

The present invention relates to high-frequency heating generators. These generators may be used especially in electromagnetic-induction, dielectric or plasma heating devices.

5 Such generators generally include a resonant circuit electromagnetically coupled to a component to be heated, this circuit being connected at the output of at least one electron tube mounted as a self-oscillating oscillator (see, for example, the document EP-A 0238122).

10 Electromagnetic-induction heating consists in producing heat in a conductive component caused by the flow of currents induced by a magnetic field. This means enables the component to be heated throughout it, without direct contact with the energy source. The component to
15 be heated (or the part subject to induction) is surrounded by at least one current circulation loop (or inductor). The working frequencies of the generator are between a few tens of kilohertz and a few megahertz. The powers necessary vary between a few kilowatts and more
20 than one megawatt. Electromagnetic-induction heating is used widely in industry and in the scientific field. In industry, it is used especially in metallurgy to refine metals, to heat-treat metal components or to produce seam-welded tubes.

25 Dielectric heating consists in heating an insulating component by causing losses throughout it, using an alternating electric field. The component to be heated is a poor insulator. It is placed between two conducting plates supplied by an AC supply. A capacitor is created
30 in which the dielectric is the component to be heated. The generators used generally have working frequencies higher than those of electromagnetic-induction heating generators. They may be between a few tens of megahertz and a few gigahertz. This mode of heating is used in the
35 timber industry for drying or bonding, in the textile industry or in the manufacture or shaping of plastics.

 Plasma heating consists in ionizing a gaseous medium in order to convert it into a plasma. The kinetic energy of the electrons is converted into heat. A

considerable temperature rise is produced. The component to be heated is placed in the plasma. Conversion of the gas medium into a plasma is achieved by the emission from an antenna. The working frequencies of the generator are
5 between 1 megahertz and a few tens of megahertz. The mode of heating is used in many industrial applications, such as the melting of refractory products, chemical synthesis, etc.

Optimum performance of the high-frequency heating
10 generators occurs if the load impedance seen from the electron tube is matched at all times. The resonant circuit electromagnetically coupled to the component to be heated is equivalent either to a parallel RLC circuit or to a series RLC circuit. The quality factor, Q , of the
15 resonant circuit is high and mismatching is easy in the vicinity of the resonant frequency. In order for the load impedance seen from the tube to be matched, it should be real and its modulus should have an optimum value for the tube. The load impedance is essentially variable since it
20 depends on the characteristics of the elements constituting the resonant circuit and especially of the material of the component to be heated, on their size and on their relative position. This position is most especially
25 important if the component to be heated is moving, for example if it is an induction-heated sheet-metal plate that is being rolled and seam-welded.

Most of the characteristics also vary with temperature and time. The variation in impedance leads to a variation in resonant frequency of the resonant circuit. The performance characteristics of the electron
30 tubes are affected by these variations. Their efficiency decreases. Since the tube is used in a self-oscillating oscillator set-up, its working frequency is influenced by the resonant frequency of the resonant circuit but
35 without being identical to it. The variation in resonant frequency may lead to the stalling of the oscillator, which then refuses to oscillate. All this mismatching requires overexcitation of the tube, which may damage it.

In order to match the load impedance seen from

the tube, it is possible to insert switchable elements into a matching transformer interposed between the oscillator tube and the resonant circuit. This matching is carried out, before the start of heating, as a function of the assumed impedance which the load will have.

It is also possible to interpose a circuit comprising variable inductors and capacitors between the resonant circuit and the oscillator tube. These variable elements are permanently slaved in order to lock the resonant frequency of the resonant circuit on to the chosen working frequency of the generator and so that the modulus of the impedance permanently keeps its optimum value. The slaving means are often electromechanical. This system is employed when high powers are involved. The elements used are expensive, since they are designed to receive high currents. They are bulky and introduce not-insignificant Joule-effect losses.

The present invention aims to remedy these drawbacks. It provides a high-frequency heating generator including an amplifier having at least one tetrode, the output of which is connected to a resonant circuit electromagnetically coupled to a component to be heated and the working frequency of which is permanently matched to the frequency of the resonant circuit.

