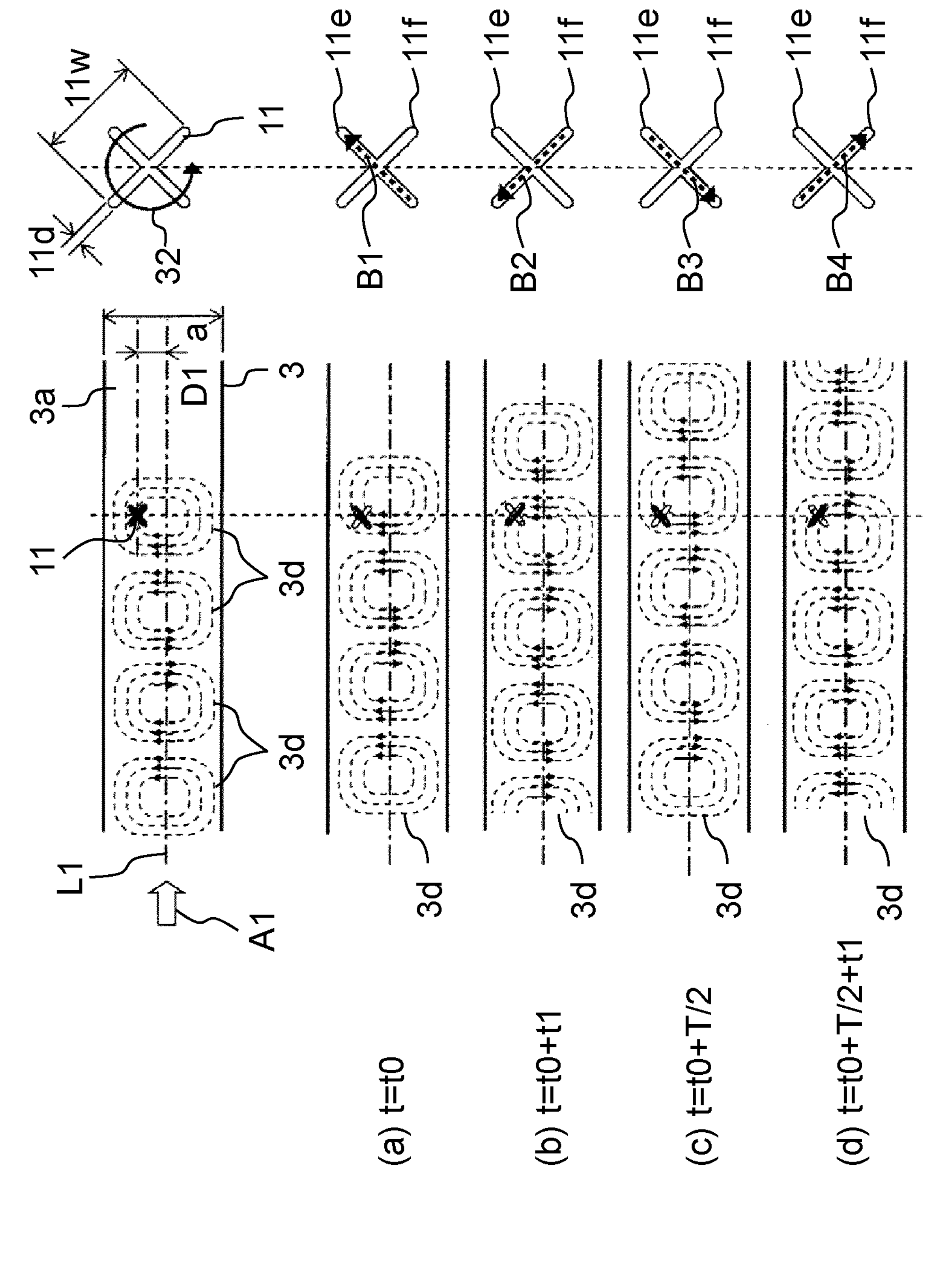

5
L2
11f
E1
20b
11e
12b(12)
P2
P1
11ea
11fa
13aa
13ba
L3
20c
L4
31
20a
30
13b
13a
13
11
11c
13ab
13bb
20d
132
131
L1
16
15
19
18

