May 26, 1959 D. B. HAAGENSEN 2,888,543

ELECTRONIC HEATING APPARATUS

Original Filed Nov. 12, 1953 3 Sheets-Sheet 1

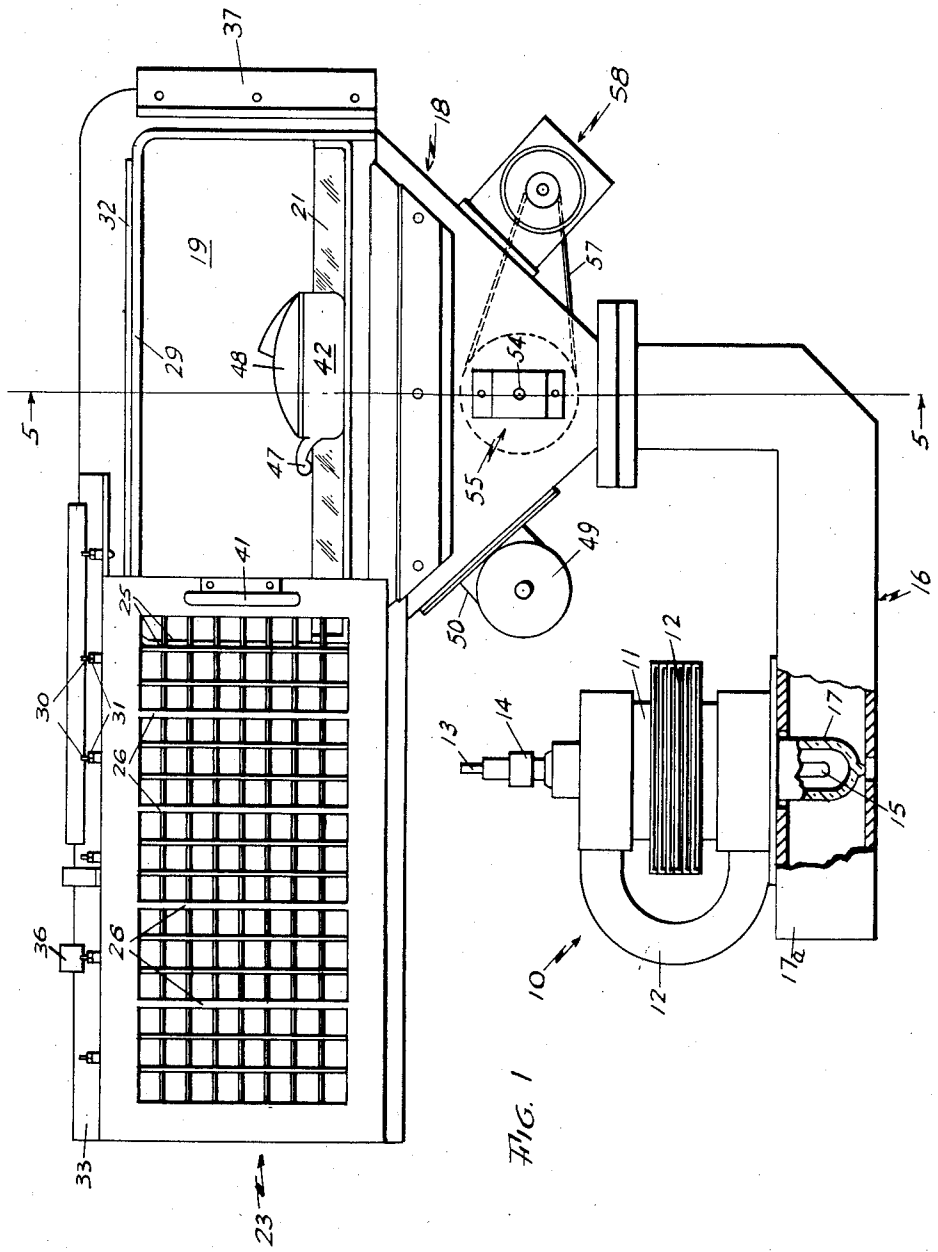


FIG. 1

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Original Filed Nov. 12, 1953 3 Sheets-Sheet 2

