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## Electromagnetic wave heating device


## Abstract

In order that it may be possible to form a strong-electric-field region at a level at which a electromagnetic waves are easily absorbed by an object to be heated **20** with low power in an electromagnetic-wave heating device **10** for heating the object to be heated **20** utilizing an electromagnetic waves, the electromagnetic-wave heating device **10** comprises: an oscillator **21** for outputting an electromagnetic waves; and a radiation antenna **22** being a conductor that radiates the electromagnetic waves outputted from the oscillator **21** and having a resonance structure in which resonance occurs in the conductor by the electromagnetic waves in a frequency band transmitted from the oscillator **21**, and is configured that a strong-electric-field region for heating the object to be heated is formed along the radiation antenna **22** by the electromagnetic waves supplied from the oscillator **21** to the radiation antenna **22.**



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## Background/Summary

TECHNICAL FIELD
(1) The present disclosure relates to an electromagnetic-wave heating device and the like used for heating an object to be heated.
BACKGROUND ART
(2) Conventionally, electromagnetic-wave heating devices employing dielectric heating have been used for various applications such as heating of food. Electromagnetic-wave heating devices irradiate

dielectrics included in an object to be heated with electromagnetic waves. Then, by the action of the electric field by the electromagnetic waves, molecule-scale dipoles in the dielectrics vibrate, and dielectric loss due to the vibration causes heat, whereby the object to be heated is heated. In addition, according to high-frequency heating different from the dielectric heating, an object to be heated is heated due to conductive (Joule) loss caused by a current when the object to be heated contains conductor components or ionic substances, and due to magnetic loss when the object to be heated contains magnetic components.

(3) Patent Document 1 discloses a dielectric heating unit that dielectric-heats a fixing member that heats and melts a toner image and fixes the toner image on a recording medium. The dielectric heating unit includes at least a pair of rod-shaped electrodes that form a high-frequency electric field around a dielectric of the fixing member, facing an outer peripheral surface or/and an inner peripheral surface of the fixing member. The rod-shaped electrodes are arranged to have different polarities from the adjacent rod-shaped electrodes, and high-frequency power is supplied from a power source.

REFERENCE DOCUMENT(S) OF CONVENTIONAL ART

Patent Documents

(4) Patent Document 1: JP 2008-292606 JP

DESCRIPTION OF THE DISCLOSURE

Problem(s) to be Solved by the Disclosure

(5) Notably, Patent Document 1 describes an experimental result using a high-frequency of 40 MHz. In this case, the wavelength of the high-frequency is about 7.5 m. Therefore, in the prior art described in Patent Document 1, resonance does not occur by the high-frequency in each rod-shaped electrode, and an electric field in the length direction of each rod-shaped electrode is considered to be substantially uniform. On the other hand, the inventors of the present application have considered an electromagnetic-wave heating device in which resonance occurs by the electromagnetic waves in a radiation antenna in order to increase an electric field intensity by the radiation antenna, since the stronger electric field is, the easier it is the electromagnetic waves to be absorbed by an object to be heated, whereby the object to be heated can be heated efficiently.

(6) However, in such an electromagnetic-wave heating device, a resonance frequency in the radiation antenna may be sequentially changed depending on an object to be heated or the like, and in this case, it is difficult to maintain an efficient heating state. Therefore, the inventor of the present application considered employing frequency control to control an oscillation frequency of an oscillator with respect to the resonance frequency.

(7) Here, Patent JP6157036B describes frequency control in which phase control and reflected power control are sequentially performed. However, since it takes time to detect reflected power in the reflected power control, in this frequency control, an oscillation frequency cannot be made to follow a resonance frequency at a high speed.

(8) The present disclosure has been made in view of these circumstances, and the object of the present disclosure is to provide an electromagnetic-wave heating device, in which resonance by electromagnetic waves in a radiation antenna occurs, that can make an oscillation frequency follow a resonance frequency at a high speed.

SUMMARY OF THE DISCLOSURE

(9) In order to solve the above problems, according to the present disclosure, an electromagnetic-wave heating device, provided with an oscillator for outputting electromagnetic waves and with a radiating antenna having a resonance structure in which resonance by the electromagnetic waves in a frequency band transmitted from the oscillator occurs, the electromagnetic-wave heating device for heating in an electromagnetic-wave strong-electric-field region formed by the resonance structure an object to be heated, comprises: a signal extraction unit provided in a transmission line extending from the oscillator to the radiation antenna, for extracting reflected-wave information representing a waveform of a reflected wave returning from the radiation antenna; a phase-difference information generating unit for generating, by arithmetic processing utilizing the reflected-wave information and incident-wave information representing a waveform of an incident wave transmitted from the

oscillator to the radiation antenna, phase-difference information representing a phase difference between the incident wave and the reflected wave; and a control unit for repeatedly performing a control process of: detecting, based on the phase-difference information and on reference information about a state in which the incident-wave phase and the reflected-wave phase are equal, a direction of oscillation-frequency adjustment whereby a difference between a resonance frequency in the radiation antenna and the oscillation-frequency of the oscillator is minimized, and controlling the oscillation-frequency based on the detected adjustment direction.

Effect of the Disclosure

(10) According to the present disclosure, a phase-difference signal representing a phase difference between the incident wave and the reflected wave is generated by arithmetic processing utilizing incident-wave information and reflected-wave information. Then, the control process of detecting an adjustment direction of the oscillation frequency based on the phase-difference signal and reference information and controlling the oscillation frequency based on the detection result is repeatedly performed, whereby the oscillation frequency follows the resonance frequency. Here, the arithmetic processing utilizing the incident-wave information and the reflected-wave information can be performed at a high speed. That is, generation of the phase-difference information can be performed at a high speed. Further, since the reference information can be prepared in advance, the adjustment direction of the oscillation frequency can also be detected at a high speed. According to the present disclosure, it is possible to make the oscillation frequency follow the resonance frequency at a high speed.

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## Description

BRIEF DESCRIPTION OF DRAWINGS

(1) FIG. **1** is a perspective view of an electromagnetic-wave heating device according to an embodiment as viewed obliquely from above with a cover being removed.

(2) FIG. **2** is a perspective view of the electromagnetic-wave heating device according to the embodiment as viewed obliquely from above.

(3) FIG. **3** is a sectional view of A-A of FIG. **2**.

(4) FIG. **4** is a cross-sectional view of B-B of FIG. **2** showing a base material being transported.

(5) FIGS. **5**A and **5**B are cross-sectional views of the electromagnetic-wave heating device according to the embodiment.

(6) FIG. **6** is a schematic circuit diagram of the electromagnetic-wave heating device according to the embodiment.

(7) FIG. **7** is a flowchart of a processing performed by a control unit of the electromagnetic-wave heating device according to the embodiment.

(8) FIG. **8** is a diagram drawn a graph showing a relationship between a phase-difference voltage and a resonance frequency.

(9) FIG. **9**A to **9**F are diagrams for explaining how an oscillation frequency is made to follow a resonance frequency.

(10) FIG. **10** is a diagram for explaining an averaging processing according to Modification 1-1.

(11) FIG. **11** is a schematic circuit diagram of an electromagnetic-wave heating device according to Modification 1-3.

(12) FIGS. **12**A and **12**B are flowcharts of processes performed by a control unit of the electromagnetic-wave heating device according to Modification 1-3.

(13) FIG. **13** is a diagram (Smith chart) for explaining how an oscillation frequency is made to follow a resonance frequency.

(14) FIG. **14** is a schematic circuit diagram of an electromagnetic-wave heating device according to Modification 1-4.

(15) FIG. **15** is a schematic circuit diagram of an electromagnetic-wave heating device according to

Modification 1-5.
(16) FIG. **16**A is a cross-sectional view of an electromagnetic-wave heating device according to Modification 2-1,
(17) FIG. **16**B is a cross-sectional view of an electromagnetic-wave heating device according to Modification 2-2, and
(18) FIG. **16**C is a cross-sectional view of an electromagnetic-wave heating device according to Modification 2-3.
(19) FIG. **17**A is a cross-sectional view of an electromagnetic-wave heating device according to Modification 2-4,
(20) FIG. **17**B is a cross-sectional view of an electromagnetic-wave heating device according to Modification 2-5, and
(21) FIG. **17**C is a cross-sectional view of an electromagnetic-wave heating device according to Modification 2-6.
(22) FIG. **18** is a perspective view of an electromagnetic-wave heating device according to Modification 2-7 as viewed obliquely from below.
(23) FIG. **19** is a schematic configuration diagram of an electromagnetic-wave heating device according to Modification 2-8 as viewed from a side.
(24) FIG. **20**A is a cross-sectional view of C-C of FIG. **16**B, FIG. **20**B is a cross-sectional view of a variation different from FIG. **20**A with respect to the planar configuration of a choke structure **55**, and FIG. **20**C is a cross-sectional view of yet another variation.
(25) FIG. **21**A is a schematic configuration diagram of an electromagnetic-wave heating device according to another modification of a shield unit as viewed from aside, and
(26) FIG. **21**B is a plan view of a substrate of the electromagnetic-wave heating device.
(27) FIG. **22** is a perspective view of an electromagnetic-wave heating device and a processing system according to Modification 3-1 as viewed obliquely from above.
(28) FIG. **23** is a side view of an electromagnetic-wave heating device and a processing system according to Modification 3-1.
(29) FIGS. **24**A and **24**B are top views of an electromagnetic-wave heating device according to Modification 3-1.
(30) FIG. **25** is a top view of an electromagnetic-wave heating device according to Modification 3-2.
(31) FIG. **26** is a top view of an electromagnetic-wave heating device according to Modification 3-3.
(32) FIG. **27**A is a top view of an electromagnetic wave heater according to Modification 3-4, and FIG. **27**B is a A-A cross-sectional view (traverse cross-sectional view) of FIG. **27**A.
(33) FIG. **28** is a top view of an electromagnetic-wave heating device according to Modification 3-5.
(34) FIG. **29** is a perspective view of an electromagnetic-wave heating device according to Modification 3-6 as viewed obliquely from above.
(35) FIG. **30** is an enlarged top view of an electromagnetic-wave heating device according to Modification 3-7.
(36) FIG. **31** is a top view of an electromagnetic-wave heating device according to Modification 3-8.
(37) FIG. **32** is a top view of an electromagnetic-wave heating device according to Modification 3-9.
(38) FIG. **33** is a top view of an electromagnetic-wave heating device according to Modification 3-10.
(39) FIG. **34** is a top view of an electromagnetic-wave heating device according to Modification 3-11.
(40) FIG. **35** is a top view of an electromagnetic-wave heating device according to Modification 3-12.
(41) FIG. **36** is a perspective view of an electromagnetic-wave heating device and a processing system according to Modification 3-13 as viewed obliquely from above.
(42) FIG. **37**A is a cross-sectional view of an electric field forming portion, as sectioned from a first direction, of an electromagnetic-wave heating device according to another modification of a structure for forming a strong-electric-field region, FIG. **37**B is a cross-sectional view of an electric field forming portion according to another embodiment, and FIG. **37**C is a cross-sectional view of an

electric field forming portion according to yet another embodiment.

MODES FOR CARRYING OUT THE DISCLOSURE

(43) Hereinafter, one embodiment of the present disclosure is described in detail with reference to the drawings. Note that the following embodiment is one example of the present disclosure, and it is not intended to limit the scope of the present disclosure, its application, or its use.

Embodiment

(44) The present embodiment is an electromagnetic-wave heating device **10** that heats an object to be heated **20** by utilizing electromagnetic waves such as high-frequency waves. The electromagnetic-wave heating device **10** is a heating device employing dielectric heating. The electromagnetic wave used by the electromagnetic-wave heating device **10** are of a high-frequency of 50 MHz or higher (for example, a high-frequency of 800 MHz or higher (microwave or the like)).

(45) The object to be heated **20** heated by the electromagnetic-wave heating device **10** includes a substance (a liquid, a solid or the like) that absorbs a high-frequency. The object to be heated **20** is a thin object having a small thickness and has a sheet shape or a film shape. The object to be heated **20** is, for example, an adhesive. The object to be heated **20** is applied or disposed on the surface of a sheet-shaped and elongated base material (conveyed object) **11**. The object to be heated **20** is conveyed along with the base material **11** in a predetermined direction (a direction indicated by an arrow in FIG. **1**) and passes through a high-frequency strong-electric-field region. At this time, the object to be heated **20** is heated by absorbing a high-frequency. Note that the object to be heated **20** may not be in the form of a sheet or a film and may have a certain thickness. Further, the object to be heated **20** (for example, an adhesive) may be applied to or disposed on a sheet (for example, an envelope) placed on the surface of the base material **11**, and in this case, the object to be heated **20** is conveyed together with the sheet and the base material **11**.

(46) The electromagnetic-wave heating device **10** constitutes a conveyance type processing system together with an upstream device (for example, an adhesive application device, not shown) for applying or disposing the object to be heated **20** on the surface of the base material **11**, and a conveyance mechanism **12** for conveying the base material **11** through a processing section extending from at least an inlet of the upstream device to an outlet of the electromagnetic-wave heating device **10**. The conveyance mechanism **12** conveys the base material **11** and the object to be heated **20** by using a plurality of pairs of rollers **13** (see FIG. **4**). Hereinafter, a conveying direction of the base material **11** is referred to as a “first direction”, and a direction orthogonal to the first direction is referred to as a “second direction” (see FIG. **1** and the like). Further, in the electromagnetic-wave heating device **10**, a cover **50** side is referred to as “front side”, and a substrate **23** side is referred to as “back side” (see FIG. **2** and the like).

(47) Note that the electromagnetic-wave heating device **10** may be a device for simply heating the base material **11** itself without the purpose of heating the liquid or solid of object to be heated **20** placed on the base material **11**. In addition, the electromagnetic-wave heating device **10** may be configured to heat the object to be heated **20** without conveying it.

