United States Patent

[11] **3,549,852**

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Division of Ser. No. 502,867, Oct. 23, 1965, Pat. No. 3,448,384
[45] Patented **Dec. 22, 1970**

[54] **INTEGRAL MICROWAVE RADIATING AND GENERATING UNIT FOR HEATING**
37 Claims, 10 Drawing Figs.

[52] **U.S. Cl.** **219/10.55,** 333/73; 315/39.3; 219/10.75, 219/10.57
[51] **Int. Cl.** **H05b 9/06,** H05b 5/00
[50] **Field of Search** 219/10.55

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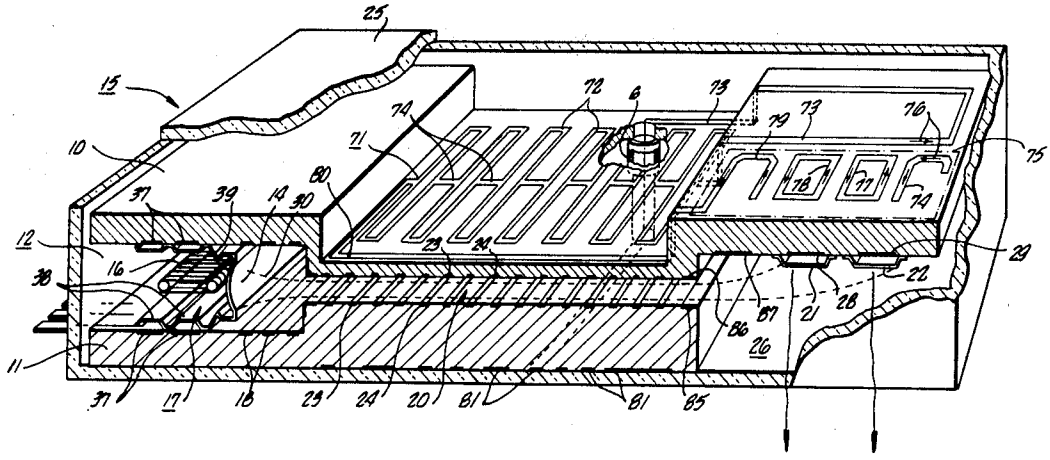
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ABSTRACT: This invention relates in general to electronic heating apparatus utilizing ultra-high frequency energy and particularly relates to microwave heating apparatus for providing uniform heating in an oven cavity. The microwave energy generator comprises a pair of dielectric sheets forming a vacuum space in which a flat electron beam is created. The essential means for converting electrical power to microwave energy are printed on the dielectric sheets. At least one antenna is printed on the surface of the dielectric sheet facing into the space of an oven cavity in which food is to be heated. Several distinct microwave frequencies may be generated in common from the flat beam, and separate printed microwave antennas are available for each frequency. In a further embodiment various collector plates for the electron beam are printed or fabricated of metal structures so as to serve the dual function of beam collection and thermal radiation for food browning. As a further embodiment a printed power control circuit, which is sensitive to a sampling of microwave output power, varies the beam location relative to a printed microwave interaction structure so as to assure a constant power for the microwave unit in spite of short or longterm variations in an ordinary line voltage supply source.



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SHEET 1 OF 5

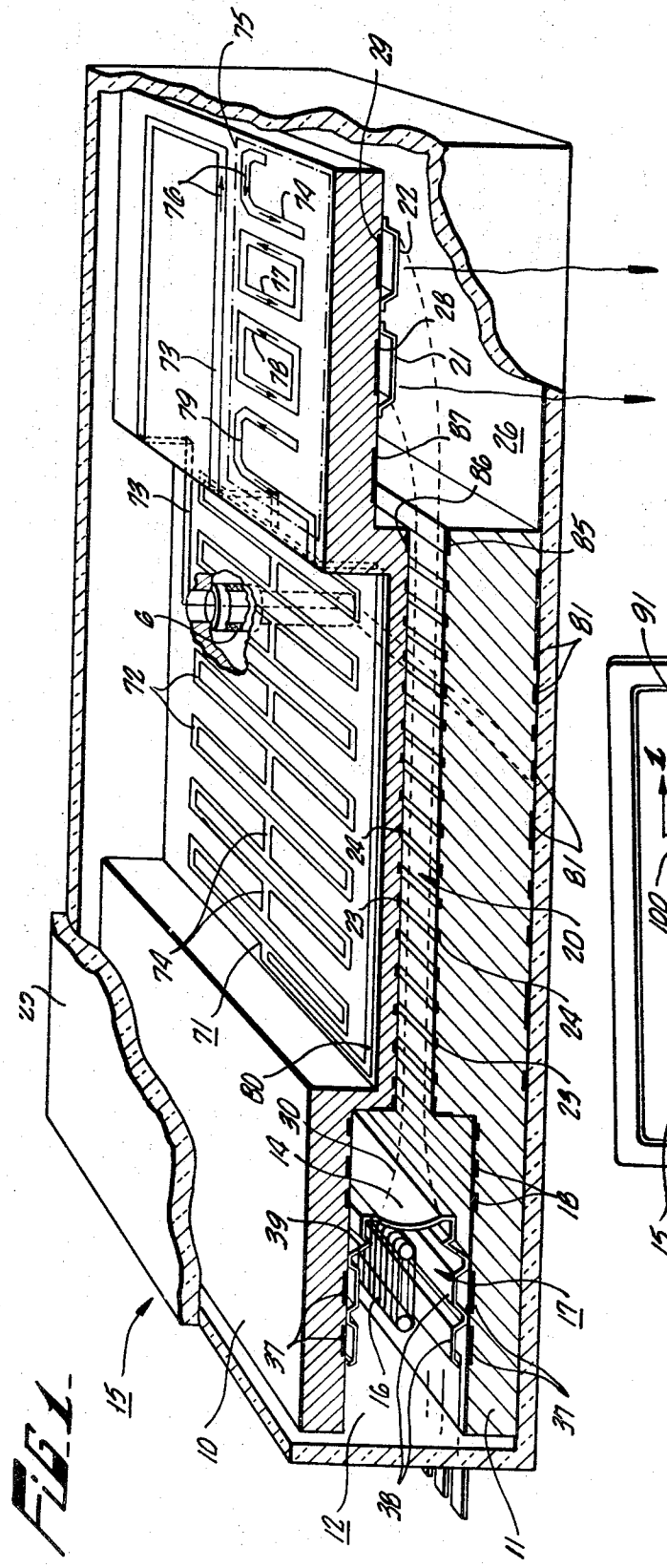


FIG. 1.

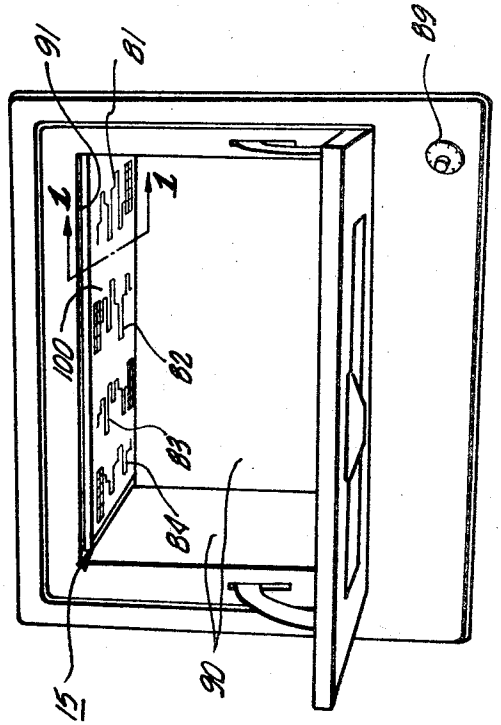


FIG. 2.