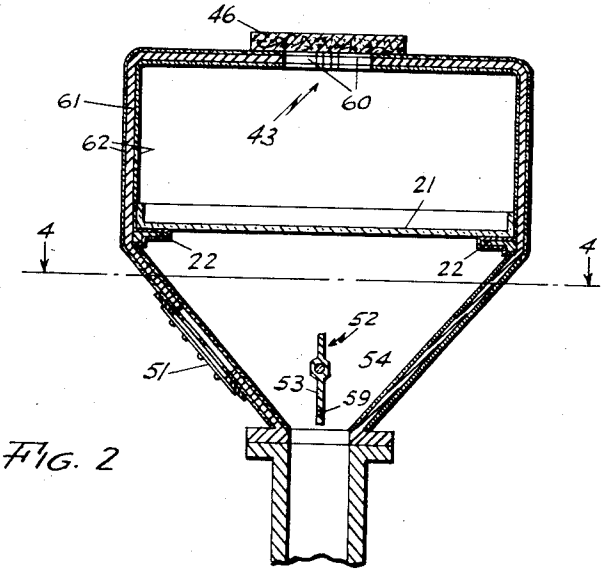


FIG. 2

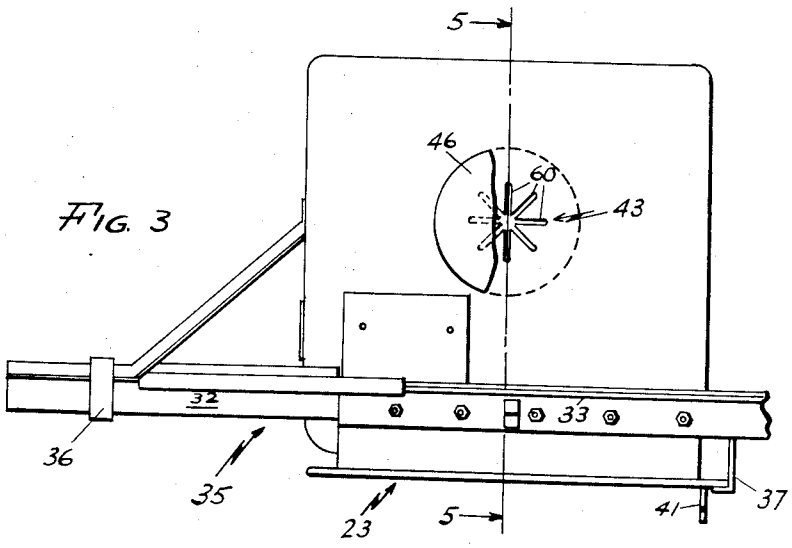


FIG. 3

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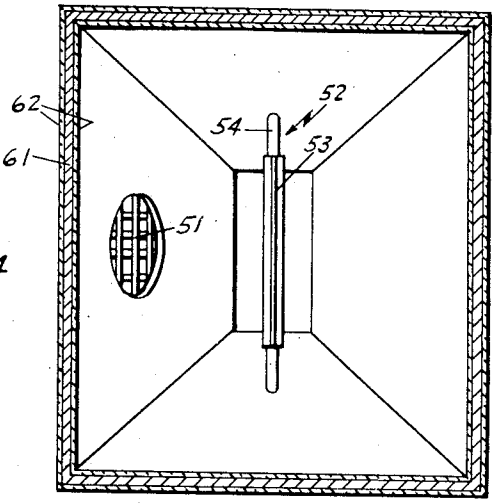