(48) Configuration of Electromagnetic-Wave Heating Device

(49) As shown in FIGS. **1** and **2**, the electromagnetic-wave heating device **10** includes an oscillator **21** that oscillates a high-frequency, a radiation antenna **22** that radiates a high-frequency for heating the object to be heated **20** and a substrate **23** on which the radiation antenna **22** is provided on its one side. The radiation antenna **22** is a conductor that radiates a high-frequency output from the oscillator **21** and has a resonance structure in which resonance occurs in the conductor under a frequency band of high-frequency transmitted from the oscillator **21**. The electromagnetic-wave heating device **10** is configured such that the strong-electric-field region (high-frequency heating region) for heating the object to be heated **20** is formed along the radiation antenna **22** by high-frequency supplied from the oscillator **21** to the radiation antenna **22**.

(50) The electromagnetic-wave heating device **10** includes the cover **50** that covers the radiation antenna **22** side of the substrate **23**. The electromagnetic-wave heating device **10** further includes a control device **75** that controls the oscillator **21**.

(51) For example, a semiconductor oscillator is used as the oscillator **21**. The substrate **23** and the cover **50** are made of metal. The substrate **23** corresponds to a grounded electrode. The substrate **23** and the cover **50** correspond to a shield unit **60** that shields from the outside an internal space **40** (see FIG. **3**) in which the radiation antenna **22** is disposed. The cover **50** corresponds to a first partition portion that partitions the internal space **40** of the shield unit **60** from one side (upper side). The substrate **23** corresponds to a second partition portion that partitions the internal space **40** from an opposite side (lower side) to the first partition portion. A continuous gap **70** is formed between the substrate **23** and the cover **50** that is continuous in the circumferential direction around an outer periphery of the shield unit **60** in a plan view.
(52) The radiation antenna **22** is constituted by an interdigital circuit. The radiation antenna **22** includes a first comb-teeth electrode **31** and a second comb-teeth electrode **32** that meshes with the first comb-teeth electrode **31** with a gap therebetween. The first comb-teeth electrode **31** is formed in a comb shape by a plurality of tooth portions **31***a*. The second comb-teeth electrode **32** is formed in a comb shape by a plurality of tooth portions **32***a*.
(53) The first comb-teeth electrode **31** includes a straight base line **31***b* and a plurality of the tooth portions **31***a* whose roots are connected to the base line **31***b*. The plurality of tooth portions **31***a* are provided to be parallel to each other. Each of the tooth portions **31***a* extends obliquely from the base line **31***b*. The plurality of tooth portions **31***a* are arranged at equal intervals in the first direction.
(54) The second comb-teeth electrode **32** includes a straight base line **32***b* and a plurality of the tooth portions **32***a* whose roots are connected to the base line **32***b*. The base line **32***b* is parallel to the base line **31***b* of the first comb-teeth electrode **31**. The plurality of tooth portions **32***a* are provided to be parallel to each other. The tooth portions **32***a* of the second comb-teeth electrode **32** are parallel to the tooth portions **31***a* of the first comb-teeth electrode **31**. Each of the tooth portions **32***a* extends obliquely from the base line **32***b*. The plurality of tooth portions **32***a* are arranged at equal intervals in the first direction.
(55) In the radiation antennae **22**, the plurality of tooth portions **31***a*,**32***a* are arranged in the same plane with a gap therebetween in a predetermined direction (the first direction). A region in which the plurality of tooth portions **31***a*,**32***a* are arranged (hereinafter, referred to as an “arrangement region”) is a band-shaped region in a plan view. The total number of tooth portions (conductive line) **31***a*,**32***a* arranged in the first direction may be three or more, and may be ten or more as in the present embodiment.
(56) The radiation antenna **22** includes, in addition to the first comb-teeth electrode **31** and the second comb-teeth electrode **32**, a first connection line **41** connecting the first comb-teeth electrode **31** and the second comb-teeth electrode **32** on one end of the arrangement region in the first direction and a second connection line **42** connecting the first comb-teeth electrode **31** and the second comb-teeth electrode **32** on the other end of the arrangement region. The radiation antenna **22** is a closed circuit. The first connection line **41** is connected to an input part **30** to which a high-frequency from the oscillator **21** is input. The input part **30** is, for example, a coaxial connector, and is connected to the oscillator **21** via a coaxial line. The input part **30** is provided on the back side of the substrate **23**. During an input period in which a high-frequency is input to the input part **30**, the strong-electric-field region for heating the object to be heated **20** is formed in a facing region (a region above the arrangement region) of the radiation antenna **22**. The strong-electric-field region is formed in the vicinity of the front side of the radiation antenna **22** in the facing region and is a parallel and thin region.
(57) The radiation antenna **22** is configured such that resonance of high-frequency occurs under a frequency band of a high-frequency oscillated by the oscillator **21** during the above-described input period. In the radiation antennae **22**, resonances of high-frequencies occur simultaneously at the respective tooth portions **31***a*, **32***a*. The length L**1** of the tooth portion **31***a* and the length L**2** of the tooth portion **32***a* are designed by using Equations 1 and 2 (n.sub.1, n.sub.2 is a natural number), where X is the wavelength (electric length) of the transmitted high-frequency. The combined length of adjacent tooth portion **31***a* and tooth portion **32***a* is expressed by 2 m×/4 (m is a natural number).

In the present embodiment, the length L**1**, L**2** of the tooth portion **31***a*, **32***a* are both λ/4. Note that the respective tooth portions **31***a* of the first comb-teeth electrode **31** and the respective tooth portions **32***a* of the second comb-teeth electrode **32** have the same length, but the lengths may be different from each other.

$L1=\lambda\times(2n_1-1)/4$ Equation 1

$L2=\lambda\times(2n_2-1)/4$ Equation 2

(58) The radiation antennae **22** is configured such that a relatively strong-electric-field coupling occurs between the tooth portion **31***a*, **32***a* adjacent to each other in the first direction during the above-described input period. Specifically, in the radiation antennae **22**, the large number of tooth portions **31***a*, **32***a* are arranged at equal intervals in the first direction, the distance (the dimension of a gap) G of the tooth portions **31***a*, **32***a* adjacent in the first direction is not more than 5 times the line width of the tooth portion **31***a*,**32***a*, and a relatively strong-electric-field coupling occurs between adjacent conductive lines **31***a*,**32***a*. Therefore, the strong-electric-field region is formed along the large number of tooth portions **31***a*, **32***a*. The distance G may be three times or less of the line width of the tooth portion **31***a*, **32***a*, or may be one time or less. Note that the respective tooth portions **31***a* of the first comb-teeth electrode **31** and the respective tooth portions **32***a* of the second comb-teeth electrode **32** have all the same line width, but the line widths may be different from each other.

(59) The substrate **23** is made of, for example, a metal plate material. The planar shape of the substrate **23** is substantially rectangular. The longitudinal direction of the substrate **23** coincides with the first direction. A recess **17** having a substantially rectangular planar shape is formed in the front side of the substrate **23**. The longitudinal direction of the recess **17** also coincides with the first direction. The radiation antenna **22** is accommodated in the recess **17**. In the recess **17**, the radiation antenna **22** is supported in a floating state by, for example, a dielectric (not shown) provided on the bottom surface. The radiation antenna **22** is electrically isolated from a metal portion of the substrate **23**. A region of the surface of the substrate **23** other than the recess **17** is a flat region **27** surrounding the radiation antenna **22**. The height of the flat region **27** is, for example, about the same level as or slightly above or below the upper surface of the radiation antenna **22**.

(60) In the present embodiment, the substrate **23** is constituted by a frame-shaped front-side metal plate **23***a* and a rectangular back-side metal plate **23***b* superposed on the back surface of the front-side metal plate **23***a*, but the substrate **23** may be constituted by a single metal plate having the recess **17** formed in one side. Further, the surface of the flat region **27** and/or the upper surface of the radiation antenna **22** may be coated with a coating (e.g., a dielectric coating) that absorbs high-frequencies in order to suppress generation of discharge due to a strong electric field.

(61) The cover **50** is a metal casing. As shown in FIGS. **2** and **3**, the cover **50** includes a main body portion **51** covering the radiation antenna **22** from the front side, an outer peripheral portion **52** integrated with the main body portion **51** so as to surround the entire periphery of the main body portion **51** and a duct portion **53** connected to an upper surface of the main body portion **51**. A blower **35** that supplies air to the heated object **20** conveyed through the internal space **40** is attached to an outer end portion of the duct portion **53**. The blower **35** is attached to a shield unit **60** (the first partition portion **50**).

(62) The main body portion **51** has a substantially rectangular shape in a plan view, and has, for example, a planar dimension equivalent to that of the recess **17**. The main body portion **51** is located directly above the recess **17**. The main body portion **51** is formed in a box shape with its lower side being opened. As illustrated in FIG. **4**, an internal space of the main body portion **51** and an internal space of the duct portion **53** are connected to each other and serve as a blowing passage **45** through which air flows from the blower **35** toward the object to be heated **20**.

(63) The outer peripheral portion **52** is an outside portion of the main body portion **51** and has a substantially rectangular frame shape in a plan view. The outer peripheral portion **52** faces the flat region **27** of the substrate **23** through the continuous gap **70** in the circumferential direction. The outer peripheral portion **52** is provided with a shield structure **55** that prevents leakage of high-frequencies through the continuous gap **70** around the entire circumference. The shield structure **55**

is, for example, a choke structure **55**. The structure and shape of the choke structure **55** are not particularly limited, but a short-circuit type λ/4 resonant choke can be adopted. The choke structure **55** is formed of a spiral (or ring-shaped) cavity in a cross-sectional view and has an opening to the radiation antenna **22**. The dimension of the choke structure **55** is, for example, "λ/2×a ("a" is a natural number)" in the circumferential length in the cross-sectional view and "λ/4×b ("b" is a natural number)" in the depth. λ is the electrical length of high-frequency in the choke structure **55**.
(64) The duct portion **53** is disposed on an upstream side (an introduction portion **71** side) in a conveyance direction (the first direction) of the base material **11**. The duct portion **53** is inclined obliquely downwardly toward the downstream side in the first direction. A blowing direction of the blower **35** faces the downstream side in the first direction. Further, inside of the main body portion **51**, a plurality of wind direction adjusting plates **68** are provided. Each wind direction adjusting plate **68** is, for example, a louver which directs a wind direction to the downstream side of the first direction. With these configurations, air blown from the blower **35** flows toward the downstream side in the first direction, is mainly discharged to the outside from a lead-out portion **72** of the continuous gap **70** and is partially discharged from side gaps **73** and **74**. The wind direction adjusting plate **68** may be omitted.
(65) The blowing passage **45** is provided with a metallic shield member **46** that shields the blower **35** from high-frequency radiated from the radiation antenna **22** and is formed with through-holes **46***a* allowing air from the blower **35** toward the object to be heated **20** to pass therethrough. The shield member **46** is formed in a plate shape. The shield member **46** is attached to the main body portion **51** so as to partition the air blowing passage **45** into the upstream side and the downstream side (so as to partition vertically). A plurality of through-holes **46***a* are formed in the shield member **46**. The respective through-holes **46***a* are formed to have a size such that high-frequency radiated from the radiation antenna **22** cannot pass therethrough.
(66) Configuration of Shield Unit
(67) The configuration of the shield unit **60** will be described with reference to FIGS. **3** and **4** and the like.
(68) The shield unit **60** is a housing for accommodating the radiation antenna **22** in the internal space **40** and is constituted by the substrate **23** and the cover **50**. The shield unit **60** is configured such that the internal space **40** becomes a shielded space while allowing passage of the base material **11** by providing the introduction portion **71**, the lead-out portion **72** and the like. In the internal space **40**, the base material **11** is conveyed from the introduction portion **71** toward the lead-out portion **72** so that the object to be heated **20** passes through a facing region of the radiation antenna **22**.
(69) In the shield unit **60**, the continuous gap **70** is formed which is continuous around an entire periphery of a side portion of the shield unit **60** as a gap for allowing the internal space **40** to communicate with the outside. For example, in the shield unit **60**, the cover **50** is supported by a support member (not shown) so as to be in a floating state with respect to the substrate **23**. The first partition portion **50** is supported by the second partition portion **23** on the other side in the direction orthogonal to the conveyance direction.
(70) The continuous gap **70** is formed by an upper surface of the flat region **27** of the substrate **23** and a lower surface of the outer peripheral portion **52** of the cover **50** in a cross-sectional view. The gap dimension (the distance between the flat region **27** and the outer peripheral portion **52**) of the continuous gap **70** in the cross-sectional view is constant over the entire periphery of the shield unit **60**, for example. The lower limit of the gap dimension of the continuous gap **70** may be any dimension that allows the base material (conveyed object) **11** to pass therethrough. The upper limit of the gap dimension of the continuous gap **70** is, for example, 30 mm or less, preferably 10 mm or less, more preferably 5 mm or less as long as it can substantially prevent leakage of high-frequency to the outside.
(71) The continuous gap **70** includes the introduction portion **71** into which the base material **11** including the object to be heated **20** is introduced, the lead-out portion **72** from which the base material **11** is derived and a pair of side gaps **73** and **74** extending in the conveying direction of the

base material **11** on both sides of the facing region. The continuous gap **70** is formed on four sides of the upstream side in the first direction, the downstream side in the first direction, and both sides in the second direction when viewed from the facing region of the radiation antenna **22** in a plan view. The side gaps **73** and **74** extend in the conveying direction of the conveyed object on the sides of the facing region. In the present specification, the "side" of the facing region means a direction orthogonal to the conveyance direction.

(72) It is to be noted that the continuous gap **70** may be constituted by at least three gaps having the introduction portion **71** on the upstream side in the conveying direction, the lead-out portion **72** on the downstream side in the conveying direction, and the side gap **73** on one side in a direction orthogonal to the conveying direction (such as the side gap **73** on one side in the second direction). In FIG. 5B, the continuous gap **70** is formed in only three directions when viewed from the facing region. Further, the support member **80** that supports the cover **50** with the substrate **23** is provided on the other side in the second direction as viewed from the facing region.

(73) Specifically, each of the introduction portion **71** and the lead-out portion **72** is constituted by a gap formed between the short side of the flat region **27** of the substrate **23** and the outer peripheral portion **52** facing the short side. Each of the side gaps **73** and **74** is constituted by a gap formed between the long side of the flat region **27** of the substrate **23** and the outer peripheral portion **52** facing the long side. The side gaps **73** and **74** are connected to the introduction portion **71** and the lead-out portion **72**, respectively.