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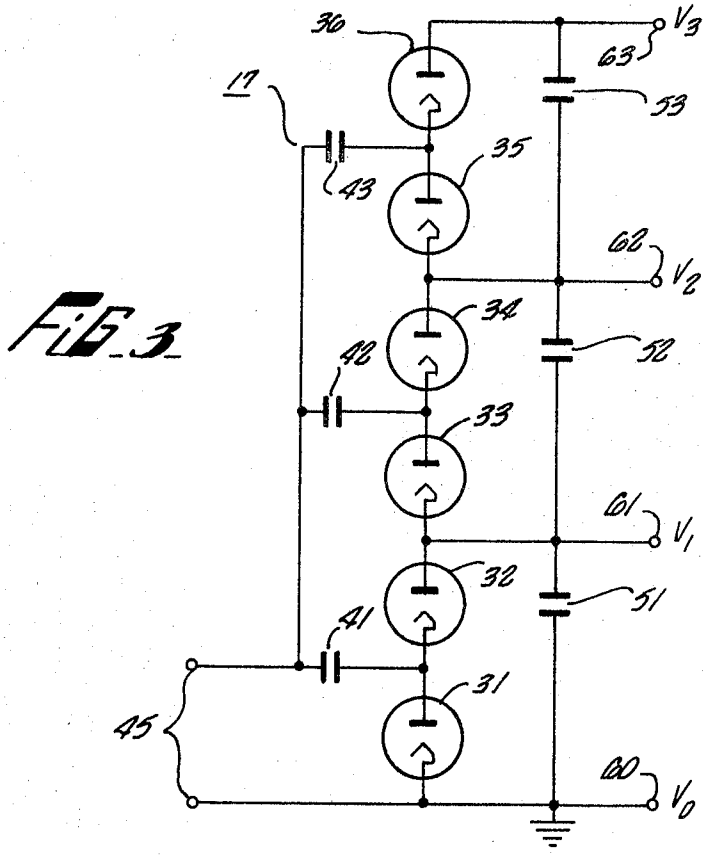


FIG. 3

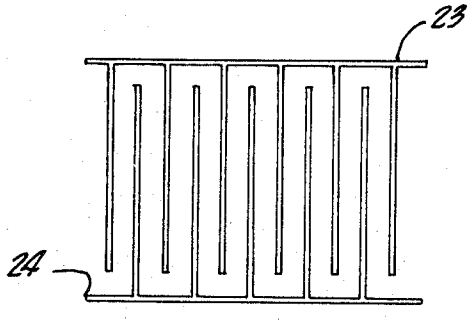


FIG. 4A

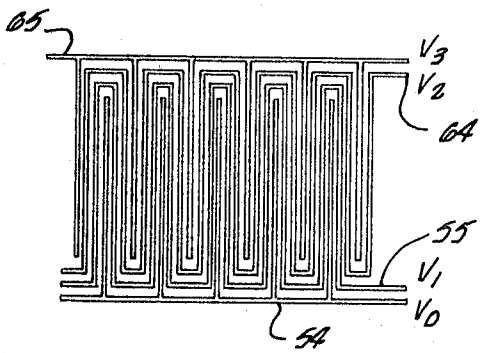


FIG. 4B

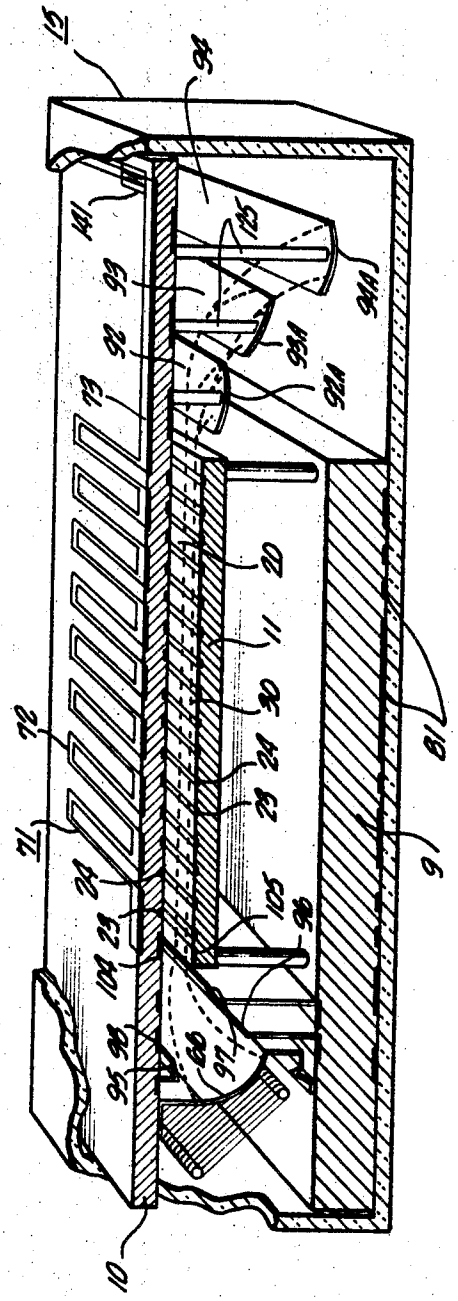


FIG. 6

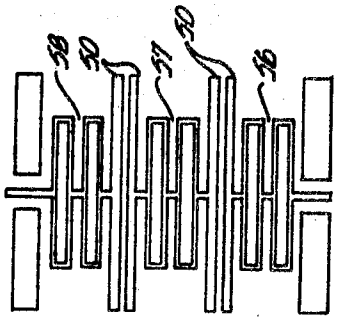


FIG. 5

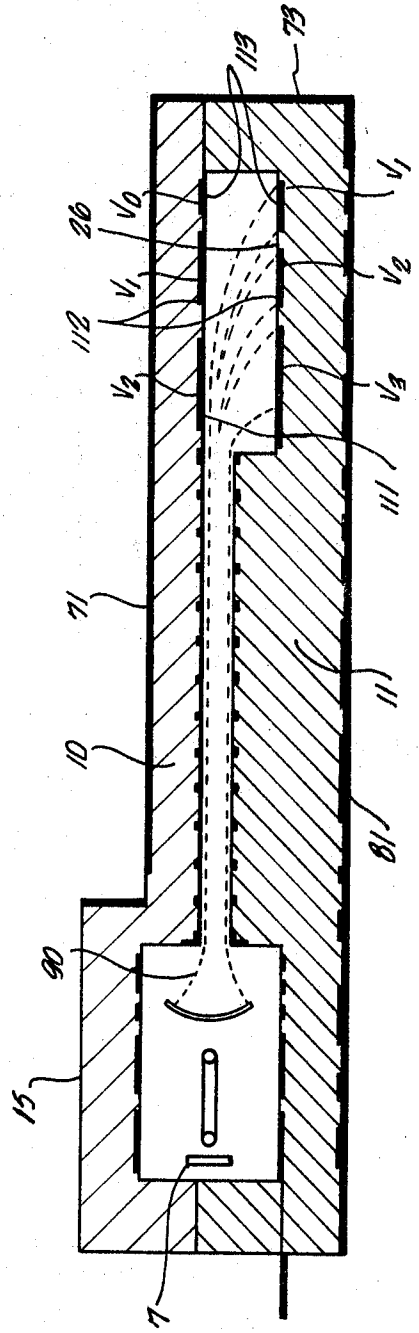


Fig. 1

FIG 8.