A frequency-controlled oscillator delivers a high-frequency signal intended to be transmitted to the input of the amplifier. A means is provided in order to measure the phase shift between the current delivered to the resonant circuit and the voltage at its terminals, and in order to modify the frequency of the oscillator as a function of the phase shift.

The means for measuring the phase shift is connected in order to receive, on one input, the voltage at the control grid of the tetrode and, on another input, the voltage at the terminals of the resonant circuit.

The means to measure the phase shift preferably includes a phase/voltage converter delivering a voltage proportional to the phase difference ϕ between the voltages applied to its inputs.

Preferably, the phase/voltage converter includes, on the input side, a phase shifter in order to add $\pi/2$ to the phase difference ϕ . This phase shifter delivers two voltages, the phase difference of which is $\phi + \pi/2$.

5 Preferably, a clipper amplifier circuit receives the two voltages phase-shifted by $\phi + \pi/2$ and delivers two logic square-wave voltages, representing the positive half-periods of the voltages phase-shifted by $\phi + \pi/2$, to a logic function which produces a voltage corresponding to the logic sum of the square-wave voltages.

10 A differential amplifier receives, on one input, the output voltage of the logic function after integration and, on another input, a constant voltage and delivers the voltage proportional to the phase difference ϕ .

15 The means for modifying the frequency of the oscillator preferably comprises an adder which receives, on the one hand, the voltage proportional to the phase difference ϕ and, on the other hand, a set-value adjustment voltage, and which delivers a control voltage to the oscillator.

20 A gain control element is preferably connected between the output of the oscillator and the input of the amplifier. A control loop receives the voltage at the terminals of the resonant circuit and acts on the gain of the control element so as to maintain the amplitude of the voltage at the terminals of the resonant circuit at a constant chosen value. The control loop preferably comprises an operational amplifier receiving, on one

25 input, the voltage at the terminals of the resonant circuit and, on another input, a set-value voltage which is a function of the voltage to be obtained at the terminals of the resonant circuit.

30 Preferably, the gain control element comprises a capacitive divider, one arm of which is a varicap diode.

35 Preferably, a preamplifier is inserted between the gain control element and the input of the electron-tube amplifier.

Preferably, an impedance transformer is connected

between the electron tube and the resonant circuit.

When the heating generator heats inductively, the resonant circuit includes at least one current circulation loop around the component to be heated.

5 When the heating generator heats dielectrically, the resonant circuit includes capacitor plates between which the component to be heated is placed.

10 When the heating generator heats by means of a plasma, the resonant circuit includes an emission antenna that excites the plasma.

The present invention will be better understood and further characteristics and advantages will appear on reading the following description, illustrated by the appended figures which depict:

15 - Figure 1 - an electrical diagram of a generator according to the invention;

- Figure 2 - an electrical diagram of the phase/voltage converter;

20 - Figure 3a - the voltages a and b, as a function of time, which are applied to the input of the phase shifter contained in the phase/voltage converter;

- Figure 3b - the voltages c and d, as a function of time, which are present on the output side of the phase shifter;

25 - Figure 3c - the voltages e and f, as a function of time, these square-wave voltages corresponding to the positive half-periods of the voltages c and d;

30 - Figure 3d - the voltage g, as a function of time, which is present on the output side of the logic function contained in the phase/voltage converter;

- Figure 4 - an electrical diagram of the gain control element and of the control loop;

- Figure 5 - an electrical diagram of the variable attenuator contained in the gain control element.

35 In the figures, alphabetical indices have been used to represent both the inputs and the outputs of the operators and the corresponding voltages, referenced with respect to earth. In Figure 1, the direction of the positive current is indicated at the output of the

amplifier AP.

Figure 1 depicts an electrical diagram of a high-frequency heating generator according to the invention. The generator comprises an electron-tube amplifier AP, the output of which supplies a resonant circuit RE electromagnetically coupled to a component to be heated. The resonant circuit is electrically equivalent to either a parallel or series RLC-type circuit. In the example described, the generator is an induction-heating generator, but it could be a dielectric-heating generator or a plasma-heating generator. There would be a difference as regards the resonant circuit but this circuit would still be electrically equivalent to a RLC-type circuit.