(74) Operation of Processing System

(75) The operation of the processing system including the electromagnetic-wave heating device **10** will be described. When the power supply of the processing system is turned ON, the respective power supplies of the electromagnetic-wave heating device **10** and the conveyance mechanism **12** are turned ON. As a result, the base material **11** is conveyed in the first direction by a conveyance mechanism **12**, and a high-frequency is oscillated from the oscillator **21**. The base material **11** is conveyed in the vicinity of the front side of the radiation antenna **22** with the object to be heated **20** side facing the front side (the upper side in FIG. **1**). Note that the base material **11** may be conveyed with the object to be heated **20** side facing the back side.

(76) In the electromagnetic-wave heating device **10**, a high-frequency outputted from the oscillator **21** is supplied to each tooth portion **31***a* of the first comb-teeth electrode **31** and each tooth portion **32***a* of the second comb-teeth electrode **32**. Resonance of a high-frequency occurs in each tooth portion **31***a*, **32***a* of the comb-teeth electrodes **31** and **32**, and the leading end of each tooth portion **31***a*,**32***a* becomes an abdominal portion of a standing wave of a high-frequency. In the radiation antenna **22**, the abdominal portions of the standing waves in the plurality of tooth portions **31***a* of the first comb-teeth electrode **31** are aligned in the first direction, and the abdominal portions of the standing waves in the plurality of tooth portions **32***a* of the second comb-teeth electrode **32** are aligned in the first direction.

(77) Further, relatively strong-electric-field coupling occurs between the tooth portions **31***a*, **32***a* adjacent to each other in the first direction. Thus, in the facing region of the radiation antenna **22**, a strong-electric-field region is formed so as to include the conveyance path of the object to be heated **20** and the base material **11**. The object to be heated **20** passing through the strong-electric-field region has its dielectric components, conductive components or the like contained therein heated by a high-frequency. As a result, A desired physical/chemical change (polymerization, annealing, drying, curing, or the like) occurs in the object to be heated **20** through the temperature rise. In the base material **11**, a plurality of objects **20** to be heated are arranged at intervals in the conveyance direction of the base material **11**. The plurality of objects **20** to be heated are conveyed at intervals so as to pass through the strong-electric-field region in order.

(78) In this embodiment, resonance of high-frequency occurs at the respective tooth portions **31***a*, **32***a* of the radiation antenna **22**, and thereby electric field strength in the strong-electric-field region becomes relatively high. Therefore, power input to the oscillator **21** can be suppressed as compared with the case where resonance does not occur. Moreover, since the continuous gap **70** is formed in the

shield unit **60**, it is possible to suppress high-frequency leakage to the outside while allowing the base material **11** to pass through. Moreover, since the shield member **46** is provided, high-frequency leakage through the inlet of the blowing passage **45** can also be suppressed. In addition, since the blower **35** is provided, in the case that the object to be heated **20** is dried by heating, an organic solvent and moisture evaporated from the object to be heated **20** can be discharged to the outside of the shield unit **60** and the object to be heated **20** can be dried efficiently.
(79) Configuration and Operation of Controller
(80) The control device **75** is configured to control the oscillation frequency of the oscillator **21**. As shown in FIG. **6**, the control device **75** includes a directional coupler **76**, a phase-difference information generation unit **77** and a control unit **78**. The directional coupler **76** corresponds the signal extraction unit provided in a transmission line **16** extending from the oscillator **21** to the radiation antenna **22**, which extracts reflected-wave information.
(81) The oscillator **21** includes a voltage variable oscillator (VCO) **21***a* in which an oscillation frequency is varied by a control voltage, an amplifier **21***b* provided after the voltage variable oscillator **21***a* and a voltage regulation circuit **21***c* provided between the voltage variable oscillator **21***a* and a DC power supply **15**. The voltage regulation circuit **21***c* is configured to change a control voltage applied to the voltage variable oscillator **21***a* by ON/OFF of switches SW**1**, SW**2**.
(82) For example, the voltage regulation circuit **21***c* includes an inductor L and a capacitor C in addition to the first switch SW**1** and the second switch SW**2**. In the voltage regulation circuit **21***c*, a first terminal of the inductor L is connected to a positive terminal of the DC power supply **15**, a first terminal of the capacitor C is connected to a negative terminal of the DC power supply **15**, and a second terminal of the inductor L and a second terminal of the capacitor C are connected to each other and connected to the voltage variable oscillator **21***a*. The first switching SW**1** is connected between the first terminal of the inductor L and the positive terminal of the DC power supply **15**. The second switching SW**2** is connected between a wiring connecting the first terminal of the inductor L and the positive terminal of the DC power supply **15**, and a wiring connecting the first terminal of the capacitor C and the negative terminal of the DC power supply **15**.
(83) In a first state in which only the first switch SW**1** from among the first switch SW**1** and the second switch SW**2** is set to ON, the capacitor C is charged. In the first state, the control voltage gradually increases, and the oscillation frequency gradually increases with the increase of the control voltage. Further, in a second state in which only the second switch SW**2** from among the first switch SW**1** and the second switch SW**2** is set to ON, the capacitor C is discharged. In the second state, the control voltage gradually decreases, and the oscillation frequency gradually decreases with the decrease of the control voltage. In a third state in which both the first switch SW**1** and the second switch SW**2** are set to OFF, a potential difference between the first terminal and the second terminal in the capacitor C and the control voltage are constant. In the third state, the oscillation frequency of the voltage variable oscillator **21***a* does not change. Note that the configuration of the voltage regulation circuit **21***c* is not limited to the present embodiment.
(84) Each element of a control device **75** will be described. A directional coupler **76** is connected to the transmission line **16**. The directional coupler **76** is configured to extract, from the transmission line **16**, an incident-wave signal representing a waveform of a high-frequency (incident wave) toward the radiation antenna **22** and a reflected-wave signal representing a waveform of a high-frequency (reflected wave) returning from the radiation antenna **22**, respectively. The directional coupler **76** has a first output terminal and a second output terminal, both connected to a phase-difference information generation unit **77**, outputs the incident-wave signal from the first output terminal to the phase-difference information generation unit **77**, and outputs the incident-wave signal from the second output terminal to the phase-difference information generation unit **77**.
(85) In a line on which the incident-wave signal is transmitter from directional coupler **76** to the phase-difference information generation unit **77**, a delay line (cable) which delays a signal by a predetermined phase is provided as a phase correction unit **99** that corrects a phase shift between the incident-wave signal and the reflected-wave signal. Instead of the delay line, a delay element that

delays the signal by a predetermined phase may be provided.
(86) The phase-difference information generation unit **77** is a device that generates a phase-difference signal representing a phase difference (θ**1**−θ**2**) between the incident wave and the reflected wave by arithmetic processing for calculating the incident-wave signal and the reflected-wave signal. The phase-difference signal corresponds to phase-difference information. A phase detector or an amplitude/phase detector can be used as the phase-difference information generation unit **77**. The phase-difference information generation unit **77** generates and outputs a phase-difference signal PDS shown in Equation 4 by, for example, performing a multiplication shown in Equation 3 and then performing a filtering processing to remove a component (a double harmonic component (cos(2ωt+θ1+θ2)) including an angular frequency ω and a time function t corresponding to the oscillation frequency f According to the filtering processing, a phase-difference PDS corresponding to a direct current remains. Generation and outputting of the phase-difference signal PDS in the phase-difference information generation unit **77** are continuously performed.
(87)

$$\mathrm{NPA} \times \mathrm{NPB} = A\sin(\omega t + \theta 1) \times B\sin(\omega t + \theta 2) = -\frac{A \times B}{2}\{\cos(2\omega t + \theta 1 + \theta 2) - \cos(\theta 1 - \theta 2)\} \quad \text{Equation3}$$

$$\mathrm{PDS} = \frac{A \times B}{2}\{\cos(\theta 1 - \theta 2)\} \quad \text{Equation4}$$

(88) In Equation 3, NPA represents the incident-wave signal (A sin(ωt+θ1)), and NPB represents the reflected-wave signal (B sin(ωt+θ2)). θ1 represents a phase of the incident-wave signal NPA, and θ2 represents a phase of the reflected-wave signal NPB.
(89) The phase-difference information generation unit **77** illustrated in FIG. **6** includes a first log amplifier **81** to which the incident-wave signal is input, a second log amplifier **82** to which the reflected-wave signal is input, a multiplier **83** (that is, a multiplier that outputs a result of multiplying signals before conversion through adding of logarithmic converted signals) in which the incident-wave signal output from the first log amplifier **81** and the reflected-wave signal output from the second log amplifier **82** are added and a filter unit **84** that performs the above-described filtering processing on an output signal of the multiplier **83**. The multiplier **83** adds the logarithmically converted incident-wave signal and the logarithmically converted reflected-wave signal (that is, multiplies the incident-wave signal and the reflected-wave signal). The filter unit **84** removes a double frequency component from the multiplication result. A low-pass filter can be used for the filter unit **84**. Note that the filter unit **84** may be a digital filter and is provided after AD converter.
(90) The control unit **78** is configured to repeatedly perform a control process. In the control process, a direction detection operation of detecting a direction of an oscillation frequency adjustment whereby a difference between the resonance frequency of the radiation antenna **22** and the oscillation frequency of the oscillator **21** is reduced based on the phase-difference signal and a frequency adjustment operation of adjusting the oscillation frequency based on the detection result of the direction detection operation are performed. The control unit **78** includes a detection unit **78***a* that performs the direction-detection operation, and a first command unit **78***b* and a second command unit **78***c* that perform the frequency adjustment operation.
(91) The control unit **78** can be constituted by, for example, a microcomputer. In this case, a control program is installed in the control unit **78**. The control unit **78** includes the detection unit **78***a*, the first command unit **78***b*, and the second command unit **78***c* as functional blocks realized by CPU executing and interpreting the control program. Note that the control unit **78** may be configured by an analog circuit.
(92) The control process of the control unit **78** will be described with reference to the flowchart of FIG. **7**. In the flow chart, steps ST**1** to ST**3** correspond to the direction detection operation, and steps ST**4** to ST**6** correspond to the frequency adjustment operation. In addition, the control unit **78** repeats the control process of the flowchart at a predetermined control cycle S. The control period S is set to be 50 ms or less.
(93) A phase-difference signal is continuously inputted to the detection unit **78***a* via an AD converter. In a step ST**1**, the detection unit **78***a* performs a normalization processing or the like on the digitally

converted phase-difference signal to detect the voltage value of the phase-difference signal as the phase-difference voltage V at a sampling period equal to the control period S, for example. In the step ST**2**, the detection unit **78***a* determines whether or not the phase-difference voltage V is lower than the lower limit −Vc of a threshold range (−Vc to Vc) as a first comparison operation of comparing the threshold range including a threshold (voltage=0) with the phase-difference voltage V. The threshold range corresponds to the reference information in a state in which the incident-wave phase and the reflected-wave phase are equal to each other.
(94) Here, in FIG. **8**, a first graph G**1** representing changes of the phase-difference voltage V with respect to frequency and a second graph G**2** representing changes of the reflected-wave intensity with respect to frequency are described in an overlapping manner. The first graph G**1** indicates that the phase-difference voltage V becomes smaller than zero in a lower frequency range fb where the oscillation frequency is smaller than the resonance frequency f.sub.0, the phase-difference voltage V becomes larger than zero in a upper frequency range f.sub.e where the oscillation frequency is larger than the resonance frequency f.sub.0, and the phase-difference voltage V becomes zero at a frequency at which the oscillation frequency is equal to the resonance frequency f.sub.0 (that is, at a frequency at which impedance matching is achieved in the radiation antenna **22**).
(95) When the phase-difference voltage V is lower than the lower limit −Vc of the threshold range in a step ST**2**, the oscillation frequency is in the lower frequency range fb smaller than the resonant frequency f.sub.0. In this case, the process proceeds to a step ST**4**, and the first command unit **78***b* that has received a command from the detection unit **78***a* outputs ON signal to the first switching SW**1** as the frequency adjustment operation. At this time, if the second switch SW**2** is ON, the detection unit **78***a* causes the second command unit **78***c* to switch the second switch OFF. As a result, the voltage regulation circuit **21***c* switches to the first state, and the control voltage to the voltage variable oscillator **21***a* gradually increases. Consequently, the oscillation frequency of the oscillator **21** gradually increases and approaches the resonant frequency f.sub.0. After the step ST**4** is executed, the process returns to the step ST**1**.
(96) On the other hand, when the phase-difference voltage V does not fall below the lower limit value −Vc of the threshold range in the step ST**2**, the process proceeds to a step ST**3**, and the detection unit **78***a* determines, as the second comparison operation, whether or not the phase-difference voltage V exceeds the upper limit value Vc of the threshold range. When the phase-difference voltage V exceeds the upper limit Vc of the threshold range in the step ST**3**, the oscillation frequency is in the upper frequency range f.sub.e larger than the resonant frequency f.sub.0. Then, the process proceeds to the step ST**5**, and the second command unit **78***c* that has received a command from the detection unit **78***a* outputs ON signal to the second switching SW**2** as the frequency adjustment operation. At this time, if the first switch SW**1** is ON, the detection unit **78***a* causes the first command unit **78***b* to switch the first switch OFF. As a result, the voltage regulation circuit **21***c* switches to the second state, and the control voltage to the voltage variable oscillator **21***a* gradually decreases. Consequently, the oscillation frequency of the oscillator **21** gradually decreases and approaches the resonant frequency f.sub.0. After the step ST**5** is executed, the process returns to the step ST**1**.
(97) When the phase-difference voltage V does not exceed the upper limit Vc of the threshold range in the step ST**3**, the phase-difference voltage V is within the threshold range. In this case, the process proceeds to the step ST**6**, and the detection unit **78***a* causes the first command unit **78***b* to switch the first switch SW**1** to OFF when the first switch SW**1** is ON, and causes the second command unit **78***c* to switch the second switch SW**2** to OFF when the second switch SW**2** is ON. As a result, the voltage regulation circuit **21***c* switches to the third state, and the control voltage becomes constant. Consequently, the oscillation frequency of the voltage variable oscillator **21***a* is held at a current value. After the step ST**6** is executed, the process returns to the step ST**1**.
(98) Referring to FIG. **9**, a manner in which the oscillation frequency follows the resonance frequency f.sub.0 will be described. In the following description, the process starting from the step ST**1** and returning to the first step ST**1** will be referred to as “n-th process” as one unit.
(99) At the time of a first process, it is assumed that the oscillation frequency is f.sub.A (see FIG.