FIG. 4

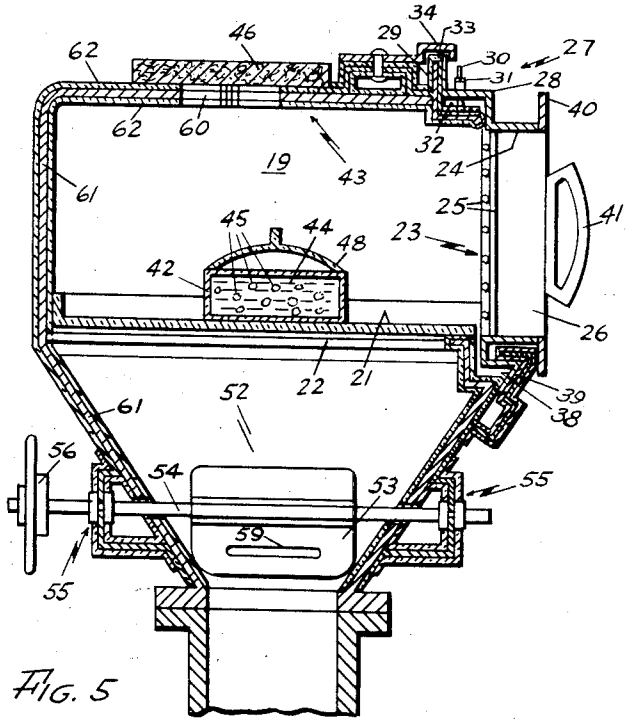


FIG. 5

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2,888,543

ELECTRONIC HEATING APPARATUS

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Original application November 12, 1953, Serial No. 391,553. Divided and this application April 30, 1956, Serial No. 581,795

5 Claims. (Cl. 219—10.55)

This is a divisional application of application, Serial No. 391,553, filed November 12, 1953 by Duane B. Haagensen, entitled "Electronic Heating Apparatus," now Patent No. 2,827,537, issued March 18, 1958.

This application relates to an electronic heating apparatus and more particularly to an apparatus utilizing radiated high frequency energy for heating food bodies.

In my patent application, Serial No. 345,372, filed March 30, 1953, copending jointly with Henry F. Argento, now Patent No. 2,820,127, January 14, 1958, there is disclosed an apparatus for heating food bodies with provision to allow the radiated energy to be coupled out of the heating chamber in the absence of a body to be heated positioned in the chamber. This application discloses several improvements and modifications over said copending application.

Specifically, this invention discloses that the efficiency with which the radiated energy is coupled into the body to be heated can be materially improved by introducing said energy into the region of the body to be heated at a point directly below said body. The support for the food body, which may include the food body container, may then be constructed to act as an impedance matching device for improving the coupling of the radiated energy into the food body.

This invention further discloses that the radiated energy may be directed uniformly into the bottom of the heating cavity throughout the entire area thereof, for example, by means of a horn. The floor of the oven may then be made of a dielectric material transparent to the radiant energy, but having a characteristic impedance substantially different from that of the horn. The thickness of the dielectric floor is then made such that it presents a substantial impedance discontinuity to the horn at any particular point thereof. However, when a food body container, having a dielectric bottom of suitable thickness, is placed on the dielectric oven floor, the combined thicknesses of the floor and the container are such that a good impedance match between the horn and the food body occurs at this point with the result that the floor of the oven appears to be an impedance discontinuity with a coupling iris therein in the area where the food body container is placed on the oven floor. As a result, a large part of the radiated energy is transferred directly from the horn into the food body without being reflected from the sides of the cooker cavity. Accordingly, only a small portion of the energy is reflected back toward the source of radiant energy thereby producing a relatively low standing wave ratio at the source of radiated energy.

This invention further discloses that the source of radiated energy may be protected from damage in the absence of a body to be heated in the cavity by means of a coupling aperture in the top of the cooker cavity, which couples out energy passing with low intensity through the large surface of the oven floor, and, hence, prevents sufficient reflection to the source of radiated energy, for example, a magnetron oscillator, to prevent damage thereto by overheating or mode shifting.