In the example described, the resonant circuit RE includes at least one inductive loop L' surrounding the component to be heated and at least one capacitor C' placed as close as possible to the inductive loop L' . The real part of the equivalent impedance representing the inductive loop L' , coupled to the component to be heated, corresponds to a resistor R' (not depicted). By placing the capacitor C' as close as possible to the inductive loop L' , the Joule-effect losses in the links between the generator and the inductive loop L' are limited.

The resonant circuit RE depicted is equivalent to a parallel circuit. This is only an example. It could be equivalent to a series circuit.

A controlled-frequency oscillator VCO delivers a high-frequency signal to the input of the amplifier AP.

The generator also includes a means to measure the phase shift between the current delivered by the electron tube to the resonant circuit RE and the voltage at its terminals and to modify the frequency of the oscillator VCO as a function of this phase shift.

A gain control element AGV is inserted between the controlled-frequency oscillator VCO and the amplifier AP and a control loop controlled by a set-value voltage enables the amplitude of the voltage at the terminals of the resonant circuit to be kept substantially constant, at a chosen value. The set-value voltage is a function of

the power to be delivered into the component to be heated.

In addition, at least one preamplifier PA is inserted between the output of the gain control element AGV and the input of the electron-tube amplifier AP. For high power, a transistor preamplifier is sufficient. For very high-power applications, it may be necessary to connect an additional, electron-tube, preamplifier at the output of the transistor preamplifier. The matching between the additional preamplifier and the electron tube is then of the wideband type.

The power amplifier AP comprises at least one electron tube. This tube is preferably a high-gain high-efficiency tetrode TE. It is mounted cathode to earth. An impedance transformer TI is connected between the anode of the tube and the resonant circuit RE. This fixed or variable transformer serves to match the modulus of the load impedance seen from the electron tube. It has a quality factor which is much lower than that of the resonant circuit RE.

The variation of the resonant frequency of the resonant circuit RE is controlled by the measurement of the phase shift between the current delivered by the tube to the resonant circuit RE and the voltage at the terminals of the resonant circuit RE. The fundamental component of the current delivered to the resonant circuit has the same phase as the voltage on the control grid of the electron tube TE, the impedance transformer TI making it possible to compensate for the π phase shift introduced by the electron tube TE according to the sign convention for currents and voltages. It is possible to conceive of a situation in which the impedance transformer TI does not have this compensation characteristic. This variant will be described subsequently. In order to make matters clearer, hereafter in the description it is assumed that the impedance transformer TI compensates for the π phase shift. The measured phase shift is made zero by modifying the working frequency of the electron-tube amplifier using the controlled-frequency oscillator VCO.

The working frequency of the amplifier AP becomes substantially equal to that of the resonant circuit RE.

A voltage divider DC is inserted between the amplifier AP and the resonant circuit RE. This divider
5 makes it possible to pick up part of the voltage at the terminals of the resonant circuit RE. It is preferably capacitive, but it could be inductive or resistive.

If the resonant circuit RE is a parallel circuit (as depicted in Figure 1) and if the current delivered to
10 the resonant circuit RE leads the voltage at the terminals of the resonant circuit RE, this means that the working frequency of the generator is greater than the resonant frequency of the resonant circuit RE. If the resonant circuit RE were to be a series circuit, the
15 working frequency of the generator would be less than the resonant frequency of the resonant circuit RE.

The phase difference ϕ between the voltage on the control grid of the tube and the voltage at the terminals of the resonant circuit is given by:

20
$$\phi = \arctan Q (w/w_0 - w_0/w)$$

Q is the quality factor of the resonant circuit RE, w is the angular frequency of the current delivered to the resonant circuit RE and w_0 is the angular frequency at resonance of the resonant circuit RE. The two voltages
25 are in phase if $w = w_0$.