**9**A). When the first process is performed in this condition, the phase difference-voltage becomes the value on the vertical axis of a detecting point A, and it is detected that the phase-difference voltage is lower than the lower limit value −Vc. Therefore, the voltage regulation circuit **21***c* is switched to the first state (only the first switch SW**1** is in ON state), and the oscillation frequency gradually increases and approaches the resonance frequency f.sub.0.
(100) At the time of a second process, it is assumed that the oscillation frequency is f.sub.B (see FIG. **9**B). When the second process is performed in this condition, it is detected that the retardation voltage remains lower than the lower limit value −Vc. The voltage regulation circuit **21***c* is maintained in the first state, and the oscillation frequency further approaches the resonant frequency f.sub.0. At the time of a third process, it is assumed that the oscillation frequency is fc (see FIG. **9**C). When the third process is performed in this condition, it is detected that the phase-difference voltage is between the upper limit value Vc and the lower limit value −Vc. In this case, the voltage regulation circuit **21***c* is switched to the third state (both the switching SW**1**, SW**2** are in OFF state), and the oscillation frequency is held.
(101) From this condition, as shown in FIG. **9**D, it is assumed that the resonant frequency f.sub.0 is reduced due to an influence of the object to be heated **20** or the like (assuming that the graphical G**1**, G**2** is moved leftward). The oscillator frequency remains at f.sub.C. When a fourth process is performed in this condition, the phase-difference voltage becomes the value on the vertical axis of a detected point C′, and it is detected that the phase-difference voltage exceeds the upper limit value Vc. Therefore, the voltage regulation circuit **21***c* is switched to the second state (only the second switch SW**2** is in ON state), and the oscillation frequency gradually decreases and approaches the resonance frequency fo.
(102) At the time of a fifth process, it is assumed that the oscillation frequency is f.sub.D (see FIG. **9**E). When the fifth process is performed in this condition, it is detected that the phase difference remains above the upper limit Vc. The voltage regulation circuit **21***c* is maintained at the second state, and the oscillation frequency further approaches the resonant frequency f.sub.0. At the time of a sixth process, it is assumed that the oscillation frequency is f.sub.E(see FIG. **9**F). When the sixth process is performed in this condition, the voltage regulation circuit **21***c* is switched to the third state and the oscillation frequency is held in the same manner as the third process. In this way, in the control process, the oscillation frequency is adjusted so as to follow the resonant frequency f.sub.0.
Effect of the Present Embodiment
(103) In the present embodiment, resonances of high-frequencies occur in the respective tooth portion **31***a*, **32***a* of the radiation antennae **22** during the input period of high-frequency. The strong-electric-field region formed along a large number of tooth portion **31***a*, **32***a* have relatively high electric field strength. According to the present embodiment, it is possible to form the strong-electric-field region at a level at which a high-frequency is easily absorbed by the object to be heated **20** with low power as compared with the case where no resonance occurs.
(104) In the present embodiment, the distance G between the tooth portions **31***a*, **32***a* adjacent to each other in the first direction is not more than five times the line width of the tooth portions **31***a*, **32***a*. Therefore, relatively strong-electric-field couplings occur between adjacent tooth portions **31***a*, **32***a*. Further, in the tooth portion **31***a* and the tooth portion **32***a* which are adjacent to each other, the leading end which becomes an abdomen portion of the standing wave and the root which becomes a node portion of the standing wave are close to each other. Therefore, the electric field strength in the gap between the adjacent tooth portions **31***a*, **32***a* is relatively high. In the arrangement region of the large number of tooth portions **31***a*, **32***a*, the area of the strong-electric-field region is increased, and the strong-electric-field region parallel to the object to be heated **20** and having a small thickness is formed.
(105) Here, when the object to be heated **20** is in the form of a sheet or a film and the surface area is large for its volume, the amount of heat radiation during high-frequency heating is large and it is not easy to raise the temperature of the object to be heated **20**. In the present embodiment, in the arrangement region of the large number of tooth portions **31***a*,**32***a*, the strong-electric-field region is

formed which is parallel to the object to be heated **20** and has a small thickness. In this strong-electric-field region, since many electric force lines are parallel to the object to be heated **20** with sheet-like or film-like shape, high-frequency energy can be concentrated on the object to be heated **20** and the object to be heated **20** can be efficiently heated and physical/chemical reactions can be generated. Further, in the arrangement region of the tooth portions **31***a*, **32***a*, the electric field strength is relatively high even in the gap between the adjacent tooth portions **31***a*, **32***a*, it is possible to continuously heat the object to be heated **20** and therefore and to effectively raise the temperature of the object to be heated **20** having a large surface area for its volume.
(106) Further, in the present embodiment, the tooth portions **31***a* in which the abdomen of the standing wave of high-frequency is formed on one end side in the widthwise direction in the arrangement region (band-shaped region) of the large number of tooth portions **31***a*, **32***a*, and the tooth portions **32***a* in which the abdomen of the standing wave is formed on the other end side are alternately arranged. Thus, in the radiation antenna **22** where four or more tooth portions **31***a*, **32***a* are arranged with a gap in a predetermined direction, two or more strong-electric-field rows in which the strong-electric-field portions of the respective tooth portions **31***a*, **32***a* serving as the abdomen of the standing wave are aligned in the first direction are formed (in the present embodiment, two rows are formed). Therefore, a strong electric field acts on the object to be heated **20** from both sides in the width direction, and the degree of heating of the object to be heated **20** in a plan view can be made uniform.
(107) In the present embodiment, since the input part **30** is provided on the back side of the substrate **23**, even when the base material **11** is wide, the input part **30** is not covered with the base material **11**, and access to the input part **30** is easy.
(108) Here, in the electromagnetic-wave heating device, it is necessary to take measures to prevent leakage of electromagnetic waves. In the electromagnetic-wave heating device, by providing an introduction portion and a lead-out portion on a shield unit that shields an internal space in which a radiation antenna is disposed from the outside, it is possible for a conveyed object including an object to be heated (for example, an adhesive) to continuously pass through the internal space of the shield unit. Then, by continuous processing, it is possible to heat many objects to be heated in a short time. However, in the case of an device (for example, the device described in JP-A-57-118281) in which an entire conveyed object from an introduction portion toward a lead-out portion passes through an internal space of a shield unit, even when an object to be heated is small with respect to the conveyed object, it is necessary to secure the size of the shield unit.
(109) In contrast, in the present embodiment, the continuous gap **70** in which the side gaps **73** and **74** are connected to each of the introduction portion **71** and the lead-out portion **72** is formed in the shield unit **60**. Therefore, not only the base material **11** having a narrow width shown in FIG. **1** but also the base material **11** having such a size that it protrudes outward from the side gaps **73** and **74** as shown in FIG. **5**A can convey the base material **11** from the introduction portion **71** toward the lead-out portion **72**. At this time, in the internal space **40**, the object to be heated **20** can be subjected to heat treatment in the facing region (strong-electric-field region) of the radiation antenna **22**. Therefore, it is not necessary to increase the size of the shield unit **60** so that the entire base material **11** can pass through the internal space **40**, and the shield unit **60** and the electromagnetic-wave heating device **10** can be made compact. The present embodiment is useful in the case, for example, where the object to be heated **20** is provided only in a part of a conveyed large-sized object **11**.
(110) Note that, in FIG. **5**A, a portion of the cover **50** upper than the shield member **46** is not shown. The same applies to FIGS. **5**B, **16**A to **16**C, **17**A to **17**C and **18**. The white arrows indicate the wind direction of the air supplied from the blower **35** to the object to be heated **20**.
(111) For example, when an adhesive applied to the mouth portion of each of a plurality of envelopes is heated, the plurality of envelopes is conveyed by the base material **11** so that the vertical direction of the envelopes is aligned in the width direction of the base material **11** and the adhesive applied regions in the plurality of envelopes are aligned in a row. In this case, it is not necessary to secure the size of the internal space **40** of the shield unit **60** by the vertical length of the envelope. The shield

unit **60** may be sized to match the adhesive applied area.

(112) In the present embodiment, by using a semiconductor oscillator for the oscillator **21**, the oscillator **21** can be operated with lower power than when a magnetron is used. As a result, the radiation intensity of the high-frequency can be suppressed low. Further, in the present embodiment, a choke structure **55** is provided so as to face the continuous gap **70**. Here, in a microwave oven that uses a magnetron, even if a choke structure is provided, a gap cannot be provided around the door. On the other hand, in the present embodiment, by using the high-frequency resonance structure (radiation antenna **22**) and the semiconductor oscillator, the radiation intensity of high-frequency can be suppressed low, and the high-frequency toward the continuous gap **70** becomes weak. Therefore, even if the continuous gap **70** through which the base material (thin material) **11** passes is provided, leakage of the high-frequency can sufficiently be suppressed. Further, in the present embodiment, as the size of the radiation antenna **22** is reduced in accordance with the size of the object to be heated **20**, and as the high-frequency is matched (absorbed) with the object to be heated **20**, the excess high-frequency is reduced, and therefore, the dimensional accuracy required for the continuous gap **70** passing through the base material **11** (thin object) is reduced in response to the request for suppression of the high-frequency leakage.

(113) In the present embodiment, since the blower **35** is provided, when the object to be heated **20** is dried by heating, the organic solvent or moisture evaporated from the object to be heated **20** can be discharged to the outside of the shield unit **60**. In addition, since the internal space **40** is constantly ventilated with dry air having no or little evaporative gas component, the mass transfer (evaporation) rate of the evaporative gas component in the object to be heated **20** to dry air is maintained. According to the present embodiment, when the electromagnetic-wave heating device **10** is used as a drying apparatus, the object to be heated **20** can be dried efficiently.

(114) In the present embodiment, since the blowing direction of the blower **35** faces the downstream side in the first direction, the air in the internal space **40** is discharged to the outside from the lead-out portion **72** or the side gaps **73** and **74**. The air in the internal space **40** is hardly discharged from the introduction portion **71**. Therefore, it is possible to prevent the exhaust gas from the shield unit **60** from reaching upstream devices.

(115) In the present embodiment, the shield member **46** that passes air and shields a high-frequency is provided in the blowing passage **45** in the cover **50**. Thus, the high-frequency hardly reaches the blower **35**. Furthermore, high-frequency leakage through the air inlet of the blowing passage **45** can be suppressed.

(116) According to the present embodiment, a phase-difference information representing a phase difference between the incident wave and the reflected wave is generated by arithmetic processing utilizing incident-wave information and reflected-wave information. Then, the control process of detecting the adjustment direction of the oscillation frequency based on the phase-difference signal and reference information (threshold range) and controlling the oscillation frequency based on the detection result is repeatedly performed, whereby the oscillation frequency follows the resonance frequency f.sub.0. Here, the above-described arithmetic processing can be performed at a high speed. That is, generation of the phase-difference information can be performed at a high speed. Further, since numerical data of the reference information can be prepared in advance, the adjustment direction of the oscillation frequency can also be detected at a high speed. According to the present embodiment, it is possible to make the oscillation frequency follow the resonance frequency at a high speed.

(117) Hence, in the processing system of the present embodiment, the object to be heated **20** is heated in the conveyance path while the object to be heated **20** is being conveyed. In this case, the resonant frequency f.sub.0 is sequentially changed by the presence or absence of the object to be heated **20**, a temporal change in the water content in the object to be heated **20**, steam generated by the heating or the like. Specifically, the object to be heated **20** is small in weight and lightly loaded, and the resonance frequency f.sub.0 changes successively within the resonance mode even in an environment in which the resonance specific mode is maintained in the internal space **40**. For example, since a

high-frequency is applied to the object to be heated **20** and the relative permittivity decreases with the rise of temperature and the drying of the object to be heated **20**, the resonant frequency f.sub.0 transitions.
(118) Here, the proportion of the high-frequency energy absorbed by the object to be heated **20** (hereinafter, referred to as “high-frequency energy absorptivity”) is maximized at the time of the resonant frequency f.sub.0. However, when the resonance frequency f.sub.0 changes successively, it is difficult conventionally to make the oscillation frequency follow the resonance frequency f.sub.0 at a high speed and therefore keep the high-frequency energy absorptivity at a high value. In addition, the high-frequency is easily leaked into an open space.
(119) On the other hand, in the present embodiment, since the oscillation frequency can be made to follow the resonance frequency f.sub.0 at a high speed, even when the object to be heated **20** is heated by the conveyance type mechanism, the high-frequency energy absorptivity can be maintained at a high value, and further, the high-frequency leakage can be suppressed.
(120) Incidentally, the inventor of the present application has confirmed by an experiment of the control period 30 ms that (i) when fixing the oscillation frequency, immediately after the power supply of the electromagnetic-wave heating device **10** is ON, in particular high-frequency energy absorptivity decreases, and (ii) by performing the above-described frequency control from a point of time when the power supply of the electromagnetic-wave heating device **10** is ON, the high-frequency energy absorptivity is greatly improved from the point of time of ON.
(121) Modification 1 of the Embodiment relating to Frequency Control
(122) Modification 1-1
(123) In this modification, the control unit **78** detects a shift direction (deviation direction) of the oscillation frequency with respect to the resonance frequency by utilizing the reference information and the phase-difference information, and performs an averaging processing on the detection result, thereby detecting an adjustment direction of the oscillation frequency. The averaging processing is performed on a result of the comparison operation that compares the threshold range (−Vc to Vc) with the phase difference V. Hereinafter, with reference to FIG. **10**, description will be given focusing on differences from the embodiment.
(124) In the present modification, when the phase-difference voltage V falls below the lower limit value −Vc of the threshold range in the first comparison operation, the detection unit **78***a* determines that the phase-difference voltage V is deviated in the negative direction and records the determination result (−X). Further, when the phase-difference voltage V exceeds the upper limit value Vc of the threshold range in the second comparison operation, it is determined that the phase-difference voltage V is deviated in the positive direction, and the determination result (+X) is recorded. Further, when the phase-difference voltage V does not exceed the upper limit value Vc of the threshold value range in the second comparison operation, it is determined that there is no phase shift, and the determination result (±0) is recorded.
(125) The detection unit **78***a* performs an averaging processing of averaging the results of determining comparison operations arranged in time series with predetermined number of samples n of the comparison results. Equation 5 is an exemplary Equation used in the averaging processing for the m-th determination result D(m) to the (m+n−1)-th determination result D(m+n−1). Y represents a calculated value of the averaging processing.
(126) $Y = \frac{\{D(m) + D(m+1) + D(m+2) \text{ .Math. } + D(m+n-1)\}}{n}$ Equation5
(127) When the calculated value Y of the averaging processing is negative, the detection unit **78***a* causes the first command unit **78***b* to output a ON signal to the first switching SW**1**. When the calculated value Y is positive, the detection unit **78***a* causes the second command unit **78***c* to output a ON signal to the second switching SW**2**. In FIG. **10**, the graph G**3** representing the time-series changes of the phase-difference voltage V and the graph G**4** representing the time-series changes of the determination result of the comparison operation and the graph G**5** representing the time-series changes of the calculated value Y are superimposed on each other. According to the present