This invention further discloses a structure for cyclically varying the mode intensity pattern in the cooker cavity whereby localized hot spots, in the body being heated, are eliminated. Briefly, this structure comprises a reflecting member rotating about an axis lying substantially parallel to the floor of the oven, said reflecting member comprising a planar member asymmetrically mounted on an insulating rod rotating about said axis with the larger portion of the planar member having an iris type coupling slot therein which substantially reduces undesirable variation in the standard wave ratio during mode stirring. The coupling aperture in the top of the oven is dimensioned and arranged to couple energy throughout any of the mode changes produced by the mode stirring.

This invention further discloses that certain new and unobvious advantages have been discovered in the use of an insulating surface on the surfaces of the oven. Specifically, arcing and sparking, which occurred close to the metal surfaces in previous high frequency cooking devices, has been substantially eliminated. This invention further discloses a particular door structure found useful with the cooking oven disclosed herein.

This invention further discloses that, by utilizing a translucent food container with a transparent top, a light may be shone into the oven through a grill having openings therein less than a half-wave length of the radiant energy in the oven whereby the contents of the dish are illuminated and may be viewed from the outside of the oven through a suitable grill, for example, in a door of the oven.

Other and further objects and advantages of this invention will be apparent as the description thereof progresses, reference being had to the accompanying drawings, wherein:

Fig. 1 illustrates a front elevation view of an electronic cooker with its door open embodying principles and discoveries of this invention;

Fig. 2 illustrates a longitudinal cross-sectional view of the oven portion of the structure illustrated in Fig. 1;

Fig. 3 illustrates a top plan view of the oven portion of the structure illustrated in Fig. 1 showing details of the coupling iris in the top of the oven and the door support structure with the door closed;

Fig. 4 illustrates a transverse cross-sectional view of the horn showing details of the mode stirrer structure; and

Fig. 5 illustrates a longitudinal cross-sectional view of the device shown in Fig. 1, taken along line 5—5 of Fig. 3.

Referring now to Fig. 1 of the drawings, there is shown a source of microwave energy **10** illustrated herein as a conventional magnetron oscillator having an anode structure **11** cooled by air blowing past fins **12**. Suitable input voltages are applied to the filament electrode **13** and cathode electrode **14** to produce microwave oscillations inside the anode structure **11**, under the influence of a magnetic field produced transverse to the direction of the electron motion by means of a permanent magnet **12**, in accordance with well-known practice.

The output of magnetron **10** is coupled by means of a radiating probe **15** into a wave guide **16**. Probe **15**, as shown here, is surrounded by a ceramic envelope **17** inside wave guide **16**, envelope **17** being part of the vacuum envelope structure of magnetron **10** whereby the region immediately adjacent probe **15** is free from gas thereby eliminating any danger of a gaseous breakdown or ionization in this region. The field intensity decreases rapidly with distance away from probe **15** such that the field intensity outside envelope **17** in the wave guide **16** is below the level required for ionization of the air in the wave guide **16**.

One end of the wave guide **16** is blocked by a shorting plug, as at **17***a*, the distance of the shorting plug **17***a*

from the probe 15 being adjusted to substantially match the characteristic impedance of the wave guide 16 to the output impedance of the magnetron 10. The other end of the wave guide 16 feeds the small end of a radiating horn 18. The horn 18 is tapered such that the small end of the horn is the same size as the rectangular cross-sectional area of the wave guide 16, while the large end of the horn 18 has a cross section which is substantially square.

The large end of horn 18 feeds directly into a heating cavity or oven 19, preferably at the bottom of the oven 19, with the large end of horn 18 covering the entire area of the bottom of the oven 19. In order to allow radiated energy to be coupled into the oven 19 from the horn 18 in any region of the bottom of oven 19, the entire floor of the oven is made of a material which is transparent to the radiated energy. Specifically, this floor is shown here in the form of a glass tray 21, which may be, for example, one of the standard heat resistant glasses, such as Pyrex. Tray 21 rests on brackets 22 attached to the walls of oven 19 at the lower edges thereof and is removable to facilitate cleaning thereof. As shown here, tray 21, in addition to the bottom, has three sides and is normally oriented in the oven such that three sides are positioned against the back and two side walls of the oven, while the edge of the tray having no side is positioned adjacent the front of the oven in which is a door 23, such that material spilled in tray 21 will run out at the front of the oven by the door 23 and will not interfere with the heating operation. If desired, however, the tray 21 may have four sides thereby retaining any spillage therein until it is removed and cleaned.