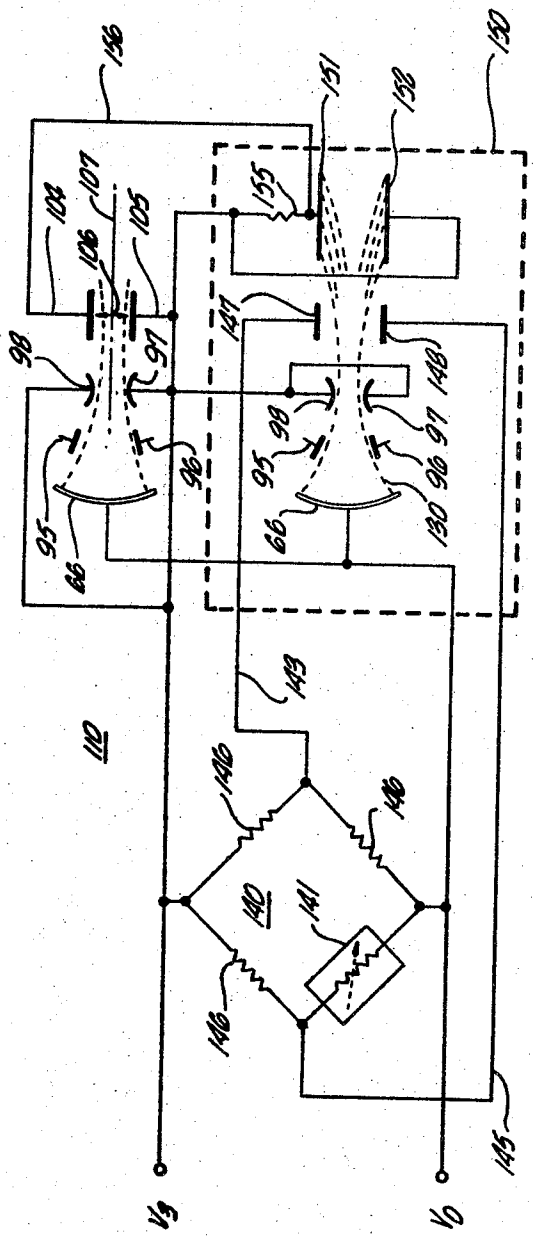
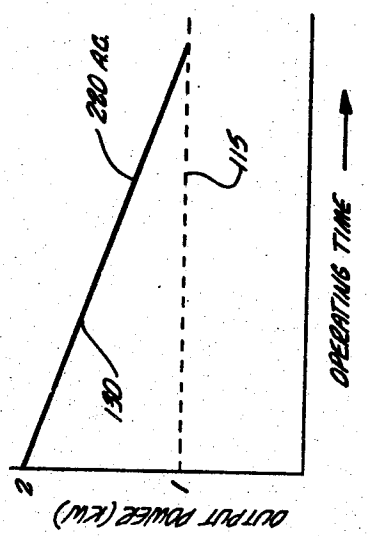

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151
152
150
104
107
105
106
155
141
98
97
140
96
95
99
66
130
110
143
146
140
141
145
V_s
V_o

FIG 8A.


280 A.G.
115
130
OPERATING TIME
OUTPUT POWER (KW)
2
1

INTEGRAL MICROWAVE RADIATING AND GENERATING UNIT FOR HEATING

CROSS-REFERENCES TO RELATED APPLICATIONS

This is a divisional application divided from an application entitled "Integral Microwave Radiating and Generating Unit", having a Ser. No. 502,867, filed Oct. 23, 1965, now U.S. Pat. No. 3,448,384 by inventor Allan W. Scott.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The fields of the invention include ultra-high frequency generators and heating ovens for commercial, industrial and military applications.

2. Description of the Prior Art

Microwave generators for heating, commonly referred to as microwave oven units, are known in the art. The existing prior art microwave oven units generally comprise a plurality of electronic components, each of which perform a single function, and the majority of which components are external of the cavity, or oven enclosure. These units of the prior art, depending upon alternating or direct current power requirements, normally include a complex rectifier, filter and high voltage transformer and high voltage leads; such equipment being required to convert standard line voltage to the high valued voltage necessary for powering a standard magnetron tube. The magnetron tube is a primary component of prior art microwave oven units, and is located externally of the cavity. The magnetron serves to convert high voltage electrical energy to microwave energy. In operation, the magnetron tube consumes a significant amount of energy and generates considerable heat. Accordingly, the prior art ovens require a fan for air circulation or a pump for liquid circulation to cool the magnetron tube. Such equipment is expensive, creates electrical disturbances, and increases the bulk of prior art microwave ovens to the extent that they are not satisfactory or practical for home or industrial use. (1)

Normally connected to the magnetron tube is an external wave guide having dimensions precisely designed and machined so as to conduct the microwave energy generated by the magnetron tube to the oven cavity. This wave guide generally terminates at a stub or point source located at a small opening in one wall of the cavity. Positioned near the opening is a mechanically rotating or reciprocating stirrer for uniformly dispersing the radiated microwave energy throughout the cavity's enclosure. These stirrers of the prior art are not entirely satisfactory in dispersing microwave energy in the oven, with the result sometimes being the presence of "hot" and "cold" spots rather than an even distribution of heating energy. In addition, such mechanical parts represent additional expense, are unreliable and unattractive and thus greatly detract from the commercial acceptance of prior art microwave ovens.

In summary, the prior art microwave ovens are complex, costly, and normally unsuitable for many microwave oven uses in that they are very bulky and require many external components and dangerous high voltages, making such units unattractive and impractical for commercial and home use.

SUMMARY OF THE INVENTION

The foregoing disadvantages of the prior art are avoided in accordance with the principle of this invention wherein a new and improved microwave generating and radiating unit is provided as one integral component. It is compact and may be mounted internally as one side of the oven cavity. The microwave unit of this invention is a low-voltage unit that operates directly from conventional household line voltage, and thus requires no external magnetrons or external cooling equipment which characterize the prior art.

Printed circuitry on dielectric sheets is employed for substantially all operating structures for this microwave unit including, but not limited to, the electron beam creating and collecting elements, the electron beam focusing means,

microwave interaction structure, the microwave antenna or radiating means, and feedback means. A plurality of microwave units chosen with individual and different operating frequencies may be positioned side-by-side in a common vacuum envelope on one wall of the cavity to be heated. Each unit has its own printed circuit antenna on a dielectric surface facing into the oven cavity. These antenna structures may be either of a random or of a uniform pattern. The microwave signals from the plurality of units are purposely made to be noncoherent, and this factor tends to radiate microwave energy uniformly throughout the cavity, thus eliminating all mechanical stirring apparatus. Printed circuit structure of this invention is readily adaptable for automation and, accordingly, the unit of this invention represents not only a decrease in size and voltage requirements, but also represents a decrease in the cost of manufacturing as compared to prior art microwave oven units.

One further advantage of the structure of this invention may be appreciated by considering that prior art apparatus utilizes rather elaborate schemes for detecting the output line voltage level and feeding a portion of that detected level back through an elaborate power supply so that the high power supplied to the magnetron tube is held at a constant value. In accordance with the principles of this invention, such elaborate circuitry and extra equipment is avoided by utilizing a simple reliable power control circuit. As the microwave unit varies its output power, a power control circuit of this invention varies the coupling between the electron beam and an interaction structure so as to assure a constant power and constant performance for the microwave unit without regard to either short or long time variations in the voltage supply, and without regard to aging effects manifested by decreased electron emission. In one nonlimiting embodiment the control circuit comprises a differential deflection amplifier which employs one distinct portion of the main electron beam for its amplifier beam. A printed microwave power sensitive device forms part of a printed bridge circuit which applies voltages to deflection electrodes positioned on opposite sides of the main electron beam. Such deflection voltages are of appropriate polarity and strength so as to automatically move the beam away from or toward the interaction circuitry so that a constant microwave power output is assured.

BRIEF DESCRIPTION OF THE DRAWING

Specific embodiments of the present invention will now be described by way of example, with reference to the accompanying drawing in which:

FIG. 1 is a combined perspective and cutaway view of an integral microwave radiating and generating unit in accordance with this invention;

FIG. 2 is a front perspective view of an oven constructed in accordance with the present invention where substantially the upper oven wall is formed by the microwave unit of this invention, said unit employing a plurality of microwave radiating means;

FIG. 3 is a circuit schematic of a voltage multiplier circuit;

FIGS. 4A and 4B are plan view of printed circuits serving as electrostatic focusing arrays or serving as interaction arrays in accordance with this invention;

FIG. 5 is a plan view of an additional form for a printed interaction array of this invention;

FIG. 6 is a combined perspective and sectional view of an alternative embodiment of the microwave unit of this invention employing an electron gun and electron collection plates, both of which are offset from the main axis of the electron beam.

FIG. 7 is a side elevation of an embodiment wherein opposed planar dielectric sheets define a flat elongated vacuum cavity;

FIG. 8 is a circuit schematic of a power control circuit in accordance with the principles of this invention; and

FIG. 8A is a chart of output power as a function of microwave oven operating time useful in promoting a full understanding of the operation of the power control circuit of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Turning now to FIG. 1, a microwave oven unit in accordance with this invention comprises a compact and integral power conversion and ultra-high frequency radiating and generating unit 15. This unit 15 includes a pair of opposed plane dielectric sheets 10 and 11. These sheets may be any suitable dielectric such as ceramic, glass, pyroceram or other similar dielectric materials capable of receiving and supporting printed circuitry. Assuming that ceramic is used, for example, the bottom ceramic sheet 11 is selected shorter than the top ceramic sheet 10 by an amount sufficient to expose the electron beam collecting plates 21 and 22.