modification example, noise can be removed by the averaging processing, and thus the tracking accuracy of the oscillation frequency is improved. Therefore, the high-frequency energy absorptivity increases, and the power required for heating can be reduced.
(128) In this modification, a comparison target of the calculated value Y of the averaging processing may be the threshold range. The detection unit **78***a* causes to output a ON signal to the first switch SW**1** when the calculated value Y is lower than the lower limit value −Vc of the threshold range and causes to output a ON signal to the second switch SW**2** when the calculated value Y is higher than the upper limit value Vc of the threshold range. In this case, since noise can be removed as compared with the case where the calculated value Y is compared with the threshold value (V=0), power required for heating can be reduced.
(129) Further, the control unit **78** may adjust the number of samples n of the detection results used in the averaging processing based on the conveyance speed of the object to be heated **20**. When the conveyance speed is high, the resonant frequency f.sub.0 varies finely. Therefore, the higher the conveyance speed is, the smaller the number-of-samples n is made, so that finer follow-up control is performed. Note that the control period S may be adjusted based on the conveyance speed, and the more the control period S may be increased for noise removal, the higher the conveyance speed is.
(130) Modification 1-2
(131) In the present modification, the control unit **78** detects an adjustment amount (or a deviation amount) of the oscillation frequency in addition to the adjustment direction of the oscillation frequency based on the reference information and the phase-difference information. In this case, the adjustment amount of the oscillation frequency can be detected based on the magnitude of the phase-difference voltage V (the difference between the phase-difference information and the reference information). For example, the larger the difference between the phase-difference voltage V and zero, the smaller the adjustment amount of the oscillation frequency. In this modification, the control unit **78** adjusts the oscillation frequency in the adjustment direction in accordance with the adjustment amount, so that the oscillation frequency can be made to follow the resonance frequency f.sub.0 at a higher speed.
(132) Modification 1-3
(133) This modification differs from the embodiment in the configuration of the control device **75**.
(134) As shown in FIG. **11**, the oscillator **21** includes a voltage variable oscillator **21***a*, a synthesizer **21***d* provided after the voltage variable oscillator **21***a*, a quadrature modulator **21***e* provided after the synthesizer **21***d*, an amplifier **21***b* provided after the quadrature modulator **21***e* and a voltage regulation circuit **21***c*. In this modification, the voltage regulation circuitry **21***c* is comprised of DA converters.
(135) When a high-frequency f.sub.Vc0 is inputted from the voltage variable oscillator **21***a*, the synthesizer **21***d* outputs a high-frequency of which frequency f(f=f.sub.Vc0+R) is obtained by adding the register value R to the frequency f.sub.Vc0. The synthesizer **21***d* is provided with a register (not shown) for recording and updating the register R. In the present modification, the oscillation frequency of the oscillator **21** is a frequency of the high-frequency outputted from the synthesizer **21***d*.
(136) Further, the quadrature modulator **21***e* modulates the high-frequency output from the synthesizer **21***d* into a first I component signal and a first Q component signal, and outputs the modulated signals to the amplifier **21***b*. The oscillator **21** outputs a quadrature-modulated high-frequency.
(137) The control device **75** includes a directional coupler **76**, a first quadrature demodulation unit **91**, a second quadrature demodulation unit **92** and a control unit **78**. The first quadrature demodulation unit **91** and the second quadrature demodulation unit **92** constitute the quadrature demodulation unit.
(138) The first quadrature demodulator **91** demodulates the incident-wave signal into the first I component signal and the first Q component signal. The second quadrature demodulator **92** demodulates the reflected-wave signal into a second I component signal and a second Q component

signal. Synchronization signals for synchronizing with the quadrature modulator **21***e* are inputted to the quadrature demodulators **91** and **92** from the synthesizer **21***d*.

(139) The control unit **78** is configured to repeatedly perform a control process. In the control process, information generation operation of generating phase-difference information representing a phase difference between an incident wave and a reflected wave on the basis of a demodulated incident-wave signal (the first I component signal and the first Q component signal) and a demodulated reflected-wave signal (the second I component signal and the second Q component signal), a direction detection operation of detecting an adjustment direction of an oscillation frequency in which the difference between the resonance frequency f.sub.0 and the oscillation frequency of the oscillator **21** in the radiation antenna **22** is reduced based on the phase-difference information and a frequency adjustment operation of adjusting the oscillation frequency based on the detection result of the direction detection operation are performed. The control unit **78** can be constituted by, for example, a microcomputer. A control program is installed in the control unit **78**. The control unit **78** includes a detection unit **87** and a command unit **88** as functional blocks realized by CPU executing and interpreting the control program.

(140) The detection unit **87** performs the information generation operation and the direction detection operation. The detection unit **87** also serves as the phase information generation unit. In the detection unit **87**, by the arithmetic processing utilizing the first I component signal and the first Q component signal, the second I component signal and the second Q component signal, a phase difference calculation value PDC representing the phase difference (θ1−θ2) of the incident wave and the reflected wave is calculated as the phase-difference information. Then, the adjustment direction of the oscillation frequency is detected based on the phase difference calculation PDC.

(141) For example, the detection unit **87** calculates an incident-wave information NPA and a reflected-wave information NPB by performing the arithmetic processing shown in Equation 6 and Equation 7, and then performs the calculation (complex division (multiplication of conjugate complex numbers)) shown in Equation 8 to calculate the phase difference calculation value PDC as a value obtained by dividing the reflected-wave information NPB with the incident-wave information NPA.

(142) In Equations 6 and 7, the first I component signal is represented by Acos(ωt+θ1), the first Q component signal is represented by Aisin(ωt+θ1), the second I component signal is represented by Bcos(ωt+θ2), and the second Q component signal is represented by Bisin(ωt+θ2). α=ωt+θ1 and R=ωt+θ2.

$$NPA=A\{\cos(\omega t+\theta 1)+i\sin(\omega t+\theta 1)\} \qquad \text{Equation 6}$$

$$NPB=B\{\cos(\omega t+\theta 2)+i\sin(\omega t+\theta 2)\} \qquad \text{Equation 7}$$

(143)
$$\begin{aligned} PDC &= NPB / NPA \\ &= \frac{B\{(\cos\alpha\cos\beta+\sin\alpha\sin\beta)+\ i(\sin\alpha\cos\beta-\cos\alpha\sin\beta)\}}{A\{\cos^2\alpha+\sin^2\alpha\}} \\ &= \frac{B\{(\cos(\alpha-\beta)+i\sin(\alpha-\beta)\}}{A} \\ &= \frac{B\{(\cos(\theta 1-\theta 2)+i\sin(\theta 1-\theta 2)\}}{A} \end{aligned} \qquad \text{Equation8}$$

(144) The operation of the control unit **78** will be described with reference to the flowchart of FIG. **12**. In the present modification, before the conveyance of the object to be heated **20** is started, a search control is performed to search for a band in which reflected-wave intensity is lower than a predetermined determination level k within a frequency band (hereinafter, referred to as an “oscillatable band”) in which the oscillator **21** can oscillate, and then frequency control is performed.

(145) Search Control

(146) FIG. **12**A is a flowchart of the search control. In the search control, in a step ST**11**, the control unit **78** sets an initial-frequency fi (for example, a lower limit of the oscillatable band) of the oscillator **21**, and starts oscillation of a high-frequency by the oscillator **21**. Next, in a step ST**12**, the controller **78** causes the oscillator **21** to perform a frequency-sweep. A bandwidth (fi to fi+Δf) over which frequency-sweep takes place is equal to an initial value of the resister value R.

(147) Here, during a period in which a high-frequency is oscillated from the oscillator **21**, the first I component signal and the first Q component signal demodulated by the first quadrature demodulating unit **91**, and the second I component signal and the second Q component signal demodulated by the second quadrature demodulating unit **92** are inputted to the detection unit **87** as consecutive signals. In the detection unit **87**, each of the I component signals and the Q component signals is digitally converted.
(148) In a step ST**13**, the detection unit **87** calculates the phase difference calculation PDC by the calculation of Equations 6 to 8 at a predetermined calculation cycle during a period in which the frequency-sweep is performed. The calculated phase difference calculation PDC represents a coordinate value of the complex plane of the Smith-chart shown in FIG. **13**. A step ST**14** is performed after frequency-sweep has ended. In the step ST**14**, the detection unit **87** determines whether or not there is a coordinate value (a coordinate value on the center line P passing through the center point Po in the Smith-chart) in which an incident-wave phase θ**1** and a reflected-wave phase θ**2** are equal among coordinate values (hereinafter, referred to as “calculated coordinate values”) represented by a plurality of phase difference calculated values PDC calculated in the predetermined calculation cycle. In FIG. **13**, a region above the center line P is 0 to π/2, and a region below the center line P is −π/2 to 0.
(149) If there is no coordinate value in which the phase θ**1** and the phase θ**2** are equal in the step ST**14**, there is no resonant frequency f.sub.0 within the band in which the frequency-sweep is performed, and therefore, the process returns to the step ST**12** after adding a predetermined value Δf (the above-described bandwidth) to the resister value R in a step ST**15**. The resister value R is Δf×2. In the step ST**12**, the control unit **78** causes the oscillator **21** to perform the frequency-sweep in the upper band (f.sub.i+Δf to f.sub.i+Δf×2) adjacent to the band in which the frequency-sweep has performed immediately before.
(150) On the other hand, when there is a coordinate value in which the phase θ**1** and the phase θ**2** are equal in the step ST**14**, since there is the resonance frequency f.sub.0 within the band in which the frequency-sweep is performed, in a step ST**16**, the detection unit **87** determines whether or not the reflection coefficient B/A in the resonance frequency f.sub.0 in which the phase θ**1** and the phase θ**2** are equal is lower than a determination level k. The determination level k is stored in advance in the control unit **78**.
(151) When the reflection coefficient B/A does not fall below the determination level k in the step ST**16**, the reflected-wave intensity is not small in the resonance frequency f.sub.0 within the band where the frequency-sweep is performed, and therefore, the process returns to the step ST**12** after adding the predetermined value Δf to the resister value R in the step ST**15**. On the other hand, when the reflection coefficient B/A is lower than the determination level k in the step ST**16**, a band in which the reflected-wave intensity is small is found in the resonance frequency f.sub.0, and therefore, after detecting the resonance frequency f.sub.0 of the band in which the frequency-sweep has performed as a step ST**17**, the search control is terminated and the frequency control is started.
(152) Frequency Control
(153) FIG. **12**B is a flowchart of the control process configuring the frequency control. In the flow chart, a step ST**23** corresponds to the information generation operation, steps ST**26** to ST**27** correspond to the direction detection operation, and steps ST**28** to ST**29** correspond to the frequency adjustment operation.
(154) In the frequency control, in a step ST**21**, the power supply of the conveyance device **12** is switched ON, and the conveyance of the object to be heated **20** is started. Next, in a step ST**22**, the control unit **78** sets the oscillation frequency f of the oscillator **21** to the resonance frequency f.sub.0 detected in the step ST**17**. In the step ST**23**, the detection unit **87** calculates the phase difference calculation PDC by calculation of Equations 6 to 8 utilizing the first I component signal, the first Q component signal, the second I component signal and the second Q component signal at that time.
(155) Next, in the ST**24** of steps, the detection unit **87** determines whether or not the reflection coefficient B/A is lower than the determination level k. When the reflection coefficient B/A does not