The door 23 covers the entire front side of the oven 19, which is otherwise open. Thus the tray 21 may be easily slid in and out of the oven through door 23 sliding on brackets 22. The door 23 comprises a frame member 24 supporting a structure of grid wires 25 spaced sufficiently close together, for example, substantially less than one-half wave length of the operating frequency of magnetron 10, to prevent the coupling of energy therethrough. Frame 24 also has attached thereto a plurality of vertical bars 26 positioned adjacent the grid wires 25 on the outside thereof. The purpose of bars 26 is to prevent accidental contact of the grid wires 25 by the hands while reaching to open or close the door 23. The door 23 is adapted to slide open and closed on oven 19 and is supported on oven 19 by means of an extension 27 of the upper edge of door frame 24, which has a horizontal portion 28 positioned above a lip 29 welded on the front edge of oven 19 and extending out over door 23. Portion 28 has a plurality of studs 30 extending therethrough, threadedly adjustable therein, and locked by means of lock nuts 31. Studs 30 are of insulating material, such as nylon, and bear on a strip of insulating material 32 glued to the upper horizontal surface of lip 29. A vertical portion 33 of door frame extension 27 engages a vertical extension of lip 29, and a guide member 34 attached to the top of oven 19 extends over vertical extension 33 and the vertical extension lip 29 holding them in relatively close proximity such that the upper end of the door is permitted to move only by sliding sidewise with respect to oven 19, the weight of the door being carried by nylon studs 30 resting on the ceramic strip 32. An extension 35 of the lip 29 on the left-hand side of the oven supports the door through the nylon studs 30 when the door is open. A stop 36 welded to extension 35 limits the maximum open position of the door, while a vertically extending stop 37, welded to the portion of lip 29, which extends down along the right-hand edge of oven 19, prevents movement of the door to the right of its closed position. A downward extending lip 38 at the bottom of door frame 24 engages the outside of the horn 18 and is held in sliding engagement therewith by means of a guide member 39 secured to the horn member 18. This prevents the bottom of door 23 from swinging out away from the oven 19.

Extending outwardly from the front of the door is cover plate assembly 40 having an aperture therein exposing the grid wires 25 and bars 26 and having a handle 41 secured thereto. The cover plate assembly is to slidably engage a cabinet, not shown, which entirely surrounds the cooking apparatus illustrated herein, as well as other necessary components, such as power supplies, switches, fuses and timing circuits. It is to be clearly understood that the particular door illustrated herein, while particularly useful to the embodiment of the invention illustrated herein, is by way of example only, and other types of doors could be used, such as doors which are hinged or which do not have a grill work therein. In addition, the design and dimensioning of the lip extensions around the oven at the door, for the embodiment shown herein, is approximately a quarter wave long to produce a quarter wave length choke whereby energy is prevented from leaking out around the door. This choke structure could be eliminated, if so desired, or other configurations of chokes could be used.

The particular oven illustrated herein is particularly adapted for use with the food container shown in Figs. 1 and 5, which comprises a lower portion 42 which is in the shape of a bowl having relatively steep sides. Bowl 42 is made of ceramic and has a dielectric constant on the same order of magnitude as that of the Pyrex tray 21. For the embodiment shown herein, the Pyrex tray 21 has a thickness substantially less than a quarter wave length of the operating frequency of the magnetron 10, and, hence, due to the difference between the dielectric constant of the Pyrex glass, which is on the order of 6, and the dielectric constant of the air in the horn, presents an impedance discontinuity to the energy radiated from the horn 18. However, due to the matching effect of the horn 18 between the wave guide section 16 and the tray 21, over-all reflections from the tray 21 back to the magnetron 10, while present, are not excessive when no food container 42 is present in the oven 19.