Ceramic sheets 10 and 11 are supported with proper spacing for the electron beam by a plurality of metal or ceramic posts. One such post 6 is shown broken away in FIG. 1. Post 6 includes a hollow cylinder having the microwave output lead 73 printed on the inner surface for connection to a microwave radiating antenna 81. Electrical interconnections, as necessary, may be provided in a similar manner on the same or other posts not shown.

Opening 12 is the beam forming area and houses an electron gun 14, a heater 16, and a plurality of printed beam converging electrodes 18. Communicating with the rectangular opening 12 is a narrower elongated flat opening 20 which also runs across the width of ceramic sheets 10 and 11 as well as along the length thereof. This flat opening 20 is a beam guiding area and includes printed focusing circuitry 23, 24 on its upper and lower areas, respectively, for guiding the flat sheet electron beam 30 from gun 14 to opening 26. Opening 26 is a beam collection area which houses the electron beam collecting plates 21 and 22. These beam collection plates 21 and 22 are formed from narrow metal strips having areas selected such that the strips serve to provide for effective heat dissipation through the glass envelope 25 which encases the entire oven unit.

Glass enclosure 25 encases the ceramic sheets 10 and 11 and is evacuated and vacuum sealed in any well-known manner. Thus, openings 12, 20 and 26 between the ceramic sheets 10 and 11 are maintained at a high vacuum, as required for electron emission, focusing, and collection of the flat sheet electron beam 30.

The power conversion circuitry 17 of this invention may more readily be understood by reference to the voltage multiplier circuit 17 of FIG. 3. The voltage multiplier circuit 17 of FIG. 3 converts AC line voltage applied at terminals 45 to a ripple or DC voltage of any desired maximum DC level in accordance with the number of diodes employed. For example, when three diode pairs are utilized, as shown in FIG. 3, a maximum voltage of 1000 DC volts may be obtained from an AC input of 220 volts. If the unit is operated on an AC input line voltage of 110 volts, then six diode pairs are required to generate a maximum DC output of 1000 volts. Several different valued DC voltage levels are developed by each pair of diodes 31 to 36. For example, distinct voltage levels are depicted at outputs 60 to 63 as voltage levels V_0 through V_3. These DC voltage levels are utilized in the unit of this invention to form the electron beam. They are also used in various voltage combinations to focus the electron beam adjacent to a microwave interaction structure, and are also employed in various voltage combinations to collect the electron beam once it has passed adjacent to the microwave interaction structure.

In the voltage multiplier circuit 17 each diode pair has an anode of one connected to the cathode of the other diode in the pair. These pairs are further connected in series as shown. The voltage multiplier 17 of FIG. 3, connected in this manner, operates in a conventional manner and includes capacitors 41 to 43, and capacitors 51 to 53.

All of the input capacitors 41 to 43 have one plate connected to a common terminal of the pair of input terminals 45. Input line voltage is applied through capacitors 41 to 43 to a common junction between an anode and cathode of the doubler diodes pairs 31, 32, and 33, 34 and 35, 36 respectively. Each of the doubler circuits further includes output capacitors 51, 52 and 53 connected across the doubler diode pair 31, 32 and 33, 34 and 35, 36.

It should be understood that the voltage multiplier unit 17 may be located either internally or externally of the microwave unit 15. If externally, output leads 60 to 61 would extend through the glass envelope 25 for connection to appropriate components in unit 17. The diodes 31 to 36 may be any conventional diodes such as thermionic or semiconductor to cite some typical examples.

Selected ones of the voltages V_0 to V_3, supplied by the power conversion circuitry 17 of FIG. 3, as described hereinafter, are connected to the heater coil 16 and electron gun 14; to the beam converging electrodes 18; to the focusing electrodes 23, 24; and to the beam collector plates 21 and 22 (FIG 1). Electron gun 14 may be any well-known electron gun, provided that it is employed to form a flat sheet electron beam. For example, the electron gun 14 of this invention may be fabricated from a stamped, nickel strip that is sprayed with an emissive coating so that electrons are emitted from the concave surface when heater coil 16 is energized. Heater coil 16 comprises a high resistance wire such as tungsten wire which is connected to voltage circuit 17 or to the AC line voltage. This tungsten wire is wound around a ceramic rod supported in opening 12. This voltage, in a well-known manner, heats coil 16 which in turn heats the electron gun 14. A steady stream of electrons is emitted from the emissive coating of heated gun 14. The electrons emitted from the curved surface of an electron gun 14 are converged into a flat sheet electron beam 30 by converging electrodes 18. The high current density of the electron beam would cause the beam to spread in thickness in area 20 due to mutual repulsion of the electrons forming the beam 30. Beam 30, however, is held essentially in the flat sheet beam as shown by the dashed lines of FIG. 1 by a pair of electrostatic focusing arrays 23, 24 one each of which is located above and below beam 30.

It should be understood that numerous focusing arrays are available. For example, the focusing array shown partially in FIG. 1 is repeated in FIG. 4A as one possibility. The focusing array of FIG. 4A includes two interleaved ladder circuits 23 and 24. Each one of the circuits 23 and 24 are electrically connected to different voltages of the voltage multiplier circuit 17. Electron beam 30 has an average electron beam voltage. The voltages for circuits 23 and 24 are selected to be both above and below this average voltage for beam 30. These voltages at circuits 23 and 24 establish field gradients in opening 20 which alternatively attract and repulse beam 30 toward and away from the focusing arrays on both ceramic sheets 10 and 11. The net result of this field gradient is an inwardly directed electric field that keeps the electron beam 30 focused substantially as a flat sheet beam. For increased focusing and higher current density, a multiple voltage focusing array as shown in FIG. 4B may be employed. Typical voltages for this multiple voltage array of FIG. 4B may be the voltages V_0, V_1 on the lower tortuous array leads 54, 55 and voltages V_2 and V_3 on the upper tortuous leads 64 and 65.

As is well known, the electron beam 30 represents a large amount of kinetic energy. This kinetic energy is present because the electrons are accelerated from the electron gun 14 to the beam collecting area 26. The kinetic energy of electron beam 30 is converted into microwave energy within unit 15. To achieve this conversion, a microwave interaction structure 71 is printed on the upper surface of the ceramic sheet 10. Numerous forms of microwave interaction structures are available. The form shown in FIG. 1 is an array of printed parallel wires 72 connected at their centers by a printed lead 74 so as to form a flattened ring bar helix. This ring bar helix, of selected dimensions, is so positioned that a microwave signal is propagated through the ring bar helix at the same

axial velocity as the electron beam. Microwave fields are established by the microwave signal passing through the ring bar helix 71, and such fields extend through the ceramic sheet 10 and interact with the electron beam 30. This interaction between the signal in helix 71 and beam 30 results in the generation of microwave power.

Generating microwave power from an electron beam is a typical conversion operation for all beam-type microwave tubes. Such tubes may be of the traveling wave tube type or of the klystron type. Both of these types include microwave interaction structures and result in considerable amplification. The difference in operation of the two types depends upon the type of interaction structure employed. Two suitable forms of interaction structure for both types of operation are depicted in FIGS. 4A and FIG. 5. In the interaction structure of FIG. 4A an array of parallel wires 23, 24 are printed on the ceramic sheet and have the required property of propagating a microwave signal at the same velocity as the electron beam. In FIG. 4A the two separate parallel arrays 23 and 24 are interleaved to form an interdigital line.

FIG. 5 depicts an interaction structure that is available to obtain a klystron type of operation. In a klystron, the electrons act only at intervals along the interaction structure. These intervals of interaction are actually sections of a ring bar helix identified as 56, 57 and 58 in FIG. 5. These sections are terminated by shorting bars 50. There is no interaction achieved between each of the ring bar helix sections 56 to 58 due to shorting bars 50. In the shorted sections the electron beam merely drifts without any interaction between it and the signal being propagated through the interaction structure of FIG. 5.

With respect to the focusing array 23, 24 or FIG. 4A (which is itself an interdigital line) no interaction between a signal in the focusing array and the electron beam takes place because the velocity of propagation in the focusing array is chosen to be much less than the velocity of the electron beam. On the other hand, if the array of FIG. 4A is to serve as an interaction structure, the velocity of propagation of the signal in the interdigital line is chosen to be equal to the velocity of the electron beam as this is an essential requirement for operating either in a traveling wave mode or a klystron interaction mode. By separating the focusing array 23, 24 and the microwave interaction structure 71 and placing them on opposite sides of the ceramic sheet 10, FIG. 1, each of these circuits may be optimized independently of the other, whereby a higher conversion efficiency and higher gain is obtained. However, these structures could be combined into a single structure if so desired.