fall below the determination level k in the step ST**24**, the predetermined value Δf is added to the resister value R in the step ST**25**, and then the process returns to the step ST**22**. This makes possible to move to another band when the reflected-wave strength in not small due to the variation of the resonant-frequency f.sub.0.
(156) On the other hand, when the reflection coefficient B/A is lower than the determination level k in the step ST**24**, in step ST**26**, the detection unit **87** determines whether or not the calculated coordinate value is in the positive phase (that is, whether or not θ**1**>θ**2**) as the first comparison operation of comparing the calculated coordinate value represented by the phase difference calculation PDC with the reference information representing the center line P of the Smith chart.
(157) When a condition θ**1**>θ**2** is satisfied in the step ST**26**, the calculated coordinate value (for example, position A in FIG. **13**) is in the range of 0 to π/2. Then, the process proceeds to the step ST**28**, and the command unit **88** increases the oscillation frequency by a predetermined addition frequency p (for example, p=1 MHz) via the voltage regulation circuit **21***c*. As a result, the oscillation frequency of the oscillator **21** approaches the resonant frequency f.sub.0. The phase calculation value A moves in the direction of the arrow. After the step ST**28** is executed, the process returns to the step ST**23**.
(158) On the other hand, when the condition θ**1**>θ**2** is not satisfied in the step ST**26**, the process proceeds to the step ST**27**, and the detection unit **87** determines whether or not the calculated coordinate value is in the range of −π/2 to 0 (that is, whether or not θ**1**<θ**2**) as the second comparison operation. When the condition θ**1**<θ**2** is satisfied in the step ST**27**, the calculated coordinate value (for example, position B in FIG. **13**) is in the range of −π/2 to 0. In this case, the process proceeds to the step ST**29**, and the command unit **88** reduces the oscillation frequency by a predetermined subtracting frequency q (for example, q=1 MHz) via the voltage regulation circuit **21***c*. As a result, the oscillation frequency of the oscillator **21** approaches the resonant frequency f.sub.0. The phase calculation value B moves in the direction of the arrow After the step ST**29** is executed, the process returns to the step ST**23**.
(159) When the condition θ**1**<θ**2** is not satisfied in the step ST**27**, the coordinate value is on the center line P. In this case, the process returns to the step ST**23**. The oscillation frequency is maintained at the same value.
(160) Effect of Modification 1-3
(161) According to the present modification, a phase-difference information representing a phase difference between the incident wave and the reflected wave is generated by digital arithmetic processing utilizing incident-wave information and reflected-wave information. Then, the control process of detecting an adjustment direction of the oscillation frequency based on the phase-difference signal and reference information (information of the center line P) and controlling the oscillation frequency based on the detection result is repeatedly performed, whereby the oscillation frequency follows the resonance frequency f.sub.0. Here, the above-described arithmetic processing can be performed at a high speed. Further, since numerical data of the reference information can be prepared in advance, the adjustment direction of the oscillation frequency can also be detected at a high speed. According to the present disclosure, it is possible to make the oscillation frequency follow the resonance frequency at a high speed.
(162) Modification 1-4
(163) This modification is a variation of Modification 1-3. In this modification, as shown in FIG. **14**, the quadrature demodulator includes one quadrature demodulator **91** and a changeover SW**3** that switches between a first period in which the incident-wave signal is input to the quadrature demodulator **91** from the directional coupler **76** and a second period in which the reflected-wave signal is input to the quadrature demodulator **91** from the directional coupler **76**. The changeover switch SW**3** is switched at a predetermined switching cycle by the control unit **78**. For example, the switching cycle is equal to or less than half of a generation cycle of the phase-difference information.
(164) In this modification, in the first half of the above-described step ST**23**, the changeover switch SW**3** is switched to a contact on the incident-wave signal side and it becomes the first period. In the

quadrature demodulator **91**, the incident-wave signal is demodulated into the first I component signal and the first Q component signal. In the second half of the step ST**23**, the changeover switch SW**3** is switched to a contact on the reflected-wave signal side, and it becomes the second time. In the quadrature demodulator **91**, the reflected-wave signal is demodulated into the second I component signal and the second Q component signal. Then, the detection unit **87** calculates the phase difference calculation PDC by arithmetic processing of Equations 6 to 8. According to this modification, the configuration of the quadrature demodulator can be simplified.
(165) Modification 1-5
(166) This modification is a variation of Modification 1-3. In this modification, as shown in FIG. **15**, a coupler **93** is provided in order to extract the incident-wave signal from the transmission line **16**, and an isolator **94** is provided in order to extract the reflected-wave signal from the transmission line **16**. The isolator **94** is a circulator type isolator.
(167) The incident-wave signal extracted by the coupler **93** is input to the control unit **78** without being demodulated. The control unit **78** detects the strength A of the incident-wave signal amplified by the amplifier **21***b* based on the incident-wave signal. The intensity A is used to calculate the above-described reflection coefficient B/A.
(168) The reflected-wave signal extracted by the isolator **94** is input to the quadrature demodulator **91** via the attenuator **95**. In the present modification, the quadrature demodulation unit is composed of one quadrature demodulator **91**. In the quadrature demodulator **91**, the reflected-wave signal is demodulated into the second I component signal and the second Q component signal. The second I component signal and the second Q component signal demodulated by the quadrature demodulator **91** are inputted to the control unit **78**.
(169) In the present modification, the control unit **78** is configured to generate phase-difference information by utilizing the incident-wave information (the incident-wave information derived from the oscillation information) of the phase at the output timing of the high-frequency of the oscillator **21**. Specifically, the control unit **78** performs the arithmetic processing of Equations 6 to 8 utilizing the first I component information and the first Q component information of the incident-wave information derived from the oscillation information, and the second I component information and the second Q component information demodulated by the quadrature demodulator **91**, and calculates the phase difference calculation value PDC. In the arithmetic processing, the control unit **78** corrects the phase shift of the incident-wave information with respect to the reflected-wave information before the arithmetic processing. By this correction, the phase deviation between the phase of the incident wave output from the oscillator **21** and the reflected-wave signal extracted by the isolator **94** is corrected.
(170) Modification 1-6
(171) In the present modification, the control unit **78** performs the above-described frequency control during an initial heating period in which the first object to be heated **20** passes through the strong-electric-field region, and sequentially records the adjustment history of the oscillation frequency (adjustment direction in each control process) in the memory as the control history information of the frequency control, and performs the frequency control utilizing the control history information recorded in the memory during the period in which the object to be heated **20** passing through the strong-electric-field region is heated after the recording.
(172) As the control history information, the history of the resonant frequency f.sub.0 calculated from the phase-difference information and the oscillation frequency, or the history of the oscillation frequency (e.g., voltage information indicating the frequency) of the oscillator **21** may be recorded. Further, in the frequency control utilizing the control history information, the oscillation frequency of the history information may be applied as it is, but a frequency obtained by correcting the oscillation frequency of the history information utilizing the phase-difference voltage V sequentially detected by the detection unit **78***a* may be given to the oscillator **21**.
(173) Further, an object detection sensor (for example, a light receiving element or an imaging element) for detecting the presence or absence of the object to be heated **20** may be provided in the

internal space **40**, and the control history information may be recorded together with time elapsed information from a heating start time of the object to be heated **20** (for example, a time at which the object to be heated **20** reaches a position upstream of the radiation antenna **22**). In the frequency control utilizing the control history information, the object detection sensor detects a heating start timing of the next object to be heated **20**, and the frequency control is started from the detection timing.

(174) Modification 1-7

(175) In this modification, in order to correct the phase shift due to a floating reactance generated in the radiation antenna **22**, phase modulation may be performed on the high-frequency oscillated from the oscillator **21** by an amount of a correction phase angle for correcting a difference between a frequency at which the reflection coefficient (reflected-wave power) indicates a minimum value and a frequency at a phase angle of 0°, in the stage of setting the electromagnetic-wave heating device **10**. Thus, the electromagnetic-wave heating device **10** can be shipped in a state in which the minimum value of the resonance impedance in the reflected-wave signal demodulated by the demodulation unit is matched with the phase angle of 0°.

(176) Modification 1-8

(177) In the present modification, each object to be heated **20** is ink printed on the base material **11**, and the control unit **78** detects the amount of ink of each object to be heated **20** utilizing, for example, a measured value of a light-receiving sensor using a light-receiving element. The amount of ink can be detected with, for example, an integrated value (integrated value of the amount of light) of the measured value of the light-receiving sensor in the passage period of the object to be heated **20**.

(178) The control unit **78** controls the output of the oscillator **21** based on the detection-value VI of ink amount. Here, by utilizing the phase-difference information, the amount of high-frequency energy P absorbed by the object to be heated **20** per unit time can be estimated. The control unit **78** estimates the high-frequency-energy-quantity Pt absorbed by the object to be heated **20** by integrating the phase-difference information over the elapsed time from the start of heating of the object **20**. Then, by comparing the detection value VI of ink amount with the high-frequency energy-amount Pt, the output of the oscillator **21** is increased or decreased.

(179) For example, the output of the oscillator **21** can be stopped at a timing when the calculated value T of Equation 9 exceeds a predetermined drying threshold value, and the output of the oscillator **21** can be adjusted so that the calculated value T becomes the drying threshold value at a timing when the object to be heated **20** reaches the downstream end of the radiation antenna **22**. In Equation 9, K is a drying coefficient that is set according to the object to be heated **20**.

$T=(Pt\times K/VI)$ Equation 9

(180) Note that a measured value of a humidity sensor that detects the humidity of the air in the internal space **40** or the air discharged from the internal space **40** may be used for the output control of the oscillator **21**. When the measured humidity by the humidity sensor is higher than the predetermined value, the control unit **78** determines that drying of the object to be heated **20** is proceeding early, decreases the output of the oscillator **21**, and when the measured humidity by the humidity sensor is lower than the predetermined value, determines that drying of the object to be heated **20** is delayed, and increases the output of the oscillator **21**.

(181) Other Modifications on Frequency Control

(182) In the above-described embodiments and modifications (hereinafter, referred to as "embodiments and the like"), the control unit **78** estimates a heating progress degree of the object to be heated **20** with respect to a target heating condition of the object to be heated **20**, and adjusts the width of the threshold-range (−Vc to Vc) based on the estimation result. In this case, the heating progress degree of the object to be heated **20** can be calculated as an estimated value by utilizing the integrated value of the measured values by the humidity sensor, the high-frequency energy amount Pt absorbed by the object to be heated **20**, the detected amount VI of ink and the like. The target heating condition of the object to be heated **20** can be prepared as a threshold value in advance. In addition, when the estimated value of heating progress degree of the object to be heated **20** is small, it may be

determined that it is not a band in which the reflected-wave intensity is small, and move to another band is executed.
(183) In the above-described embodiment and the like, when the object to be heated **20** is ink printed by a printer, the control unit **78** may use the print pattern information of the object **20** to adjust the control parameter of the control process. For example, depending on the resolution of the print pattern, the control period S, the width of the threshold-range (−Vc to Vc) or the number of samples n for averaging processing can be increased or decreased. When the resolution is high, the resonant frequency f.sub.0 may vary finely, so that the higher the resolution, the shorter the control period S, the narrower the width of the threshold-range, and the smaller the number of samples n.
(184) Modification 2 of the Embodiment Relating to the Shield Unit
(185) Modification 2-1
(186) In the present modification, as shown in FIG. **16**A, the spiral direction of the cavity of the choke structure **55** is opposite to that of FIG. **5** described above.
(187) Modification 2-2
(188) In the present modification, the choke structure **55** is a straight choke groove in a cross-sectional view, as shown in FIG. **16**B.
(189) Modification 2-3
(190) In the present modification, as shown in FIG. **16**C, the height of the outer peripheral portion **52** is about half of that of the above-described embodiment. Further, the shape of the cavity in the choke structure **55** in a cross-sectional view extends straight outward from an opening facing the flat region **27**.
(191) Modification 2-4
(192) In this modification, as shown in FIG. **17**A, the choke structure **56** is provided on the substrate **23** side instead of the cover **50**.
(193) Modification 2-5
(194) In the present modification, as shown in FIG. **17**B, the choke structures **55** and **56** are provided on the cover **50** and the substrate **23**, respectively.
(195) Modification 2-6
(196) In this modification, as shown in FIG. **17**C, the radiation antenna **22** is provided and supported on the cover **50** side. The radiation antenna **22** is electrically insulated from the cover **50** and is suspended by a support member (not shown). The radiation antenna **22** is disposed at the outlet of the blowing passage **45**. In the present modification, since air passes through the radiation antenna **22** that generate heat by energization and the air receives heat, the drying efficiency can be improved in the drying step.
(197) Modification 2-7
(198) In this modification, as shown in FIG. **18**, a plurality of slits **59** are provided in the choke structure **55** of the cover **50**. The distance between the plurality of adjacent slits **59** may be, for example, about one-twentieth of the electric length λ. By providing the slits **59**, high-frequency leakage can be effectively suppressed, for example, when a plurality of modes occurs in the internal space. In FIG. **18**, through-holes **46***a* of the shield member **46** is omitted.
(199) Modification 2-8
(200) In this modification, as shown in FIG. **19**, the electromagnetic-wave heating device **10** includes a waste heat utilization unit **90** that heats the air supplied to the object to be heated **20** by the blower **35** by utilizing the waste heat of the oscillator **21**. The waste heat utilization unit **90** includes a heat dissipation unit **111** that dissipates heat generated in the oscillator **21** during operation, a case **112**, with an inlet for introducing air from the outside, accommodating the heat dissipation unit **111** and a connection flow path **113** for supplying the air in the case **112** to the duct portion **53**. The heat dissipation unit **111** is, for example, a plurality of heat dissipation fins. A blower (not shown) is provided in the connection flow path **113**. Note that the connection flow path **113** may be connected to the suction port of the blower **35** so that air can be sent from the case **112** to the duct portion **53** side by using negative pressure.