Sufficient energy is coupled through the tray 21, diffused evenly throughout its area, to prevent damage to the magnetron 10 by heating or mode shifting. This energy is coupled out through an aperture 43 in the top of the oven 19. When the container 42 is positioned in the oven on the tray 21 with material to be heated positioned in container 42, a large amount of energy is coupled into the food body contained in container 42. As illustrated herein, the container 42 is filled with fluid 44, such as soup containing lumps 45, which may be, for example, meat, vegetables, or other ingredients. It has been found that extremely good coupling of energy into the contents of container 42 may be achieved by making the combined thickness of the bottom of container 42 and the tray 21 substantially equal to a quarter wave length of the radiated energy passing therethrough. Also, the average dielectric constant of the bottom of the container and the tray 21, both of which are on the order of 6, is chosen to be substantially equal to the square root of the dielectric constant of the contents of the container 42 divided by the dielectric constant of free space. Thus, if the container and tray have dielectric constants ranging from 5 to 7, a good impedance match is obtained with most food bodies whose dielectric constants may range from 30 to 50 at the operating frequency of the device which may be, for example, 2,200 megacycles per second. For this frequency, the total thickness of the tray 21 and bottom of the container 42 would be slightly less than one-half inch. In practice, a tray has been built which is two-tenths of an inch thick and a container 42 has been used with a bottom wall thickness of a quarter inch giving a total thickness of tray and container bottom of .45 inch. Since there is a such a good impedance match through the tray into the food body, in comparison to the impedance match through the tray in other portions thereof, the major part

of the energy radiated by horn **18** passes into the food body in the container **42** and is absorbed therein. As a result, a very small portion of the radiated energy is coupled out at the top of the oven through the aperture **43** when a food body to be heated is positioned in the oven, but substantially all the energy is coupled out through the aperture **43** when no body is postioned in the oven. If desired, a block of energy absorbing material, such as transite **46**, a combination of concrete and asbestos, may be positioned outside the aperture **43** to absorb radiated energy coupled therethrough from the oven **19** thereby preventing any substantial amount of energy from being radiated into the areas adjacent the cooking apparatus. It is to be clearly understood that the thickness and dielectric constants of the glass tray **21** and dish **42** are disclosed by way of example only, and that any desired thicknesses and dielectric constants could be used to produce the desired impedance matching effects.

The food container **42** has a handle **47** attached thereto whereby the dish may be placed in the oven and removed therefrom. Since the dish **42** and handle **47** are made of relatively low loss material, substantially no energy is absorbed thereby during heating of the food body, and, consequently, the handle never becomes hot to the touch when heating the material in container **42**. The container **42** may be removed from the oven **19** and served to the consumer as a bowl, such as a soup bowl, and the food may be consumed directly therefrom. The sides of the container **42** are made relatively steep so that there are no thin edge portions of the food contents to become overheated by over-concentrations of radiant energy, as would be the case if a flat sloping-sided food container were used.

There is shown a cover **48** for container **42**, cover **48** being made, for example, of glass, or of any other desired material which is transparent. Cover **48** retains, to a large degree, steam escaping from the surface of the food body being cooked and provides for observing the contents of the container **42** during the cooking process through the grill work in the door **23**, which is closed during the cooking process. The food being cooked may be illuminated during the cooking process by means of a light **49** mounted outside horn **18** on a bracket **50** and shining through a grill **51** covering an aperture in one wall of the horn **18**. The spaces of grill **51** are substantially less than a half wave length of the operating frequency of the magnetron **10** to prevent loss of the radiant energy therethrough. The light shining through wall **51** from lamp **49** passes through tray **21**, which is transparent, and through dish **42**, which is translucent, or if desired, transparent, thereby illuminating the contents of dish **42** so that it may be viewed through the transparent top **48**.