With reference to FIG. 1 it should be understood that the microwave interaction may not be inherently self-oscillatory. If self-oscillation is not established, then a source of input microwave power for the microwave interaction structure is required. Any necessity for an external microwave power source can be eliminated by employing the printed feedback circuitry shown in the upper right-hand side of FIG. 1. This feedback circuitry includes a printed directional filter 75 shown in dashed lines. This directional filter inductively samples a small portion of the output microwave power at the output lead 73 of the ring bar helix. This inductive coupling is achieved by the printed J-shaped stub 74 which has induced therein a sampled signal represented by arrows 76. This sample of the output signal is passed through the printed directional filter squares 77 and 78 and coupled back through another J-shaped printed stub 79 and lead 80 to the input of the ring bar helix 72. The printed directional filter squares 77 and 78 are dimensionally selected to provide a pass filter having a narrow pass frequency range. Accordingly, the entire microwave oven unit oscillates only at the pass frequency of the directional filter 75. For example, one typical pass frequency particularly appropriate for a microwave oven is an oscillating frequency of 915 or 2450 megacycles.

In FIG. 2 a microwave cavity or oven enclosure 90 is shown having four different random antennas 81 through 84, forming substantially the upper wall 91 of the oven cavity 90. As is well known in the art, several different microwave frequency modes exist in a typical oven enclosure 90. These different modes depend upon the enclosure dimensions which generally speaking are several wave lengths long. The dimensions of the printed circuit antenna are selected so the right amount of microwave power is coupled to all modes whereby uniform power and heating density is provided in the oven enclosure. As depicted in FIG. 2, the microwave oven unit 15 may comprise one wide flat beam having several interaction structures each having associated therewith antennas 81 to 84. Each interaction structure may operate at a frequency different from all other structures. Of course, a plurality of separate microwave power units, each of them described hereinbefore in connection with FIG. 1, may be employed rather than having one wide beam. These different units may be separately encased or encased in a common vacuum envelope 100, FIG. 2.

Employing a plurality of antennas and several different frequencies for each, in accordance with this invention, provides several advantages even though such arrangement does not yield coherent microwave power. Numerous prior art designs for traveling wave tubes have strived to achieve coherency. However, I have found a distinct advantage in non-coherency. By placing as many microwave antenna circuits, such as 81 to 84, FIG. 2, side-by-side as is desired, coherency is destroyed, but the energy coupling within the oven cavity 90 is optimized for a wide variety of foods. Furthermore, by utilizing antennas printed in random patterns, microwave energy is radiated from several different points in the oven, and even more uniform energy distribution is thereby achieved.

In FIG. 1 the antenna 81 is printed on the lower surface of dielectric sheet 11. The thickness of the dielectric sheet is properly chosen so that the focusing array 23 and 24 forms the necessary ground plane for the antenna. The antenna 81 radiates the microwave energy through the glass envelope 25. It should be realized that the antennas 81 through 84 may be printed on the lower surface of the glass envelope 25 and connected by conventional techniques to the interaction output lead 73, FIG. 1. Also, it should be appreciated that the antennas may, if desired, be designed completely separate from the microwave unit and connections made in any conventional manner from the output of the interaction structure to the separate antennas.

As a general rule the generation of microwave power utilizes approximately one-half of the original kinetic energy of electron beam 30. The interaction operation tends to establish classes of electrons with each class having a different velocity. The several voltages V_1 to V_3 from the voltage multiplier circuit are each individually connected to independent collection plates 21 and 22 to maximize efficiency. Associated with collector electrodes 21 and 22 are a plurality of electron beam deflection plates 85 to 87. These plates 85 to 87 are printed on the ceramic sheets 10 and 11 near the junction of the elongated beam guiding opening 20 and the electron beam collecting and the heat dissipating area 26, and are connected to appropriate voltages from the voltage multiplier circuit 17 so as to deflect the electron beam 30 upward toward the offset collecting plates 21 and 22. Classes of electrons with slow velocity are collected by the higher voltage collection plates and higher velocity electrons are connected by lower voltage collection plates.

The microwave antenna structures 81 through 84 establish a high frequency radiation for accomplishing what is commonly referred to as a "deep cooking" effect on food placed within the oven cavity 90. In addition, the microwave unit 15 of FIG. 1 is capable of supplying thermal energy in the form of high temperature radiant heat created by beam collection; or such heat may be dissipated by conduction and convection from the ceramic and collection plates in the beam collection area of the microwave unit 15.

The beam collector radiates heat for browning from collector electrodes 21 and 22. These radiation plates are selected

with areas appropriately designed so that the narrow metal strips operate at approximately 1,000° C. This high temperature allows effective heat radiation through the envelope 25 which heat may be used for browning. In these instances where a controlled degree of browning is desirable, any conventional control 89, FIG. 2, may be utilized to vary the amount of voltages applied to the electron beam deflection plates, whereby the temperature of the plates is regulated.

Furthermore, in accordance with the principles of this invention, the collector plates 21 and 22 in addition to beam collection and thermal radiation, may also serve as cathodes for diodes forming part of the voltage multiplier circuit 17. Thus, electrodes 21 and 22 may be coated with any suitable electron emissive material so that the collector plates 21 and 22 operate as cathodes for selected parts of the diodes required for the voltage multiplier circuit 17, FIG. 3.

In the description hereinbefore of the voltage multiplier diodes located in the electron gun enclosure 12, heat for the cathodes 38 was supplied by the cathode heater unit 16. In this alternate embodiment, only part of each diode is located in the electron gun enclosure 12 and heated by the heater 16. These parts permit the formation of a low-current beam which heats the diodes located in the beam collecting and radiating area 26. As these collector diodes 21 and 22 increase in temperature, the doubler circuit provides the required voltage for obtaining full electron beam current. Anodes 28 and 29 are again printed opposite the heated cathodes 21 and 22, and are connected to appropriate capacitors by printed circuit leads described in more detail hereinbefore.

A different form of combination beam collecting and heat radiating surfaces is shown in FIG. 6. The electron beam collection plates 92, 93 and 94 of FIG. 6 are curved metal strips mounted across the width of the oven unit 15, on a suitable mounting structure 125. Convex surfaces of plates 92A through 94A are provided for heat radiation. These convex surfaces are positioned on mounting 125 so as to establish overlapping thermal radiation patterns. By staggering these thermal radiation areas in the front and back sides of the top of cavity 90, FIG. 6, uniform browning is thus achieved without requiring any additional oven coil. Microwave radiation is achieved by antenna 81 printed on a third dielectric sheet 9, in this alternate embodiment. The spacing between 9 and 11 is selected to provide the necessary ground plane for antenna 81.

Electron gun 14, FIG. 1, is shown positioned along the velocity axis for the electron beam 30. In the formation of the electron beam 30, small particles of the emission surface as well as electrons may be emitted from the electron emitting surface of electron gun 14. Such small particles of the emission material may become lodged between the alternate electrodes of the electron beam converging and focusing arrays 23, 24. Such deposits can short out some of the beam guiding electrodes and thus reduce tube life and tube efficiency. This possible disadvantage is avoided by employing an electron gun of different configuration as shown, for sample, by the electron gun 66 of FIG. 6. This electron gun 66 is fabricated and supported in substantially the same manner as electron gun 14 of FIG. 1, however, its electron emitting surface is offset from the axis of the electron beam 30. The electron beam 30 is converged as before and in addition bends into the electron beam axis of opening 20. Converging and bending as required to guide the beam into the flat elongated beam guide opening 20 is achieved by a plurality of formed metal electrodes 95, 96, 97 and 98. These electrodes are brazed or otherwise bonded to the ceramic sheets 9 and 10, and receive voltages from appropriate outputs of the printed voltage multiplier circuit 17, FIG. 3. Bending the electron beam 30 in the manner depicted in FIG. 6 assures that all emitted particles of the emission surface are propelled into the underside of ceramic sheet 10 and are not allowed into the beam guiding area 20. The possibility of electrode shorting is thus virtually eliminated by positioning the electron emitting area at an angle either above or below the main velocity axis of the electron beam.