The means to measure the phase shift comprises a phase/voltage converter CP. The phase/voltage converter CP is depicted in Figure 2. The phase/voltage converter is aperiodic and insensitive to the amplitude variations
30 of the voltages that are applied to it.

The voltages present at the control grid of the tetrode TE and at the terminals of the resonant circuit RE are respectively applied to the two input terminals a, b of the phase/voltage converter CP.

35 It is assumed that the voltage on the resonant [sic] control grid lags the voltage at the terminals of the resonant circuit by t_0 .

The two voltages may be written as:

$$a = x \sin [(2\pi/T) (t-t_0)]$$

$$b = y \sin (2\pi t/T)$$

or else again:

$$5 \quad a = x \sin (wt + \phi)$$

$$b = y \sin wt$$

The two voltages are depicted in Figure 3a. The phase/voltage converter CP delivers, at its output i, a DC voltage of amplitude proportional to ϕ , and therefore to t_0/T , and independent of the amplitudes x and y .

The input of the phase/voltage converter CP is taken at a phase shifter DEP. The role of the phase shifter DEP is to keep one of the voltages in phase lead with respect to the other, for all the values of the phase difference ϕ which always lie between $-\pi/2$ and $+\pi/2$. This condition makes it possible to know the sign of the phase difference ϕ between the voltages a and b at the output of the phase/voltage converter CP. The phase shifter DEP receives the voltages a and b on two inputs and delivers two voltages c and d on two outputs, the voltage c leading with respect to the voltage d for all the values of the phase difference ϕ . The phase shifter DEP introduces an additional phase shift of $\pi/2$ between the voltages c and d .

$$25 \quad c = x' \sin [(2\pi/T) (t + T/4 - t_0)]$$

$$c = x' \sin [(2\pi/T) (t+t_1)]$$

$$\text{with } t_1 = T/4 - t_0$$

$$d = y' \sin (2\pi t/T)$$

The voltages c and d are depicted in Figure 3b.

30 This phase shifter DEP includes two RC networks which are reversed with respect to each other, (the first one with an input on the resistor and the second one with an input on the capacitor). The voltage c is in phase lead, with respect to the voltage a , by a value $\phi_1 = \arctan 1/RC\omega$.

35 The voltage d is in phase lag, with respect to the voltage b , by a value $\phi_2 = -\arctan RC\omega$.

The phase difference between c and d is then:

$$\varphi = \varphi_1 - \varphi_2$$

with $\varphi_1 - \varphi_2 = \arctan 1/RC\omega + \arctan RC\omega$, thus $\varphi_1 - \varphi_2$ is equal to $\pi/2$ whatever the value of $RC\omega$.

5 A clipper amplifier circuit CAM is connected up to the output of the phase shifter DEP. This clipper amplifier circuit CAM comprises two differential amplifiers A1, A2 receiving, respectively on their non-inverting inputs, the voltages c and d. Their inverting inputs
10 are earthed.

 They deliver respectively two clipped voltages e, f, as square-wave pulses, of constant amplitude K. The duration of these square-wave pulses is the half-period of the voltages c and d. The voltages e and f are respectively in phase with the voltages c and d. The square-wave pulses correspond to the positive part of the
15 voltages c and d. The voltages e and f are depicted in Figure 3c.

 The amplitude of the voltages e and f is equal to
20 the constant K when the amplitude of the voltages c and d is positive. The voltage e leads the voltage f by $t_1 = T/4 - t_0$. The voltages e and f are applied to the two inputs of a logic function. Here this is a logic OR circuit which delivers, on its output g, a voltage which
25 corresponds to the logic sum of the voltages e and f. The duration of a square-wave pulse is equal to $T/2 + T/4 - t_0$. The voltage g is depicted in Figure 3d.

 The voltage g is supplied to an integrator IN. This is a circuit R3, C3 whose time constant is long
30 compared to the period T. This integrator IN delivers a voltage h which corresponds to the mean value of the voltage g. This voltage h varies like the phase difference φ , but its origin is shifted by $3K/4$ when φ becomes zero. The voltage h is injected onto the non-inverting
35 terminal of a differential amplifier A3 which receives, on its inverting terminal, a constant-amplitude voltage p via a resistor R1. It delivers the voltage i. The amplifier A3 includes a feedback resistor R2 between the inverting input and the output i.