In order to produce uniform heating throughout the contents of dish **42**, there is provided a mode-stirring structure **52** in horn **18** which varies the pattern of standing waves in the contents of dish **42**. Specifically, mode-stirrer **52** comprises a planar member **53** mounted on an insulating rod **54**, for example, of nylon, the axis of said rod extending transverse to the axis of horn **18** and transverse to the electrostatic lines of the energy radiated into horn **18** from wave guide **16**. Rod **54** extends out through apertures in the slots of horn **18** and is supported in bearings **55** outside horn **18**. Plate **53** is rigidly attached to rod **54** such that when rod **54** is rotated by means of a pulley **56**, secured to rod **54** outside horn **18** and driven by means of a belt **57** from a motor **58** mounted on the outside of horn **18**, the plate **53** will rotate inside horn **18**. The use of an insulating material for the rod **54** eliminates any danger of arcing at the points where rod **54** passes through horn **18** and the apertures in horn **18** through which rod **54** passes are substantially less than a halfwave length of the operating frequency of said device whereby substantially no energy is coupled out of horn **18** through the said apertures.

Plate **53** is asymmetrically positioned on rod **54** with the larger side having an iris **59** therein. Iris **59** is in the form of a long slot, whose longitudinal axis is oriented transverse to the electrostatic lines of energy radiated into horn **18** from wave guide **16**, and whose length is on the order of a half wave length of the operating frequency of magnetron **10**. It has been found that the use of a mode stirrer rotating about an axis transverse to the direction of propagation of the radiated energy produces a thorough mode-stirring action. It has been further found that such a mode stirrer produces cyclically a relatively high standing wave ratio. However, the use of an iris coupling, such as **59**, reduces this standing wave ratio to a tolerable value. In addition, it has been found that the use of a plurality of iris couplings of the slot type, for example, one on either side of the axis of rotation, create conditions causing heating of the mode stirrer vane, while the use of only one iris **59** in an asymmetrical mode stirrer structure produces a device wherein substantially no heating occurs in the mode stirrer.

For best results, it is desirable that the heating oven have dimensions which are several wave lengths of the operating frequency of the device for optimum operation of the mode-stirring structure and that the height, width and depth of the oven be substantially different from each other. This dimensioning, in combination with the tapered walls of the horn **18**, produces a structure wherein a great many different modes having overlapping resonant bands may be excited within the oven and horn structure. Thus, the exact frequency of the source is not critical, since the oven structure may be energized in a substantially resonant mode by a relatively wide range of frequencies.

In order that the aperture **43** be operative to couple energy out of the cavity for any of the modes excited therein, aperture **43** is made in the form of a plurality of crossed slots, for example, three in number, as shown at **60**, said slots being on the order of a half wave length long at the operating frequency of said device whereby each slot may act as a coupling iris for a mode wherein the electrostatic lines are substantially perpendicular to the slot.

In order to substantially eliminate arcing, produced by concentrations of the radiated energy close to the walls of the oven **19** and horn **18**, horn **18** and oven **19** are made of sheet metal, as at **61**, having a coating of ceramic bonded to both sides thereof, as at **62**. Coating **62** may be a conventional porcelainized coating, preferably having areas of light-reflecting material, such as white ceramic thereon. The light-reflecting areas may be, for example, patches of white porcelain fused into a darker background, or if desired, the entire coating may be made of a light-colored porcelain, or other insulating material, such as plastic. The metal core **61** of the oven and horn may be ordinary sheet steel thereby presenting some degree of loss to the radiated energy impinging thereon. This is also a contributing factor in preventing excessive reflection of energy to the magnetron **10** in the absence of a body to be heated being positioned in the oven, since in the absence of a body to be heated, the intensity of the radiated field pattern builds up, producing higher currents in the oven and horn walls with an increase of absorption of energy thereby. On the other hand, when a body to be heated is positioned in the oven, the field intensity is lower, since the bulk of the energy is absorbed directly by the food body and a relatively small amount of energy is absorbed in the oven and the horn.