FIG. 7 depicts a side elevation of an alternative embodiment of a microwave oven unit in accordance with the principles of this invention. In FIG. 7, two opposed planar dielectric sheets 10 and 11 are bonded together in an airtight seal at the butt joints for the dielectric sheets. Numerous known techniques are available for bonding ceramic sheets together and for forming an interior vacuum. After the interior cavities are rough vacuum pumped, the structure is sealed off, and final vacuum pumping may be accomplished by activating getter 7. An electron beam 30 is formed, guided and collected by printed circuitry described hereinbefore.

In the microwave unit 15 of FIG. 7, the interaction structure 71 is located on top of sheet 10 along with associated printed feedback circuitry described earlier. Connection to an antenna 81, which is located on the bottom of ceramic sheet 11, is made by way of a printed microwave lead 73 which wraps around the beam collection end of ceramic sheets 10 and 11.

A plurality of offset beam collection plates pairs 111, 112 and 113 are printed on opposite upper and lower surfaces of the beam collection area 26. These plates are connected by printed circuit connections to voltage multiplier output leads 60 through 63, FIG. 3, and thus are at the voltages shown in FIG. 7. As electron beam 30 interacts with microwave structure 71 classes of different velocity electrons are established in beam 30. Slower velocity electrons are deflected earlier than faster electrons. Collection plates 111, 112 and 113 are selected to have different areas so that these different classes of electrons are collected by plate areas which provide proper heat transfer. Heat formed by such electron beam collection is dissipated by conduction through ceramic sheet 11, by radiation and natural convection from unit 15.

As mentioned in the introduction to this specification, prior art microwave units generate an output power which decreases with the life of the tube unless elaborate power supply units are employed to compensate for this variation. In FIG. 8A a chart of output power with respect to tube operating time is shown having curve 130 based on an unregulated 220 AC input voltage unit. It is clear from power curve 130 that the output power from a unit may start approximately at 2000 watts but tends to decrease with operating time. Such output power reduction reflects a corresponding variation in the cooking time required for different foodstuffs.

A regulated power control curve 115 is also shown in FIG. 8A. Curve 115 represents an output power from the microwave unit of this invention at a constant 1000-watt level throughout the entire life for the unit. Such constant output power assures a constant cooking time for any given food to be cooked in spite of the age of the microwave unit.

Constant output power of curve 115 is achieved by a power control circuit 110, FIG. 8, of this invention. Control circuit 110 measures the microwave power output from the tube in accordance with the heating effect created by such microwave power, and converts this measurement in a simple and straightforward manner to a deflection voltage which automatically varies the degree of interaction so as to compensate for any heat, i.e. power loss. For a new microwave tube 15, the power control circuit initially positions electron beam 30 near the bottom focusing array as shown in FIG. 6. As the tube ages, the electron beam 30 moves upward toward the interaction structure 71 so as to interact in a more efficient manner, and thus generate more microwave power output. Although described thus far with respect to long term performance degradation, short term variations or fluctuations in input voltage are also compensated for by control circuit 110 of this invention as will become clear in the detailed description hereinafter.

Power control circuit 110, as is true of most of the operative structures for the microwave unit 15, is advantageously a printed circuit. For simplicity of description, however, the power control circuit is shown in combined pictorial and circuit schematic form in FIG. 8. The power control circuit 110 includes beam deflection plates 104 and 105 which are shown in FIG. 6, positioned across the width of the flat ceramic

sheets 10 and 11 on opposite sides of electron beam 30. These deflection plates 104 and 105 move the main electron beam 30 in a direction 106, FIG. 8, which is transverse to its main electron velocity axis 107. It should be understood that when the main electron beam 30 is deflected upon entry into the beam guiding area 20, the focusing electrodes 23, 24 of FIG. 6 maintain beam 30 in the initial position throughout beam guiding area 20. Thus, if the beam 30 is initially deflected by deflection voltages at plates 104 and 105, downward toward the bottom focusing array, the beam holds this position as it passes through beam guiding area 20 until the deflection voltage across plates 104 and 105 changes the initial position of beam 30.

FIG. 8 in addition to the deflection plates 104, 105 which control the position of the electron beam relative to the microwave structure 71, comprises a resistance wheatstone bridge 140, having in one arm thereof a means 141 for sensing microwave output power. An amplifier 150 (dashed lines) is connected between the output terminals 143 and 145 of the bridge 140 and the deflection plates 104 and 105. Means 141 senses any variation in heating power from unit 15 and may advantageously be any known electrical component in which the resistance varies proportionately to changes in temperature in the component 141. For example, means 141 may be a bolometer which measures microwave power by its heating effect. As shown in FIG. 6, bolometer 141 may advantageously be positioned at a section of the output lead 73 from the ring bar helix 72 and may take the form of printed variable resistor or a thin tungsten wire. Microwave heating effects in the tungsten wire change the wire's resistance and this resistance change in turn is converted to a voltage change by the resistance bridge 140. In resistance bridge 140, each resistor 146 is a heat compensated fixed value resistor. The bolometer 141 of FIG. 6 has a resistance which varies as microwave power varies, as shown schematically by the dashed arrow in the remaining arm of bridge circuit 140.

In the representative curve 115 shown in FIG. 8A, it was assumed that a constant output power for the microwave unit would be 1000 watts. This output power value establishes a predetermined initial resistance value in bolometer 141 which value is chosen with respect to the resistance values of fixed resistors 146 so as to initially balance bridge circuit 140. Input voltages V_0 and V_3 are applied across circuit 140 and with bridge circuit 140 balanced, there is no output voltage signal present on the bridge output leads 143 and 145.

Input voltages V_0 and V_3 also serve as electron beam forming voltages for both the main electron beam 30 and a secondary electron beam 130. This secondary electron beam 130 may be an outer edge of the main beam 30 or it may be an entirely separate electron beam. Associated with both electron beams 30 and 130 are beam converging and focusing electrodes 95 through 98. These converging electrodes were discussed in detail with respect to the operation of unit 15, FIG. 6, and need not be repeated here. Their function is to converge and form the electrons emitted as a result of the voltage difference between the electron gun 66 and the anodes 97 and 98, into flat sheet electron beams 30 and 130.

The secondary electron beam 130 allows a difference amplifier 150 to be readily and economically incorporated as an integral operative structure in the microwave unit 15. It should be understood that any suitable amplifier means could be employed in place of differential deflection amplifier 150, for supplying output power correction voltages to deflection plates 104 and 105. Deflection amplifier 150, however is particularly applicable to the feedback servo operation of this invention because small variations in output voltage signals from bridge circuit 140 are amplified to large magnitude differential correction voltage which are independent of errors normally associated with many amplifier means, particularly if two standard amplifiers were to be employed.

In the operation of differential deflection amplifier 150, when bridge circuit 140 is balanced and there are no output voltage signals present on leads 143 and 145, the electron beam 130 divides equally between the upper and lower collection plates 151 and 152. A resistor 155 is connected between upper deflection plate 151 and the input voltage V_3. Input voltage V_3 is also applied to the main electron beam deflection plate 105. Resistor 155 is chosen to have a resistance value which represents a predetermined voltage drop with bridge 140 balanced. Output lead 156 from amplifier 150 connects plate 151 directly to the deflection plate 104. This connection establishes an initial voltage gradient across plates 104 and 105, which acts to deflect the electron beam 130 downward in the position shown in FIG. 6.

In order to fully appreciate the operation of control circuit 110, assume that the power output as represented by the resistance value of bolometer 141 decreases either due to age or because of a variation in the input voltage for the microwave oven unit. This decreased output power represents a lower temperature in the bolometer 141 which in turn is manifested by a variation in the resistance value of bolometer 141. Bridge 140 is consequently unbalanced and an output voltage signal on leads 143 and 145 applies a voltage gradient across the deflection electrodes 147 and 148 of the different amplifier 150. This voltage disturbs the normal division of the electron beam 130 to plates 151 and 152, and thus the current through resistor 155 develops a different voltage gradient that is applied between the deflection plates 104 and 105. This new voltage gradient deflects the entire electron beam 30 upward so as to increase the degree of interaction between beam 30 and the microwave interaction structure 71, FIG. 6. Increased interaction of course, increases the power output from the microwave unit 15, which, in turn, is reflected in bolometer 141 so as to rebalance bridge circuit 140.