The output voltage i of the differential amplifier A3 has the value:

$$i = [(R1 + R2)/R1] \cdot [3K/4 - Kt_0/T] - R2p/R1$$

By suitably choosing the value of p , it is possible to get rid of the offset voltage $3K/4$ so that the voltage i is proportional to the phase difference ϕ .

This suitable value of p is:

$$p = (3K/4) [(R1/R2) + 1]$$

The voltage i then becomes:

$$i = - [(R1 + R2)/R1] K (t_0/T)$$

This voltage i is proportional to $-t_0/T$, and therefore to the phase difference ϕ .

When the impedance transformer TI does not compensate for the π phase shift between the current delivered to the resonant circuit RE and the voltage on the control grid of the tube TE, the voltages present on the control grid of the tetrode TE and at the terminals of the resonant circuit are respectively:

$$a = x \sin (wt + \phi + \pi)$$

$$b = y \sin wt$$

The output voltage i of the phase/voltage converter CP then becomes:

$$i = [(R1 + R2)/R1] K (t_0/t) [\text{sic}]$$

In order to re-establish the sign of the voltage i , it is sufficient to invert the voltages on the inputs a and b of the phase/voltage converter CP.

In equilibrium, when the phase difference ϕ becomes zero, the voltage on the control grid of the tube TE is in phase opposition with the voltage at the terminals of the resonant circuit.

This voltage i serves to modify the frequency of the oscillator VCO. This voltage i is injected into an amplifier A4. The gain G of the amplifier A4 is determined so as to obtain a maximum phase difference, which is less than a given limit over the entire range of the variations in resonant frequency of the resonant circuit RE.

The output of the amplifier A4 supplies, through a switch I, a first input j of an adder S. A second input

of the adder S receives a set-value adjustment voltage 1.

The voltage j is equal to the voltage i amplified when the switch I is closed. The adder S delivers a control voltage m to the oscillator VCO.

$$\begin{aligned} j &= G i \\ m &= j + 1 \end{aligned}$$

The voltage 1 is open-loop adjusted (I open) so that the frequency of the oscillator VCO approaches the maximum theoretical value of the resonant frequency of the resonant circuit RE. A presetting of the frequency of the oscillator VCO is carried out.

The maximum phase difference obtained in closed loop depends on the gain G and on the characteristics of the oscillator VCO and of the phase/voltage converter CP.

A heating generator according to the invention has been tested. These [sic] characteristics are as follows:

- quality factor of the resonant circuit:

$$Q = 60$$

- presetting frequency of the oscillator VCO (in open loop):

$$f' = 2,500 \text{ kHz}$$

- resonant frequency of the resonant circuit, at a given instant:

$$f_0 = 2550 \text{ kHz}$$

- characteristic of the oscillator VCO:

$$df_0/dV_{\text{control}} = 40.6 \text{ kHz/V}$$

around 2,500 kHz.

- characteristic of the phase/voltage converter:

$$133 \text{ mV/degree}$$

- maximum phase difference allowed:

$$- 1.5^\circ < \phi_{\text{max}} < + 1.5^\circ$$

The corresponding open-loop phase difference (before correction) is:

$$\phi = \arctan 60 [(2500/2550 - 2550/2500)] = - 67^\circ$$

In closed loop, the maximum phase difference allowed is, in this case, -1.5° ; it corresponds to a frequency difference of $- 0.5 \text{ kHz}$.

The working frequency f' of the amplifier and of

the oscillator VCO should be 2,549.5 kHz after correction.

The frequency delivered by the oscillator VCO has to be increased by 49.5 kHz.