(201) Modification 2-9
(202) In the present modification, the choke structure **55** can be continuously provided over the circumferential direction of the cover **50** in a plan view, as shown in FIGS. **20**A and **20**B.
(203) In FIG. **20**B, the width of the choke structure **55** is partially different in the circumferential direction, and the choke structure **55** in a plan view is constituted by a narrow portion **55***a* and a wide portion **55***b* having a wider width than the narrow portion **55***a*. As described above, by partially varying the width of the choke structure **55**, the resonance frequency and the resonance point can be adjusted. This makes it possible to design the choke structure **55** so that, for example, resonance does not occur at a corner portion of the choke structure **55** in a plan view.
(204) In addition, as shown in FIG. **20**C, the choke structure **55** in a plan view may be constituted by a plurality of choke portion **55***c*, **55***d* which are interrupted in the middle. In FIG. **20**C, the choke structure **55** is constituted by a first choke portion **55***c* having an I-shape in a plan view and a second choke portion **55***d* having a U-shape in a plan view. The lengths of the respective choke portions **55***c*, **55***d* are designed to be $\lambda \times n/2$ (n is a natural number). $\lambda$ is the electric length of high frequency in the choke portion **55***c*, **55***d*.
(205) Other Modifications of the Shield Unit
(206) In the above-described embodiment and the like, the upper partition portion may be the substrate **23** and the lower partition portion may be the cover **50**. That is, the electromagnetic-wave heating device **10** according to the embodiment may vertically be inverted.
(207) In the above-described embodiment and the like, as shown in FIGS. **21**A and **21**B, one of the above-described side gaps **73** and **74** may serve as an introduction portion of the base material (conveyed object) **11** including the object to be heated **20**, and the other may serve as a lead-out portion. In this case, in the internal space of the shield unit **60**, the base material **11** is conveyed from the side gap (introduction portion) **73** toward the side gap (lead-out portion) **74** by the conveyance mechanism **12** so that the object to be heated **20** passes through the facing region of the radiation antenna **22**. The blower **35** supplies air to the object to be heated **20** conveyed through the internal space.
(208) Modification 3 of the Embodiment Relating to the Structure for Forming Strong-Electric-Field Region
(209) Modification 3-1
(210) In this modification, the substrate **23** includes a dielectric layer **24** exposed on the surface of the substrate **23** and a ground electrode layer **25** superimposed on the back surface of the dielectric layer **24**. The substrate **23** is provided with an input part **30** to which a high-frequency from the oscillator **21** is input. The radiation antenna **22** is connected to the input **30**. In the radiation antenna **22**, an input location (power supply location) X of the high-frequency from the oscillator **21** is located outside the passing region of the object to be heated **20** conveyed by the conveyance mechanism **12**.
(211) As shown in FIG. **22**, the radiation antenna **22** includes a first comb-teeth electrode **31** to which a high-frequency input to the input part **30** is supplied, and a second comb-teeth electrode **32** electrically connected to a ground electrode layer **25**. The first comb-teeth electrode **31** is a high-pressure-side electrode and has a plurality of tooth portions **31***a*. The second comb-teeth electrode **32** is a ground-side electrode and has a plurality of tooth portions **32***a*. The first comb-teeth electrode **31** and the second comb-teeth electrode **32** are arranged in the same plane such that the respective tooth portions **31***a*, **32***a* are meshed with each other with a gap therebetween. The plurality of tooth portions **31***a*, **32***a* are provided perpendicularly to the base line **31***b*,**32***b*.
(212) Here, each tooth portion **31***a* of the first comb-teeth electrode **31** and each tooth portion **32***a* of the second comb-teeth electrode **32** correspond to the conductive line according to the present disclosure. The respective tooth portions **31***a*, **32***a* are linear conductive lines. In the radiation antennae **22**, a large number of tooth portions **31***a*,**32***a* are arranged with a gap therebetween in a predetermined direction (the first direction). In the radiation antenna **22**, a high-frequency from the input part **30** is supplied to the first comb-teeth electrode **31** which is a part of a large number of conductive lines. In the radiation antenna **22**, a strong-electric-field area for heating the object to be

heated **20** is formed along a large number of tooth portions **31***a*, **32***a* during an input period in which a high-frequency is input to the input part **30**.
(213) Note that in the present specification, "large number" means 5 or more. However, the number of tooth portions (conductive line) **31***a*, **32***a* arranged with a gap in a predetermined direction may be three or more. Further, as in the radiation antenna **22** shown in FIG. **22**, the respective comb-teeth electrodes **31** and **32** may have a large number of (five or more) tooth portions **31***a*,**32***a*, and the total number of tooth portions **31***a*,**32***a* may be 10 or more.
(214) Further, in the present embodiment, a high-frequency is directly supplied to every other conductive line of many conductive lines constituting the radiation antenna **22**, the high-frequency may be directly supplied to every three conductive lines.
(215) The comb-teeth electrodes **31** and **32** shown in FIG. **24** will be described in detail. The first comb electrode **31** is supported on the surface of the dielectric layer **24**. The first comb-teeth electrode **31** includes a base line **31***b* extending from the input part **30** side, and a large number of tooth portions **31***a* whose roots are connected to the base line **31***b*. The base line **31***b* is connected to a conductive line extending in the second direction from the input part **30** and extends straight in the first direction from the input location X located at a bent portion. The large number of tooth portions **31***a* protrude from the base line **31***b* so as to be parallel to each other. The large number of tooth portions **31***a* are arranged at equal intervals in the first direction. The tooth portions **31***a* extend in the second direction along the surface of the dielectric layers **24** and are perpendicular to the base line **31***b*.
(216) The second comb electrode **31** is also supported on the surface of the dielectric layer **24**. The second comb-teeth electrode **31** includes a base line **32***b* and a large number of tooth portions **32***a* whose roots are connected to the base line **32***b*. The base line **32***b* extends parallel to the base line **31***b* of the first comb-teeth electrode **31**. The base line **32***b* is partially superimposed on the dielectric layers **24** and is bent at the outer peripheral position of the substrate **23**. The remaining part of the base line **32***b* extends from the bent portion to the back side along the side surface of the substrate **23** and is connected to the ground electrode layer **25**. Further, the large number of tooth portions **32***a* protrude from the base line **32***b* toward the first comb-teeth electrode **31** side so as to be parallel to each other. The large number of tooth portions **32***a* are arranged at equal intervals in the first direction. The tooth portions **32***a* extend in the second direction along the surface of the dielectric layers **24** and are perpendicular to the base line **32***b*.
(217) The length L**1** of the tooth portion **31***a* and the length L**2** of the tooth portion **32***a* are designed using Equation 10 when the transmitted high-frequency wave length (electric length) is λ (n is a natural number). Note that the respective tooth portions **31***a* of the first comb-teeth electrode **31** and the respective tooth portions **32***a* of the second comb-teeth electrode **32** are all of the same length and are all of the same line width. However, the lengths or widths may be different from each other. In the radiation antennae **22**, the respective tooth portions **31***a*, **32***a* have the resonance structure. This resonance structure is not a structure that causes a resonance mode due to an electromagnetic field distribution in space, but a structure that causes a resonance of a standing wave in the radiation antenna **22** (a high-frequency transmitter) itself.
$L1=L2=\lambda\times(2n-1)/4$ Equation 10
(218) The radiation antennae **22** is configured such that a relatively strong-electric-field coupling occurs between the tooth portion **31***a*, **32***a* adjacent to each other in the first direction during the above-described input period. Specifically, in the radiation antennae **22**, the large number of tooth portions **31***a*, **32***a* are arranged at equal intervals in the first direction, the distance (the dimension of a gap) G of the tooth portions **31***a*, **32***a* adjacent in the first direction is not more than 5 times the line width of the tooth portion **31***a*,**32***a*. The distance G may be three times or less of the line width of the tooth portion **31***a*, **32***a*, or may be one time or less. Note that regarding the line widths of the tooth portions **31***a*, **32***a*, when the line width of the tooth portions **31***a* and the line width of the tooth portions **32***a* are different from each other, the average value of the line widths of the tooth portions **31***a*, **32***a* is used. This point is the same for the line width of the conductive line that defines the

numerical range of the gap G in each embodiment and each modification described later.
(219) The dielectric layer **24** is made of a dielectric material such as ceramic. The thickness of the dielectric layer **24** is, for example, uniform over the entire surface. The dielectric layer **24** separates the first comb-teeth electrode **31** and the second comb-teeth electrode **32** from the ground electrode layer **25**.
(220) The ground electrode layer **25** is formed of a conductor (for example, a metal plate) and has a ground potential. The ground electrode layer **25** is arranged on the back side of the large number of tooth portions **31***a*, **32***a* and faces the tooth portions **31***a*, **32***a* of the arrangement region via the dielectric layer **24**. The ground electrode layer **25** is disposed on the opposite side to the side where the object to be heated **20** is disposed with respect to three or more conductive lines and faces at least a part of three or more conductive lines. By providing the ground electrode layers **25**, high-frequency wave is radiated only to the front sides of the large number of tooth portions **31***a*, **32***a* in the above-described input period, and the strong-electric-field region is formed in the vicinity of the front sides of the large number of tooth portions **31***a*, **32***a*. In the strong-electric-field region, the conductive components or the ionic materials of the object to be heated **20** is heated by the conductive loss, the magnetic component is heated by magnetic loss, and the dielectric components are heated by the dielectric loss.
(221) The Operation of the Processing System
(222) The operation of the processing system including the electromagnetic-wave heating device **10** will be described. When the power supply of the processing system is turned ON, the respective power supplies of the electromagnetic-wave heating device **10** and the conveyance mechanism **12** are turned ON. As a result, the base material **11** is conveyed in the first direction by a conveyance mechanism **12**, and a high-frequency is oscillated from the oscillator **21**. The base material **11** is conveyed in the vicinity of the front side of the radiation antenna **22** with the object to be heated **20** side facing the front side (the upper side in FIG. **23**). Note that the base material **11** may be conveyed with the object to be heated **20** side facing the back side.
(223) In the electromagnetic-wave heating device **10**, a high-frequency outputted from the oscillator **21** is supplied to each tooth portion **31***a* of the first comb-teeth electrode **31** and each tooth portion **32***a* of the second comb-teeth electrode **32**. As described above, the length of each tooth portion **31***a* is λ/4. Resonance of a high-frequency occurs in each tooth portion **31***a* of the first comb-teeth electrodes **31**, and the leading end of each tooth portion **31***a* becomes an abdominal portion of a standing wave of a high-frequency.
(224) Further, as described above, a relatively strong-electric-field coupling occurs between the first comb-teeth electrode **31** and the second comb-teeth electrode **32**. As a result, resonance of a high-frequency occurs in each tooth portion **32***a* of the second comb-teeth electrodes **32**, and the leading end of each tooth portion **32***a* becomes an abdominal portion of a standing wave of a high-frequency. Moreover, the electric field strength in the gap between the first comb-teeth electrode **31** and the second comb-teeth electrode **32** is relatively high.
(225) In the facing region of the radiation antenna **22**, a strong-electric-field region is formed so as to include and the conveyance path of the object to be heated **20** and the base material **11**. The object to be heated **20** passing through the strong-electric-field region is heated. As a result, A desired physical/chemical change (polymerization, annealing, drying, curing, or the like) occurs in the object to be heated **20** through the temperature rise.
(226) In the present embodiment, the high-frequency input location X in the radiation antenna **22** is located outside the passing region of the object to be heated **20**. The input location X of does not overlap with the passing region. Here, in the case where the input part the high-frequency overlaps with the passing region, there is a possibility that an electric field is concentrated in the vicinity of the input location, and the object to be heated **20** is locally heated. On the other hand, in the present embodiment, such locally heating does not occur, and the degree of heating of the object to be heated **20** in a plan view can be made uniform.
(227) Modification 3-2

(228) In this modification, as shown in FIG. **25**, as in the above-described embodiment, the respective tooth portions **31***a*, **32***a* extend obliquely with respect to an arrangement direction (the first direction) of the tooth portions **31***a*, **32***a*.
(229) In the present modification, even when the width of the object to be heated **20** is shorter than the length of the tooth portion **31***a*, **32***a*, the width of the strong-electric-field area can be adjusted in accordance with the width of the object to be heated **20** by obliquely setting the respective tooth portions **31***a*, **32***a*. Therefore, it is possible to effectively use high-frequency energy for heating the object to be heated **20**.
(230) Modification 3-3
(231) In this modification, as shown in FIG. **26**, the length L**1** of the tooth portion **31***a* of the first comb-teeth electrode **31** is longer than the length L**2** of the tooth portion **32***a* of the second comb-teeth electrode **32**. The length L**1** of the tooth portion **31***a* of the first comb-teeth electrode **31** is designed using Equation 11, and the length L**2** of the tooth portion **32***a* of the second comb-teeth electrode **32** is designed using Equation 12 (n.sub.1, n.sub.2 are both natural numbers, and the relationship n.sub.1>n.sub.2 holds).
$L1=\lambda\times(2n_1-1)/4$ Equation 11
$L2=\lambda\times(2n_2-1)/4$ Equation 12
(232) In the present modification, in the respective tooth portions **31***a* of the first comb-teeth electrodes **31**, two positions, i.e., a position separated from the root by λ/4 and a distal end, are the abdomen of the standing wave. On the other hand, in the respective tooth portions **32***a* of the second comb-teeth electrodes **32**, one position of the distal end is the abdominal portion of the standing wave.
(233) Modification 3-4
(234) In this modification, as shown in FIGS. **27**A and **27**B, the dielectric layers **24** on the back side of the arrangement regions of the large number of tooth portions **31***a*, **32***a* are eliminated in the substrate **23** on the back side of the arrangement region, substantially rectangular-shaped openings (recesses) **24***a* are formed in the dielectric layers **24**. The ground electrode layers **25** face the respective tooth portions **31***a*, **32***a* through air (dielectric) in the opening **24***a*.
(235) According to the present modification, by replacing the dielectric layer **24** with air having a low dielectric constant, the dielectric loss in the substrate **23** can be reduced, and the heating efficiency of the object to be heated **20** is improved.
(236) Modification 3-5
(237) In the present modification, as shown in FIG. **28**, the area of the dielectric layer **24** in the substrate **23** is further reduced for the modification 3-4.
(238) Modification 3-6
(239) In this modification, as shown in FIG. **29**, a covering member **26** is provided to cover a side (front side) where the object to be heated **20** is disposed with respect to a large number of tooth portions **31***a*, **32***a* of the first comb-teeth electrode **31** and the second comb-teeth electrode **32**. The covering member **26** is formed of a plate-shaped dielectric. Accordingly, it is possible to prevent foreign matter from entering the gap between the first comb-teeth electrode **31** and the second comb-teeth electrode **32**.
(240) Further, in the present modification, the housing **28** is provided so as to surround the first comb-teeth electrode **31** and the second comb-teeth electrode **32**. The housing **28** is formed in a box shape with an open lower portion and is provided so as to cover the surface of the substrate **23**. The housing **28** is provided so that a gap **28***a* is formed between itself and the substrate **23** at a position where base material **11** and the object to be heated **20** pass. Note that an opening (for example, a horizontally long slit) may be formed in the housing **28**, and the base material **11** and the object to be heated **20** may pass through the opening. The object to be heated **20** can be taken in and out of the housing **28** through the opening formed in the housing **28** or the gap **28***a* formed by the housing **28**.
(241) Modification 3-7
(242) In this modification, as shown in FIG. **30**, the position of the second comb-teeth electrode **32** is

slightly slid in the first direction. In the radiation antennae **22**, a portion where a gap between adjacent tooth portions **31***a*, **32***a* is narrow and a portion where the gap is wide are alternately arranged. This makes it possible to adjust the resonant frequency of the respective tooth portions **31***a*,**32***a*.