Power control circuit 110 also compensates for periodic increases in microwave output power by reducing the degree of interaction between electron beam 30 and the microwave interaction structure 71, FIG. 6. This operation need not be described in detail because it is evident from the previous description. In short, therefore, the power control unit 110 of this invention varies, i.e., increases or decreases, the amount of interaction between microwave structure 71 and the electron beam 30 in a manner which assures constant output power throughout the entire tube life.

It should be understood in the microwave unit 15 of FIGS. 1, 6 and 7, that a plurality of offset beam collection plates as an alternative to stamped metal sheets 21, 22 and 92 through 94 may be printed on either the opposite upper or lower surfaces of the beam collection area 26. These printed plates may also be connected by printed circuit connections to voltage multiplier output leads 60 to 63 of FIG. 3. As electron beam 30 interacts with microwave structure 71 classes of different velocity electrons are established in beam 30. Slower velocity electrons are deflected earlier than faster electrons. Each of the plurality of collection plates are selected to have different areas and different potentials so that these different classes of electrons are collected by plates areas which provide proper heat transfer. Heat formed by such electron beam collection is dissipated by conduction through ceramic sheet 10, and by radiation and natural convection from the glass enclosure of unit 15.

I claim:

1. Heating apparatus comprising:

a. a heating cavity including means for enabling a body to be heated to be placed inside said heating cavity; and

b. an energy generating and microwave radiating unit for heating said body, said unit including a pair of opposed planar dielectric sheets forming a substantially flat energy generating cavity, one of said sheets forming substantially one side of said heating cavity.

2. Heating apparatus comprising:

a. a cavity including means for enabling a body to be placed inside said cavity; and

b. an energy source substantially forming one wall of said cavity for supplying energy to cook said body, said source comprising an integral unit located within said cavity and

having means for generating and radiating microwave energy to deep cook said body, and further having means associated with said microwave generating means for radiating thermal energy to brown said body.

3. Heating apparatus comprising:

a. a cavity including means for enabling a body to be placed inside said cavity;

b. a source of electric power;

c. means located within said cavity and connected to said source for converting said electric power to microwave energy having a plurality of distinct microwave frequencies; and

d. a plurality of antennas located within said cavity and connected to said conversion means, one each of said antennas being responsive thereto for radiating one each of said distinct frequencies of microwave energy throughout said cavity.

4. Heating apparatus comprising:

a. a cavity including means for enabling a body to be placed inside said cavity;

b. a source of electric power;

c. means located within said cavity and connected to said source for converting said electric power to microwave energy; and

d. means integral with said power converting means for radiating said microwave energy throughout said cavity.

5. Heating apparatus in accordance with claim 4 wherein said means for converting electric power to microwave energy comprises:

a. means forming a vacuum enclosure comprising substantially one wall of said cavity;

b. a stream of electrons moving in a sheet electron beam within said enclosure;

c. a dielectric member supported adjacent to said electron beam; and

d. an electromagnetic structure printed on said dielectric member for interacting with the moving electrons in said beam so as to convert the electron translation to microwave energy.

6. Heating apparatus in accordance with claim 5 and further comprising an antenna means also printed on said dielectric member and connected to said electromagnetic structure for radiating said microwave energy throughout said cavity.

7. Heating apparatus in accordance with claim 6 wherein said antenna means comprises a printed random zigzag pattern for radiating said microwave energy in a random fashion to optimize coupling of said energy for a wide variety of food to be cooked.

8. Heating apparatus in accordance with claim 5 and further comprising an electrostatic structure also printed on said dielectric member for focusing said stream of electrons in the form of said sheet electron beam.

9. Heating apparatus comprising:

a. a cavity including means for enabling a body to be cooked to be placed inside said cavity;

b. means forming a vacuum enclosure and comprising substantially one wall of said cavity;

c. a source of electric power connected to said vacuum enclosure means;

d. means located in said vacuum enclosure and connected to said source of electric power for converting said electric power to microwave energy; and

e. means connected to said conversion means for radiating said microwave energy throughout said cavity.

10. Heating apparatus in accordance with claim 9 wherein said radiating means is within said vacuum enclosure.

11. Heating apparatus in accordance with claim 9 wherein said radiating means is printed on the outside of said vacuum enclosure.

12. Heating apparatus in accordance with claim 9 wherein said means forming a vacuum enclosure comprises:

a. a pair of opposed plane dielectric sheets, said sheets being joined in an airtight seal at their periphery and having countersunk regions within the periphery for forming a substantially flat elongated vacuum cavity;

b. means positioned at one end of said flat elongated cavity capable, when heated, of emitting a stream of electrons;

c. means connected to said source of electrical power for heating said emissive means to emit a stream of electrons therefrom;

d. means positioned at the opposite end of said elongated cavity for collecting said emitted stream of electrons;

e. electrostatic means printed on the inner surfaces of said opposed plane dielectric sheets and on opposite sides of said emitted electron to focus the electrons in a flat sheet beam between said emitting means and said collecting means;

f. a microwave signal conductive structure printed on the outside surface of one of said opposed plane dielectric sheets for interacting with the moving electrons in said beam so as to convert electron translation in said beam to microwave signal energy in said printed microwave structure; and

g. an antenna means printed on the outer surface of said remaining dielectric plane member and connected to said microwave structure for radiating said microwave energy throughout said cavity.

13. Heating apparatus in accordance with claim 9 wherein:

a. said means forming a vacuum enclosure comprises a substantially flat vacuum-sealed glass envelope; and further wherein

b. said means for converting electrical energy to microwave energy comprises:

1. a flat sheet beam of moving electrons;

2. a pair of flat dielectric sheets positioned on opposite sides of said electron beam;

3. a pair of electrostatic focusing means printed on the surfaces of said pair of dielectric sheets facing said electron beam, one each of said pair of focusing means printed on one each of said dielectric sheets and being operative for holding said electron beam in its flat sheet form;

4. a microwave signal conductive structure printed on a surface of one of said pair of dielectric sheets, said surface being opposite from the surface having said focusing means printed thereon for interacting with the moving electrons in said beam to convert the electron translation to microwave energy;

5. antenna means printed on the remaining flat surface of said pair of dielectric sheets and connected by microwave transmission means to said microwave interaction structure for radiating said microwave energy into said cavity to be heated; and

6. feedback means coupled between said microwave transmitting means and said microwave interacting means for causing said unit to oscillate at predetermined frequency.

14. Heating apparatus in accordance with claim 13 wherein said feedback means comprise a printed filter for passing said predetermined frequency.

15. Heating apparatus comprising:

a. a cavity including means for enabling a body to be cooked to be placed inside said cavity;

b. means forming a vacuum enclosure;

c. a source of standard line voltage connected to said vacuum enclosure means for supplying line voltage within said vacuum enclosure;

d. a voltage multiplier circuit located in said vacuum enclosure and connected to said line voltage supplying means for establishing a plurality of successive higher valued voltages;

e. means at one end of said vacuum enclosure for emitting a stream of electrons and focusing means associated with said emitting means and connected to voltages of said voltage multiplier circuit for accelerating and focusing said emitted electrons in the form of a flat sheet electron beam;

f. electron collecting means positioned at the opposite end of said enclosure and connected to a plurality of said successive voltages of said voltage multiplier circuit for collecting the emitted stream of electrons;
g. a first and a second flat dielectric sheet spaced on opposite sides of said electron stream;
h. a first pair of distinct tortuous printed electrical circuits interleaved on the surface of said first dielectric sheet and facing said electron stream;
i. a second pair of distinct tortuous printed electrical circuits interleaved on the surface of said second dielectric member facing said electron stream;
j. printed circuit means connecting distinct ones of said first and second pair of tortuous electrical circuits to one of said voltages of said voltage multiplier circuit, and for connecting the remaining one of said first and second pair of tortuous circuits to a second voltage of said multiplier circuit, said first and second voltages selected to focus said emitted electron stream into a flat electron beam between said first and second dielectric sheets;
k. a convoluted electromagnetic structure printed in a planar configuration of the remaining surface of said second dielectric sheet for interacting with the moving electrons in said beam for propagating a microwave signal therethrough at the same velocity as of the said electron beam; and
l. an antenna comprising a convoluted electromagnetic circuit printed in a planar configuration on the remaining surface of said first dielectric sheet and connected in microwave signal transmitting relationship with said electromagnetic structure for radiating said microwave signal energy throughout said cavity.