FIG. 5



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

FIG. 6

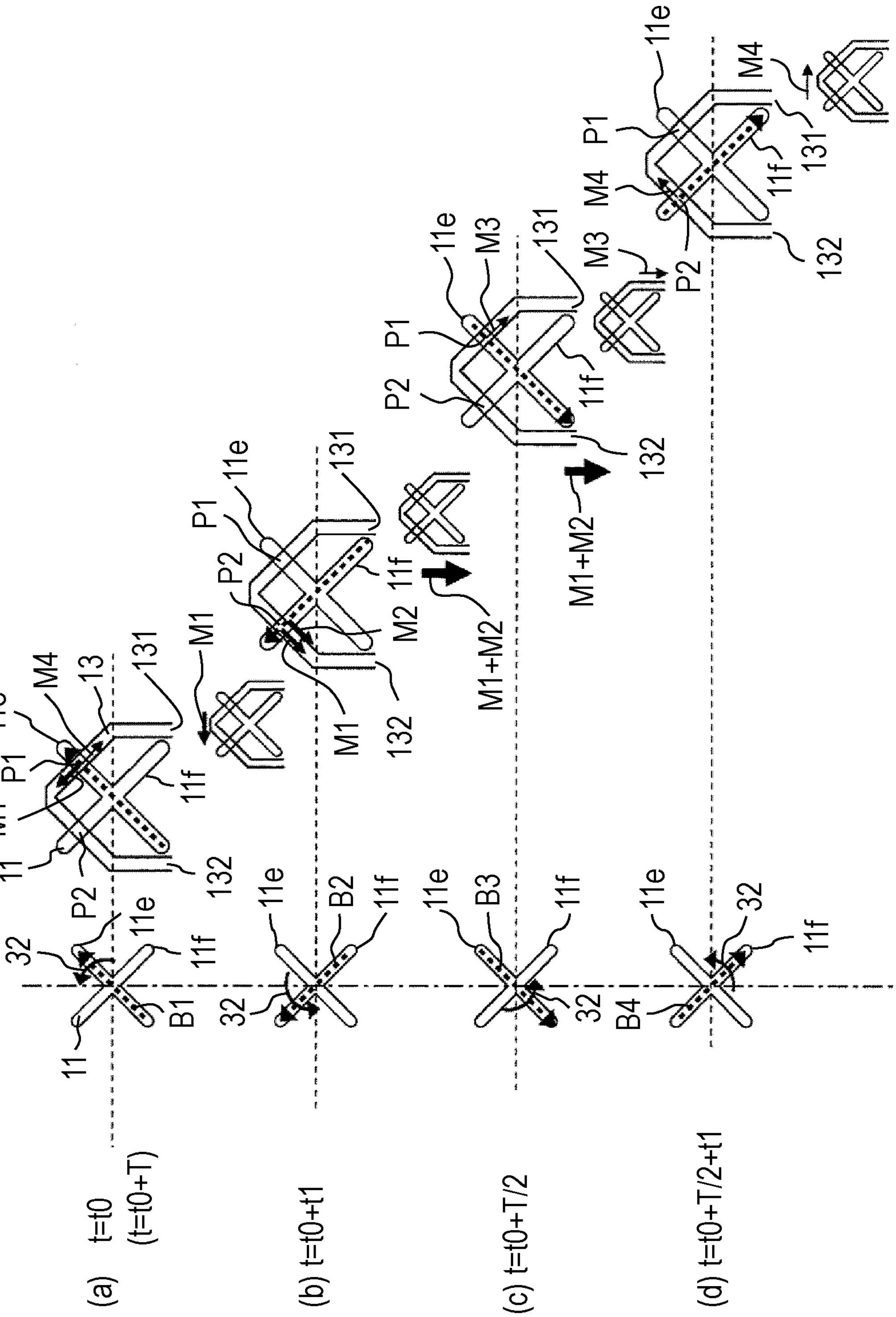
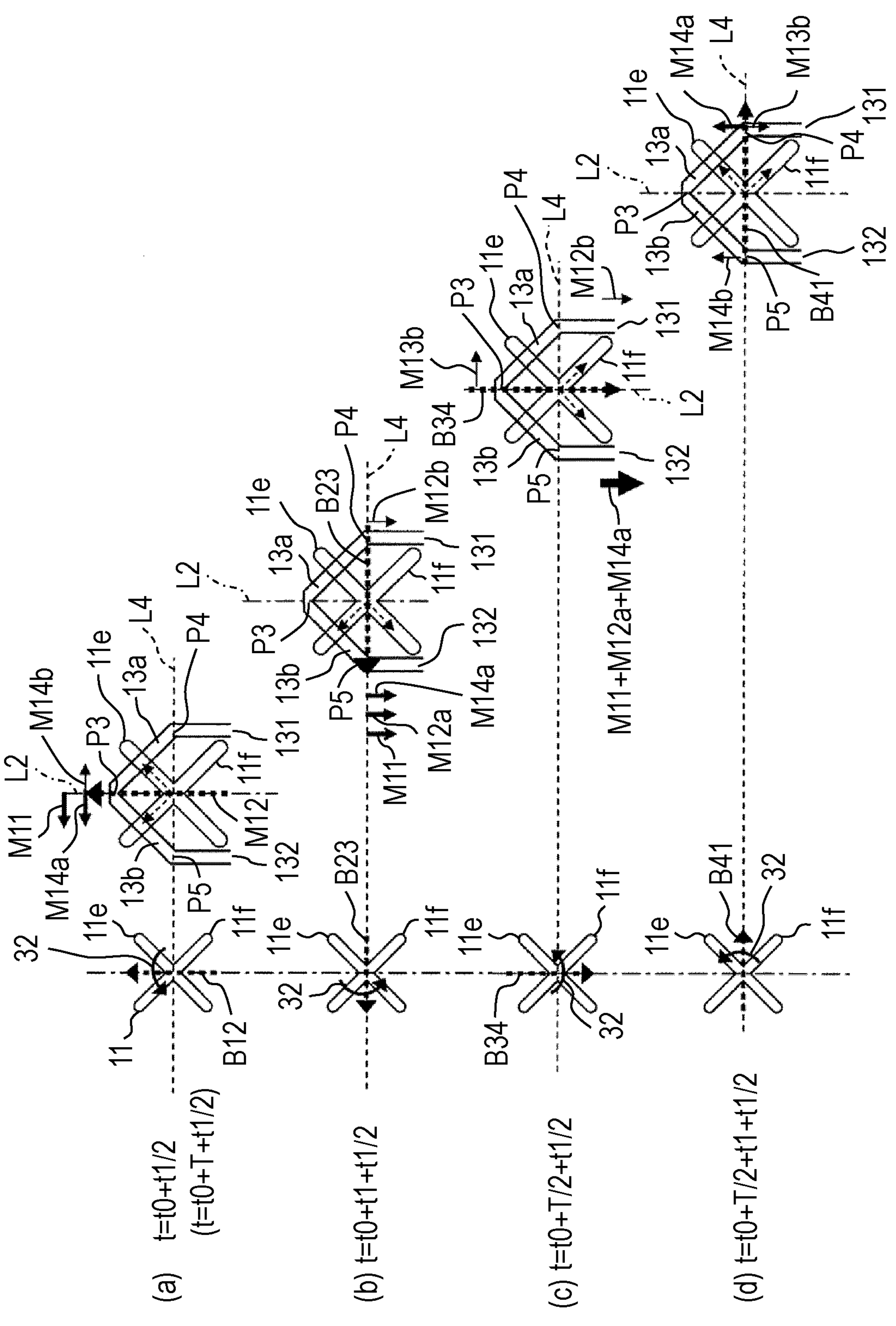