5 This increase corresponds to an increase dm in the voltage m :

$$dm = (49.5 \text{ kHz} \cdot 1V) / 40.6 \text{ kHz} = 1.22 \text{ V}$$

The voltage m comes from the adder S and is equal to:

10
$$m = j + l = G_i + l$$

The voltage l is constant, set before use, then:

$$dm = G_i$$

i is the output voltage of the phase/voltage converter for a phase difference ϕ of -1.5°

15
$$i = -1.5^\circ \times 133 \text{ mV}/1^\circ = -0.2 \text{ V}$$

The gain G which the amplifier $A4$ has to have is equal to:

$$G = -1.22/0.2 = -6.1$$

20 The closed-loop frequency error is approximately one hundred times smaller than that obtained without slaving.

If the generator according to the invention is used, per production cycle, to heat different components or, in the case of induction heating, if different
25 inductors are used, the load impedance seen from the tube is different at each cycle. In order to optimize the efficiency of the generator, it is possible, before the start of the cycle, to set the impedance transformer TI appropriately in order to be closer to the matching
30 conditions. The matching transformer TI is then variable. The primary of the matching transformer TI generally includes at least one tap-switchable element in order to preset it.

35 The power which serves to heat the component is a function of the voltage at the terminals of the resonant circuit RE . In order to control this power, all that is required is to control the amplitude of the voltage at the terminals of the resonant circuit RE .

In order to do this, the generator according to

the invention also includes a gain control element AGV, between the output n of the oscillator VCO and the input of the amplifier AP, and a control loop. The control loop includes an amplifier A5 receiving, on its inverting
5 input, the voltage a at the terminals of the resonant circuit RE and, on its non-inverting input, a set-value voltage, this depending on the power desired in the component to be heated. This variable-gain element and this control loop are depicted in Figure 4. The amplifier
10 A5 delivers a control voltage o to the gain control element AGV. This gain control element is a variable-gain amplifier.

The control voltage o acts on the gain of the variable-gain amplifier AGV in a direction tending to
15 keep the amplitude of the voltage at the terminals of the resonant circuit RE constant, at a chosen value. The voltage at the terminals of the resonant circuit RE is slaved to the set-value voltage.

The variable-gain amplifier AGV includes a
20 variable attenuator AV whose output s is connected to an impedance-matching amplifier A6.

The variable attenuator AV is depicted in Figure 5. It includes a capacitive divider bridge (C1, D), one arm of which includes a varicap diode D, and a circuit
25 POL for biasing the varicap diode D.

The other arm of the divider bridge includes a capacitor C1 having one end connected to the output n of the oscillator VCO and the other end connected to the cathode of the varicap diode D. The anode of the varicap
30 diode D is earthed. The output s of the variable attenuator AV is applied to the cathode of the varicap diode D.

The circuit POL for biasing the varicap diode D is connected up between the cathode of the varicap diode
35 D and the output o of the amplifier A5. For a given bias voltage, the varicap diode has a capacitor C2.

The input impedance of the amplifier A6 and the resistance of the bias circuit POL are large compared to the quantity $1/C2.w$.

The attenuation of the variable attenuator is given by:

$$s/n = 1/[1 + (C2/C1)].$$

It is independent of w , and therefore of the
5 frequency.

The known generators are made from tube-based self-oscillating oscillators. Self-oscillating oscillators are adjustable in terms of power only by modifying the anode voltage. They require continuously variable
10 power supplies, with thyristor-based devices. These power supplies are very expensive.

Due to the fact that the generator in accordance with the invention includes an electron-tube amplifier, the output power of the generator becomes easily adjustable in terms of the voltage delivered by the
15 preamplifier P_a [sic] and applied to the grid of the tube. There is no need for the anode voltage to be continuously variable, as in the prior art.

The anode voltage may be fixed or can be varied
20 by contact-switching. If it is contact-switchable, this enables the efficiency to be maintained without modifying the load impedance seen from the tube. This has the same effect as the tap-switchable impedance transformer TI . In all cases, the cost of the anode power supply remains
25 well below that of a continuously variable power supply, this reducing the cost of the generator not insignificantly.

The high-frequency heating generator described enables a component to be inductively heated.

30 It could also be used to heat a component dielectrically. Only the resonant circuit would be modified. It would comprise at least two plates between which the component to be heated is placed.