16. Heating apparatus in accordance with claim **15** wherein said vacuum enclosure means comprises a vacuum sealed dielectric envelope.

17. Heating apparatus in accordance with claim **15** wherein said vacuum enclosure means comprises said first dielectric sheet and a raised metal cover vacuum sealed to said first dielectric sheet.

18. Heating apparatus in accordance with claim **15** wherein said electron emitting means is offset from a main velocity axis of said electron beam.

19. Heating apparatus in accordance with claim **15** wherein:
a. said voltage multiplier circuit comprises a plurality of series connected diode doubler circuits; and
b. the diodes of said doubler circuits being a thermionic emission type wherein said heat for emission in said diodes is supplied by collection of said electron beam.

20. Heating apparatus comprising:
a. a cavity including means for enabling a body to be placed inside said cavity;
b. a source of line voltage;
c. means located within said cavity and connected to said source for converting said line voltage to a sheet beam of moving electrons;
d. a dielectric member positioned parallel to said sheet beam of moving electrons;
e. a microwave signal conductive structure printed on said member and interactively coupled with said moving electrons to convert said electron movement to microwave energy;
f. microwave energy radiating means connected by a microwave transmitting lead to said interaction structure; and
g. means for maintaining said microwave energy at a constant value for uniform radiation in said cavity during the operative life of said heating apparatus.

21. Heating apparatus in accordance with claim **20** wherein said constant energy maintaining means comprises:
a. signal responsive beam deflection means for controlling the degree of interaction between said moving electrons and said microwave signal conductive structure;
b. means for emitting signals proportional to microwave energy variations from said constant microwave energy value; and
c. signal applying means connected between said beam deflection means and said signal emitting means, for applying beam deflection signals to said beam deflection means.

22. Heating apparatus in accordance with claim **21** wherein said beam deflection means comprises a pair of beam deflection plates, one each of said pair positioned on opposite sides of said flat sheet of moving electrons.

23. Heating apparatus in accordance with claim **22** wherein said signal emitting means comprises:
a. microwave power sensitive means coupled to said microwave transmitting lead for sampling the amount of microwave power transmitted;
b. means for converting samples obtained by said sampling means to a first signal proportional to variations in said microwave power above said constant value and to a second signal proportional to variations in said microwave power below said constant value.

24. Heating apparatus in accordance with claim **23** wherein said microwave power sensitive means comprises a resistance means having a first predetermined resistance for said constant value microwave power and a variable valued resistance from said first predetermined resistance value for microwave power variations from said constant microwave power value.

25. Heating apparatus in accordance with claim **24** wherein said signal applying means comprises:
a. a difference amplifier having input and output terminals;
b. means connecting said amplifier input to said signal emitting means; and
c. means connecting said amplifier output to said beam deflection means.

26. Heating apparatus in accordance with claim **25** wherein said difference amplifier comprises:
a. a deflection amplifier sharing one portion of said flat sheet of moving electrons as its operative electron beam;
b. means connected to said amplifier input for controllably deflecting said one electron beam portion in response to signals emitted from said signal emitting means;
c. means for collecting said one beam portion;
d. means connected between said collecting means and said amplifier output for developing a first amplified signal proportional to variations in said microwave power above said constant value, and for developing a second amplified signal proportional to variations in said microwave power below said constant value.

27. Heating apparatus in accordance with claim **26** wherein:
a. said sheet of moving electrons is a flat form;
b. said dielectric member comprises a pair of plane dielectric sheets spaced on opposite sides of said flat sheet of moving electrons; and
c. said means for collecting said sheet beam of moving electrons comprises collection electrodes printed on one of said dielectric sheets, said electrode area being selected to transfer said thermal energy to said cavity by conduction through said dielectric sheet and by radiation and natural convection from said dielectric sheet.

28. Heating apparatus comprising:
a. a cavity including means for enabling a body to be placed inside said cavity;
b. a source of line voltage;
c. means located within said cavity and connected to said source for converting said line voltage to a sheet beam of moving electrons;
d. a dielectric member post positioned parallel to said sheet beam of moving electrons;
e. a microwave signal conductive structure printed on said member and interactively coupled with said moving electrons to convert said electron movement to microwave energy;
f. microwave energy radiating means connected by a microwave transmitting lead to said interaction structure; and
g. means for collecting said sheet beam of moving electrons to convert said electron movement to thermal energy,

said collecting means being operative for radiating said thermal energy to said cavity for browning said body.

29. Heating apparatus in accordance with claim 28 wherein said beam collecting means comprises:

a. a plurality of plates;

b. a plurality of successively increasing valued voltages;

c. means applying one each of said successively increasing valued voltages individually to one each of said plurality of beam collection plates for attracting electrons, moving in said sheet at different velocities to different ones of said collection plates whereby controlled thermal energy is generated at said plurality of plates.

30. Heating apparatus in accordance with claim 29 wherein:

a. said sheet of moving electrons is a hollow cylindrical beam;

b. said dielectric member comprises a pair of dielectric cylinders, one cylinder of said pair being hollow and positioned with said cylindrical beam inside the inner surface thereof, said remaining cylinder being positioned on the inside of said hollow cylindrical beam.

31. Heating apparatus in accordance with claim 29 wherein:

a. said sheet of moving electrons is a flat beam focused in a substantially circular path;

b. said dielectric member comprises a pair of dielectric cylinders, one cylinder of said pair being hollow and positioned with said circular beam path inside the inner surface thereof, said remaining cylinder being positioned on the inside of said circular beam path.

32. Heating apparatus comprising:

a. a cavity including means for enabling a body to be cooked to be placed inside said cavity;

b. means forming a vacuum enclosure and comprising substantially one wall of said cavity;

c. a voltage source;

d. a voltage multiplier circuit connected to said voltage source for establishing a plurality of successive voltage levels;

e. means in said vacuum enclosure connected to said successive voltage levels for forming, focusing and collecting an electron beam; and

f. means in said vacuum enclosure interacting with said electron beam for generating microwave power.

33. Heating apparatus comprising:

a. a cavity including means for enabling a body to be heated to be placed inside said cavity;

b. a source of electric power;

c. means connected to said source for converting said electric power to a flat electron beam;

d. means for converting said flat electron beam to microwave energy having a plurality of distinct microwave frequencies; and

e. antenna means connected to said microwave energy conversion and facing into said cavity with said antenna means being responsive to said frequencies for noncoherently radiating said plurality of frequencies of microwave energy throughout said cavity.

34. Heating apparatus in accordance with claim 33 wherein said means for converting electric power to a flat electron beam comprises:

a. a pair of opposed planar dielectric sheets defining therebetween a substantially flat elongated vacuum cavity;

b. means at one end of said vacuum cavity for emitting an electron beam and means at the other end of said cavity for collecting said electron beam;

c. electrostatic focusing means printed on the planar surfaces of said opposed dielectric sheets which define said vacuum cavity for focusing the electron beam into a flat sheet beam positioned between the dielectric sheets; and wherein said means for converting said beam into microwave energy comprises:

d. a microwave interaction structure printed on at least one of the dielectric sheets and interacting with the moving electrons in said beam for converting electron translational energy in said beam to microwave energy in said printed microwave interaction structure.

35. Heating apparatus in accordance with claim 34 wherein said printed interaction structure comprises a plurality of distinct microwave interaction structures for interacting with the moving electrons in said beam to convert electron translational energy in said beam to microwave energy having a plurality of distinct microwave frequencies, one each for each of said plurality of interaction structures.

36. Heating apparatus in accordance with claim 35 wherein said antenna means comprises:

a. a plurality of distinct antennas printed on the dielectric sheet facing into said cavity with one antenna each associated with one each of said interaction structures; and

b. means connecting said antenna means to said interaction structures for radiating said microwave energy at all of said plurality of frequencies throughout said cavity.

37. Heating apparatus in accordance with claim 36 wherein said connecting means comprises a plurality of printed leads on said dielectric sheets for connecting one each of said plurality of printed antennas to one each of said plurality of printed interaction structures.