This completes the description of the particular embodiment of the invention illustrated herein. However, many modifications thereof will be apparent to persons skilled in the art without departing from the spirit and scope of this invention. For example, many different types of mode stirrers could be used in place of the mode stirrer illustrated herein, or, indeed, the mode stirrer could be eliminated altogether, or the mode stir-

ring could be accomplished by cyclical frequency variation of the radiated energy. The impedance matching produced by the combined action of the tray **21** and dish **42** could be used without a covering oven **19**, if so desired, and any desired means for protecting the magnetron **10** against failure caused by excess reflection of energy to the magnetron could be used, such as relay devices controlled by the energy directionally coupled out of wave guide **16**, and any desired safety interlock switch system could be used on door **23** to deenergize magnetron **10** when door **23** is opened. Accordingly, it is desired that this invention be not limited by the particular details of the embodiments disclosed herein, except as defined by the appended claims.

What is claimed is:

1. Electronic heating apparatus comprising an enclosure defining a cavity, means for radiating electromagnetic wave energy into said cavity, said enclosure having a plurality of electromagnetic wave reflecting wall portions one of said portions comprising a door, an electromagnetic radiation seal for a juncture of said door portion and the adjacent wall portion, said seal comprising a solid dielectric adhered to the surface of said wall and door portions so as to be positioned between substantial areas of adjacent regions of said door and wall portions when said door is closed, whereby the capacity coupling between said regions presents a low electrical impedance between said portions at said juncture at the frequency of said energy to prevent leakage of said energy through said juncture, and means for positioning a body to be heated in said cavity.

2. Electronic heating apparatus comprising an enclosure defining a cavity, said enclosure having a plurality of electromagnetic wave reflecting wall portions one of said portions comprising a door, an electromagnetic radiation seal for a juncture of said door portion and the adjacent wall portion, said seal comprising a solid dielectric coating of vitreous insulating material on the surface of said adjacent wall and door portions so as to be positioned between substantial areas of adjacent regions of said door and wall portions when said door is closed, means for radiating electromagnetic wave energy into said cavity, and means for positioning a body to be heated in said cavity.

3. Electronic heating apparatus comprising an enclosure defining a cavity, said enclosure comprising electromagnetic wave reflecting walls at least partially coated with insulating material, superimposed on said walls over at least a substantial interior surface area of said walls, means for radiating electromagnetic wave energy into said cavity, said enclosure having a plurality of wall portions, an electromagnetic radiation seal for a juncture of said portions, said seal comprising a solid dielectric positioned between substantial areas of adjacent regions of said portions, and means for positioning a body to be heated in said cavity.

4. Electronic heating apparatus comprising an enclosure defining a cavity, said enclosure comprising electromagnetic wave reflecting walls at least partially coated with insulating material superimposed on said walls over at least a substantial interior surface area of said walls, means for radiating electromagnetic wave energy into said cavity, said enclosure having a plurality of wall portions one of said portions comprising a door, an electromagnetic radiation seal for a juncture of said portions, said seal comprising a solid dielectric positioned between substantial areas of adjacent regions of said portions, whereby the capacity coupling between said regions presents a low electrical impedance between said portions at said juncture at the frequency of said energy to prevent leakage of said energy through said juncture, and means for positioning a body to be heated in said cavity.

5. Electronic heating apparatus comprising an enclosure defining a cavity, said enclosure comprising electromagnetic wave reflecting walls substantially entirely coated with insulating material superimposed on said walls over at least a substantial interior surface area of said walls, means for radiating electromagnetic wave energy into said cavity, said enclosure having a plurality of wall portions, an electromagnetic radiation seal for a juncture of said portions, said seal comprising a solid dielectric positioned between substantial areas of adjacent regions of said portions, whereby the capacity coupling between said regions presents a low electrical impedance between said portions at said juncture at the frequency of said energy to prevent leakage of said energy through said juncture, and means for positioning a body to be heated in said cavity.

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