(243) Modification 3-8

(244) In the present modification, the input parts **30** are provided at two positions on the back side of the substrate **23**. One input part **30** is provided on the back side of the dielectric layer **24** that supports the first connection line **57**, and is connected to the first connection line **57**. The other input part **30** is connected to, for example, the second connection line **58** (see FIG. **31**).

(245) Modification 3-9

(246) In this modification, the radiation antenna **22** is constituted by a meander circuit (meander wiring pattern) as shown in FIG. **32**. Specifically, the radiation antenna **22** is a circuit meandering a plurality of times in a predetermined band-shaped region in which a straight line **44** extending in the second direction and a folded portion **47** which is continuous to the end portion of the straight line **44** are provided alternately. Each straight line **44** corresponds to the conductive line according to the present disclosure. The length of the straight line **44** is designed to be $\lambda\times(2n-1)/4$ (n is a natural number). The number of the straight lines **44** may be three or more.

(247) In addition, in the radiation antenna **22**, a base line **48** extending from the input part **30** is connected to the straight line **44** that is the end in the first direction among the large of straight lines **44**.

(248) In the present modification, resonance of the high-frequency occurs in each straight line **44** during the input period of high-frequency. The distance G between the adjacent straight lines **44** in the first direction is not more than five times the line width of the straight lines **44**, and a relatively strong-electric-field coupling occurs between the adjacent straight lines **44**.

(249) Modification 3-10

(250) In this modification, the radiation antenna **22** includes a large number of spiral lines **63** formed to have the same length as shown in FIG. **33**. Each spiral line **63** corresponds to the conductive line according to the present disclosure. In the radiation antenna **22**, a large number of spiral lines **63** are arranged at equal intervals in the first direction. The length of the spiral line **63** is designed to be $\lambda\times(2n-1)/4$ (n is a natural number). In FIG. **33**, the conductor portion including the spiral line **63** is hatched.

(251) In addition to the large number of spiral lines **63**, the radiation antenna **22** includes a first base line **61** and a second base line **62** arranged in parallel with each other at a distance from each other. In the radiation antenna **22**, the spiral line **63** whose root is connected to the first base line **61** and the spiral line **63** whose root is connected to the second base line **62** are alternately arranged.

(252) In the present modification, during the input period of the high-frequency, resonance of the high-frequency occurs in each spiral line **63**, strong-electric-field coupling occurs between the lines inside the spiral line **63**. In addition, the distance G between the spiral lines **63** adjacent to each other in the first direction is not more than five times the line width of each spiral line **63**, and relatively strong-electric-field coupling occurs between the spiral lines **63** adjacent to each other.

(253) Modification 3-11

(254) In this modification, as shown in FIG. **34**, the radiation antenna **22** includes one base line **85** and a large number of branch-type lines **86** whose roots are connected to the base line **85**. Each branch-type line **86** corresponds to the conductive line according to the present disclosure. The branch-type line **86** is designed such that the length from the root to the branched distal end is $\lambda\times(2n-1)/4$ (n is a natural number). In FIG. **34**, the conductor portion including the base line **85** and the branch-type line **86** is hatched.

(255) In the present modification, during the input period of high-frequency, resonance of high-frequency occurs in each branch-type line **86**, and strong-electric-field coupling occurs between lines inside each branch-type line **86**. The distance G between the branch-type lines **86** adjacent to each other in the first direction is not more than five times the line width of the branch-type lines **86**, and

relatively strong-electric-field coupling occurs between the branch-type lines **86** adjacent to each other.
(256) Modification 3-12
(257) In this modification, the electromagnetic-wave heating device **10** includes a plurality of radiation antennas **22** each connected to an input part **30**, as shown in FIG. **35**. The plurality of radiation antennas **22** are arranged at intervals in the first direction. Each radiation antenna **22** has three or more straight lines **38** arranged with a gap therebetween in the second direction. The length of the straight line **38** is designed to be $\lambda\times(2n-1)/4$ (n is a natural number). The distance G between the straight lines **38** adjacent to each other in the second direction is 5 times or less of the line width of the straight lines **38**. Further, in FIG. **35**, the radiation antenna **22** is the meander circuit described above, but other circuits may be employed.
(258) In this modification, during a period in which a high-frequency is input to each input part **30**, resonance of a high-frequency occurs in each linear line **38** in each radiation antenna **22**, and relatively strong-electric-field coupling occurs between the linear lines **38** adjacent to each other in the second direction.
(259) Modification 3-13
(260) In this modification, as shown in FIG. **36**, in the radiation antenna **22**, the input location (power supply location) X of high-frequency from the oscillator **21** is located on the downstream side in the conveyance direction of the object to be heated **20**. The input location X of the high-frequency, when the input part **30** is directly connected to the radiation antenna **22**, is a connection location of the input part **30** in the radiation antenna **22**, and when the input part **30** is connected to the radiation antenna **22** via a conductive line, it is the connection location of the conductive line in the radiation antenna **22**.
(261) Here, in the case where the object to be heated **20** contains moisture, the amount of moisture contained in the object to be heated **20** increases toward the upstream side in the conveyance direction. Therefore, in the case (in the case of FIG. **1** or the like) where the input location X of the high-frequency is on the upstream side in the conveyance direction, there is a possibility that the high-frequency absorbed by the object to be heated **20** on the upstream side of the radiation antenna **22** becomes too large. In this case, the high-frequency supplied to the downstream side of the radiation antenna **22** is reduced, and uniform heating in the conveyance direction is difficult.
(262) On the other hand, in the present modification, it is possible to avoid the situation that the high-frequency absorbed by the object to be heated **20** on the downstream side of the radiation antenna **22** becomes too large. According to this modification, it is possible to realize uniform heating in the conveyance direction.
(263) Other Modifications of Structure for Forming Strong-Electric-Field Region
(264) In the above-described embodiment and the like, the cross-sectional shape of the conductive line **36** according to the present disclosure is substantially rectangular, as shown in FIG. **37**A, the conductive line **36** in cross-sectional view may be provided with a curved portion **37**. Incidentally, the conductive line **36** shown in FIG. **37**A, the tooth portion **31***a*,**32***a* of the embodiment or the like, the straight line **44** of the modification 3-9, the spiral lines **63** of Modification 3-10, the branch-type line **86** of the modification 3-11, corresponds to the straight line **38** of Modification 3-12. The same applies to FIGS. **37**B to **37**C. Here, when the cross-sectional shape of the conductive line **36** is substantially rectangular, if the high-frequency power is increased, discharge occurs between the conductive lines **36**, whereby the base material **11** might be is damaged. On the other hand, by providing the curved portion **37** in the conductive line **36**, it is possible to suppress the occurrence of discharge between the conductive lines **36**. Incidentally, the curved portion **37** may be provided on the front side of the conductive line **36**. The cross-sectional shape of the conductive line **36** may be a cross-sectional shape without corners (for example, a circular shape or an elliptical shape).
(265) In Modifications 3-4 and 3-5 described above, the ground electrode layer **25** is exposed on the back side of the arrangement region of the plurality of tooth portion **31***a*, **32***a*, but as shown in FIG. **37**B, the dielectric plate **39** may be provided on the front side of the ground electrode layer **25**. As a

result, a part of the high-frequency energy is absorbed by the dielectric plate **39**, so that it is possible to suppress the occurrence of discharge between the conductive lines **36**.
(266) In the above-described embodiment or the like, as shown in FIG. **37**C, the conductive line **36** may be covered with a dielectric **43** such as a resin or a ceramic. In this case, too, it is possible to suppress the occurrence of discharge between the conductive lines **36**.
(267) In the above-described embodiment and the like, heating of the object to be heated **20** may be performed also on the back side of the radiation antenna **22** without providing the substrate **23**.
INDUSTRIAL APPLICABILITY
(268) The present disclosure is applicable to an electromagnetic-wave heating device or the like used for heating an object to be heated.
DESCRIPTION OF REFERENCE CHARACTERS
(269) **10**: Electromagnetic-wave heating device **11**: Base material **12**: Conveyance mechanism **20**: Object to be heated **21**: Oscillator **22**: Radiation antenna **23**: Substrate **24**: Dielectric layer **25**: Ground electrode layer **30**: Input part **31**: First comb-teeth electrode **31***a*: Tooth portion (conductive line) **32**: Second comb-teeth electrode **32***a*: Tooth portion (conductive line) **40**: Internal space **50**: Cover **60**: Shield unit **70**: Continuous gap **75**: Control device

## Claims

1. An electromagnetic-wave heating device comprising: an oscillator for outputting and transmitting a frequency band of electromagnetic waves; a radiating antenna connected to the oscillator and having a resonance structure in which resonance by the electromagnetic waves in a frequency band transmitted from the oscillator occurs, the resonance structure forming a radio-frequency strong-electric-field region in which the electromagnetic-wave heating device carries out heating of an object to be heated; a signal extraction unit provided in a transmission line extending from the oscillator to the radiating antenna, for extracting reflected-wave information representing a waveform of a reflected wave returning from the radiating antenna; a phase-difference information generating unit for generating, by arithmetic processing utilizing the reflected-wave information and incident-wave information representing a waveform of an incident wave transmitted from the oscillator to the radiating antenna, phase-difference information representing a phase difference between the incident wave and the reflected wave; and a control unit for repeatedly performing a control process of: detecting, based on the phase-difference information and on reference information about a state in which the incident-wave phase and the reflected-wave phase are equal, a direction of oscillation-frequency adjustment whereby a difference between a resonant frequency in the radiating antenna and the oscillation frequency of the oscillator is reduced, and controlling the oscillation frequency based on the detected adjustment direction.
2. The electromagnetic-wave heating device according to claim 1, wherein the control unit detects a direction in which the oscillation frequency deviates with respect to the resonance frequency by utilizing the reference information and the phase-difference information and performs an averaging processing on the detected results to detect the direction of oscillation-frequency adjustment.
3. The electromagnetic-wave heating device according to claim 2, wherein the object to be heated is conveyed so as to pass through the strong-electric-field region, and wherein the control unit adjusts, based on a conveyance speed of the object to be heated, a number of samples of the detected results used in the averaging processing.
4. The electromagnetic-wave heating device according to claim 1, wherein the oscillator outputs a quadrature modulated electromagnetic waves to the radiation antenna, further comprising a quadrature demodulator for quadrature demodulating the reflected-wave information, and wherein the phase-difference information is generated by the arithmetic processing utilizing a first I component information and a first Q component information constituting the incident-wave information, and a second I component information and a second Q component information constituting the reflected-wave information.

5. The electromagnetic-wave heating device according to claim 4, wherein the signal extraction unit extracts the incident-wave information from the transmission line, the quadrature demodulation unit comprising: one quadrature demodulator; and a changeover switch for switching between a first period in which the incident-wave information is input to the quadrature demodulator from the signal extraction unit and a second period in which the reflected-wave information is input to the quadrature demodulator from the signal extraction unit; and wherein the first period and the second period are switched by the changeover switch in a period shorter than a generation period of the phase-difference information.
6. The electromagnetic-wave heating device according to claim 1, wherein the signal extraction unit extracts the incident-wave information from the transmission line, and wherein a delay line or a delay element for correcting a phase shift between the incident-wave information and the reflected-wave information is provided in a line on which the incident-wave information is transmitter from the signal extraction unit to the phase-difference information generation unit.
7. The electromagnetic-wave heating device according to claim 1, wherein the control unit generates, utilizing the incident-wave information of a phase at a point of output timing of the electromagnetic waves of the oscillator, the phase-difference information, and corrects a phase shift between the incident-wave information and the reflected-wave information before the arithmetic processing.
8. The electromagnetic-wave heating device according to claim 1, wherein the control unit estimates an amount of electromagnetic-wave energy absorbed by the object to be heated based on the phase-difference information, and performs output control of the oscillator based on the estimated result.
9. The electromagnetic-wave heating device according to claim 1, wherein the reference information is a threshold range having a predetermined width, and wherein the control unit estimates a heating progress of the object to be heated with respect to a target heating state of the object to be heated, and adjusts a width of the threshold range based on the estimated result.
10. The electromagnetic-wave heating device according to claim 1, wherein a plurality of objects to be heated are conveyed at intervals so as to pass through the strong-electric-field region in order, wherein the control unit performs frequency control of repeating the control process during a period in which one object to be heated passes through the strong-electric-field region, records control history information of the frequency control, and performs, utilizing the control history information, the frequency control during a period in which the object to be heated passing through the strong-electric-field region after the recording.
11. The electromagnetic-wave heating device according to claim 1, wherein a plurality of objects to be heated are conveyed at intervals so as to pass through the strong-electric-field region in order, wherein the object to be heated is ink printed by a printing apparatus, and wherein the control unit uses information of a print pattern of the object to be heated to adjust a control parameter of the control process.
12. The electromagnetic-wave heating device according to claim 1, further comprising: a shield unit for shielding, from an outside, an internal space in which the radiation antenna is disposed, an introduction portion and a lead-out portion for a conveyed object including the object to be heated being formed in the shield unit, the conveyed object being conveyed from the introduction portion toward the lead-out portion in the internal space so that the object to be heated passes through a facing region of the radiation antenna.
13. The electromagnetic-wave heating device according to claim 12, wherein a continuous gap in which a lateral gap extending in a conveyance direction of the conveyed object at a side of the facing region is connected to each of the introduction portion and the lead-out portion as a gap for allowing the internal space to communicate with the outside is formed in the shield unit.
14. The electromagnetic-wave heating device according to claim 1, wherein in the radiation antenna, three or more conductive lines each having the resonance structure are arranged with a gap in a predetermined direction, further comprising an input part for supplying the electromagnetic waves to at least a portion of the three or more conductive lines, wherein in the radiation antenna, during an input period in which the electromagnetic waves are input to the input part, the resonance by the

electromagnetic waves occurs in each of the three or more conductive lines and the strong-electric-field region is formed along a region in which the three or more conductive lines are arranged.