It could also be used to heat a component by
35 means of a plasma. In this application, the resonant circuit would comprise an emission antenna.



CLAIMS

1. High-frequency heating generator including an amplifier (AP), the output of which is connected to a resonant circuit (RE) electromagnetically coupled to a component to be heated, and a controlled-frequency oscillator (VCO) delivering a high-frequency signal intended to be transmitted to the input of the amplifier (AP), characterized in that the amplifier (AP) includes at least one tetrode (TE) and in that a means (CP,S) is provided in order to measure the phase shift between the current delivered to the resonant circuit (RE) and the voltage at its terminals, and in order to modify the frequency of the oscillator (VCO) as a function of this phase shift, the means being connected so as to receive, on one input (a), the voltage at the control grid of the tetrode (TE) and, on another input (b), the voltage at the terminals of the resonant circuit (RE).

2. Heating generator according to Claim 1, characterized in that the means to measure the phase shift includes a phase/voltage converter (CP) delivering a voltage (i) proportional to the phase difference $\emptyset$ between the voltages (a,b) applied to its inputs.

3. Heating generator according to Claim 2, characterized in that the phase/voltage converter (CP) includes, on the input side, a phase shifter (DEP) in order to add $\pi/2$ to the phase difference $\emptyset$, this phase shifter (DEP) delivering two voltages (c,d), the phase difference of which is $\emptyset + \pi/2$.

4. Heating generator according to Claim 3, characterized in that a clipper amplifier circuit (CAM) receives the voltages (c,d) phase-shifted by $\emptyset + \pi/2$ and delivers two logic square-wave voltages (e,f), representing the positive half-periods of the voltages (c,d) phase-shifted by $\emptyset + \pi/2$, to a logic (OR) function, this logic function producing a voltage (g) corresponding to the logic sum of the logic square-wave voltages (e,f).

5. Heating generator according to Claim 4, characterized in that a differential amplifier (A3) receives, on one input, the output voltage (g) of the logic (OR)



function after integration and, on another input, a constant voltage (p) and delivers the voltage (i) proportional to the phase difference $\emptyset$.

5 6. Heating generator according to one of Claims 2 to 5, characterized in that the means for modifying the frequency of the oscillator (VCO) as a function of the phase shift comprises an adder (S) which receives the output voltage (i) of the phase/voltage converter (CP) and a set-value adjustment voltage (1), and which
10 delivers a control voltage (m) to the oscillator (VCO).

7. Heating generator according to one of Claims 1 to 6, characterized in that a gain control element (AGV) is connected between the output of the oscillator (VCO) and the input of the amplifier (AP) and in that a control
15 loop receives the voltage (a) at the terminals of the resonant circuit (RE) and acts on the gain of the control element (AGV) so as to maintain the amplitude of the voltage at the terminals of the resonant circuit (RE) substantially equal to a constant chosen value.

20 8. Heating generator according to Claim 7, characterized in that the control loop comprises an operational amplifier (A5) receiving, on one input, the voltage at the terminals of the resonant circuit (RE) and, on another input, a set-value voltage which is a function of
25 the voltage to be obtained at the terminals of the resonant circuit (RE).

9. Heating generator according to either of Claims 7 and 8, characterized in that the gain control element (AGV) comprises a capacitive divider (C1,D), one arm of
30 which is a varicap diode (D).

10. Heating generator according to one of Claims 7 to 9, characterized in that a preamplifier (PA) is inserted between the gain control element (AGV) and the input of the amplifier (AP).

35 11. Heating generator according to one of Claims 1 to 10, characterized in that an impedance transformer (TI) is connected between the tetrode and the resonant circuit.

12. Induction-heating generator according to one of



Claims 1 to 11, characterized in that the resonant circuit (RE) includes at least one current circulation loop (L') around the component to be heated.

13. Dielectric-heating generator according to one of
5 Claims 1 to 11, characterized in that the resonant circuit (RE) includes capacitor plates between which the component to be heated is placed.

14. Plasma-heating generator according to one of
Claims 1 to 11, characterized in that the resonant
10 circuit (RE) includes an emission antenna that excites the plasma.