(a) t=t0
(t=t0+T)
(b) t=t0+t1
(c) t=t0+T/2
(d) t=t0+T/2+t1
11
11e
11f
13
131
132
32
B1
B2
B3
B4
P1
P2
M1
M2
M3
M4
M1+M2

FIG. 7


(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
M11+M12a+M14a

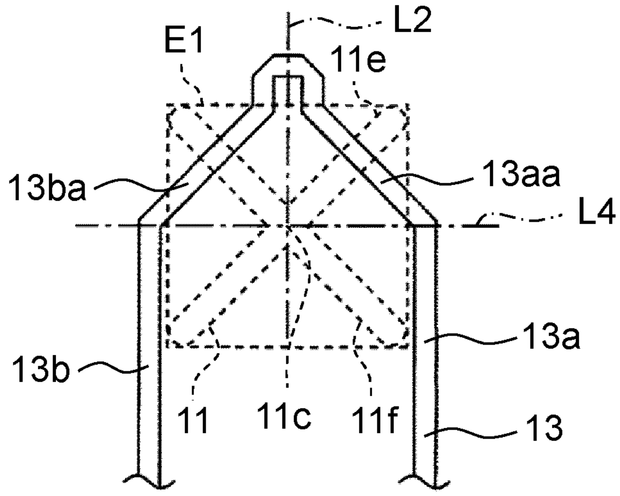


FIG. 8A

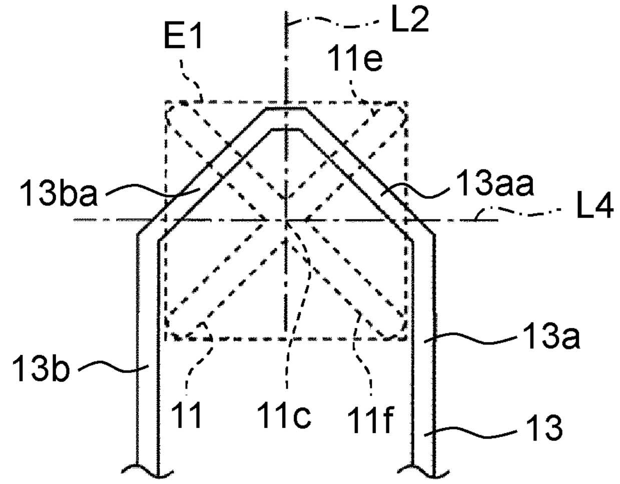


FIG. 8B

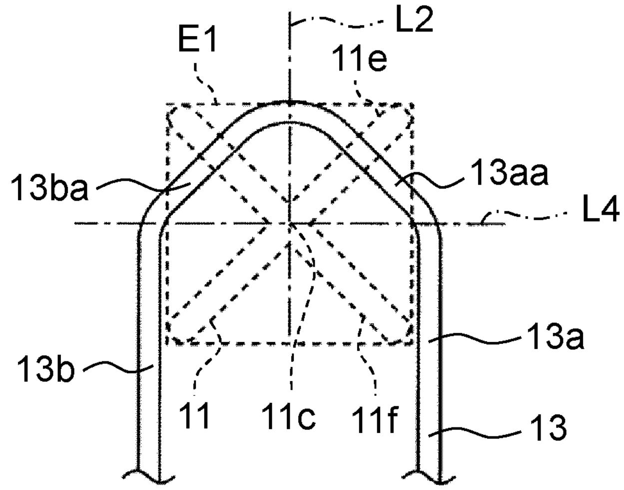


FIG. 8C

FIG. 8D

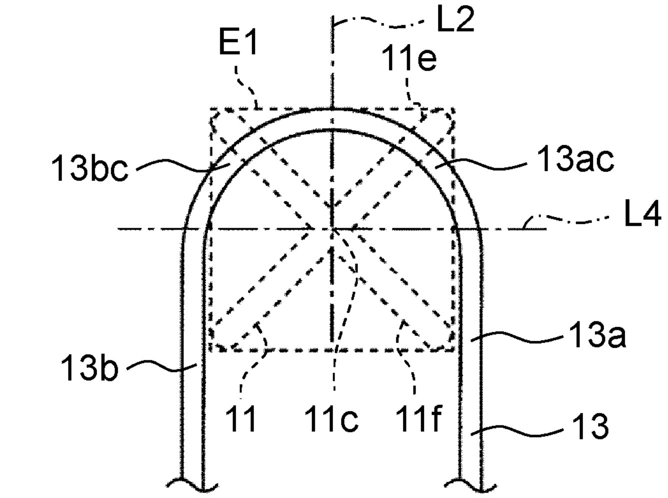


FIG. 8E

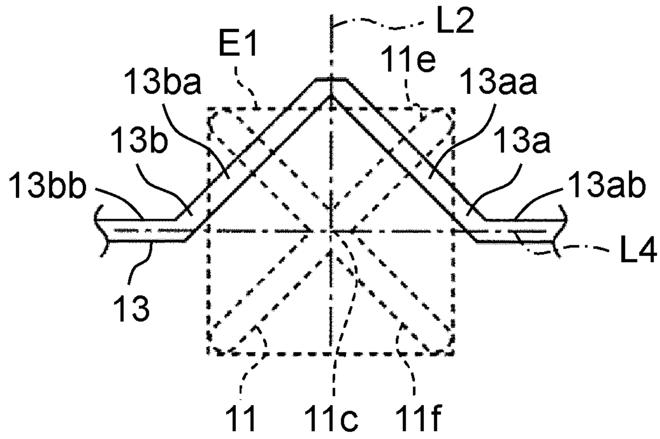


FIG. 8F

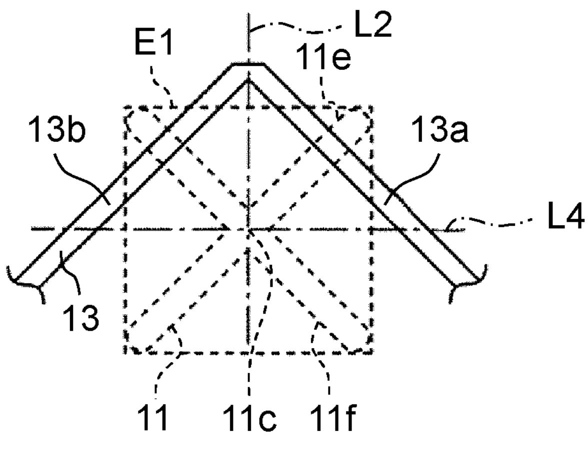
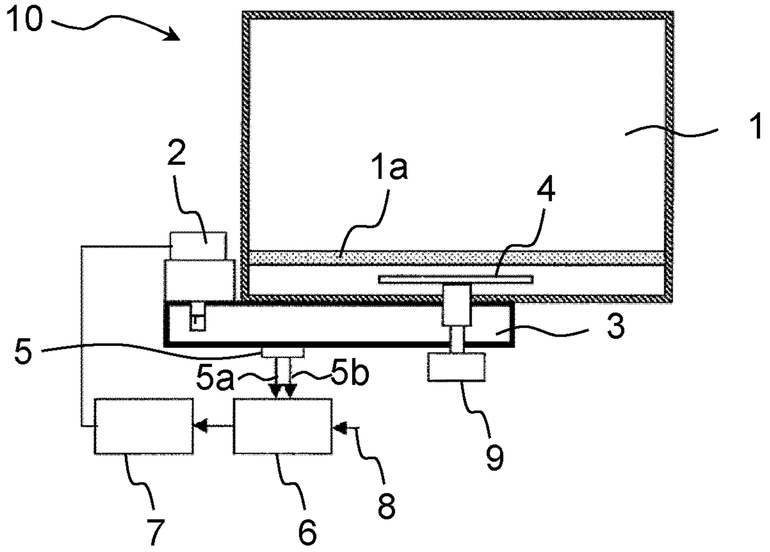


FIG. 9



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2019/016074

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl. H01P5/18(2006.01)i, H05B6/70(2006.01)i

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 1971-2019
Registered utility model specifications of Japan 1996-2019
Published registered utility model applications of Japan 1994-2019

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	WO 2014/119333 A1 (PANASONIC CORP.) 07 August 2014, & US 2015/0244055 A1 & EP 2953204 A1 & CN 104604023 A	1-9
A	JP 8-288705 A (DAEWOO ELECTRONICS CO., LTD.) 01 November 1996, & US 5668558 A & EP 735610 A2 & KR 10-0140601 B1 & CN 1139300 A	1-9

☐ 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
09.05.2019	21.05.2019

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)

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]**