United States Patent [19]

Simon et al.

[11] **3,798,404**

[45] **Mar. 19, 1974**

[54] **ELECTRONIC OVEN WITH MODE EXCITER**

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[73] Assignee: **General Electric Company,** Louisville, Ky.

[22] Filed: **Dec. 21, 1972**

[21] Appl. No.: **317,206**

[52] **U.S. Cl.** **219/10.55**
[51] **Int. Cl.** **H05b 9/06**
[58] **Field of Search** 219/10.55

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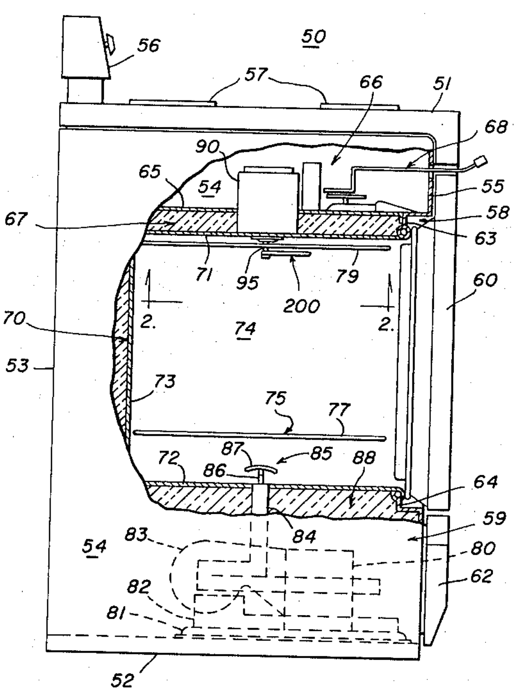
Primary Examiner—Bruce A. Reynolds
Assistant Examiner—Hugh D. Jaeger
Attorney, Agent, or Firm—Prangley, Dithmar, Vogel, Sandler & Stotland

[57] **ABSTRACT**

An electronic oven includes a boxlike enclosure defining a heating cavity therein, a microwave source coupled to an antenna centrally of the bottom wall of the cavity for radiating thereinto microwave energy of a predetermined wavelength for exciting a predetermined primary mode electromagnetic field in the cavity, a drive motor having a grounded conductive output shaft projecting into the cavity centrally of the top wall thereof coaxially with the antenna and parallel to the primary mode electric field, and a generally L-shaped conductive member having two interconnected leg portions disposed in a plane normal to the shaft, one of which leg portions is connected at the free end thereof to the inner end of the shaft for rotation about the axis thereof, the conductive element being responsive to rotation thereof in the primary mode of the electric field for exciting in the cavity two secondary modes complementary to the primary mode. A generally W-shaped conductive element and a rectangular conductive element are also provided for effecting phase reversal of the secondary modes with respect to the primary mode as the element rotates. A support rack is provided in the cavity having spaced-apart parallel rods extending parallel to the direction of propagation of the electromagnetic field.

16 Claims, 17 Drawing Figures



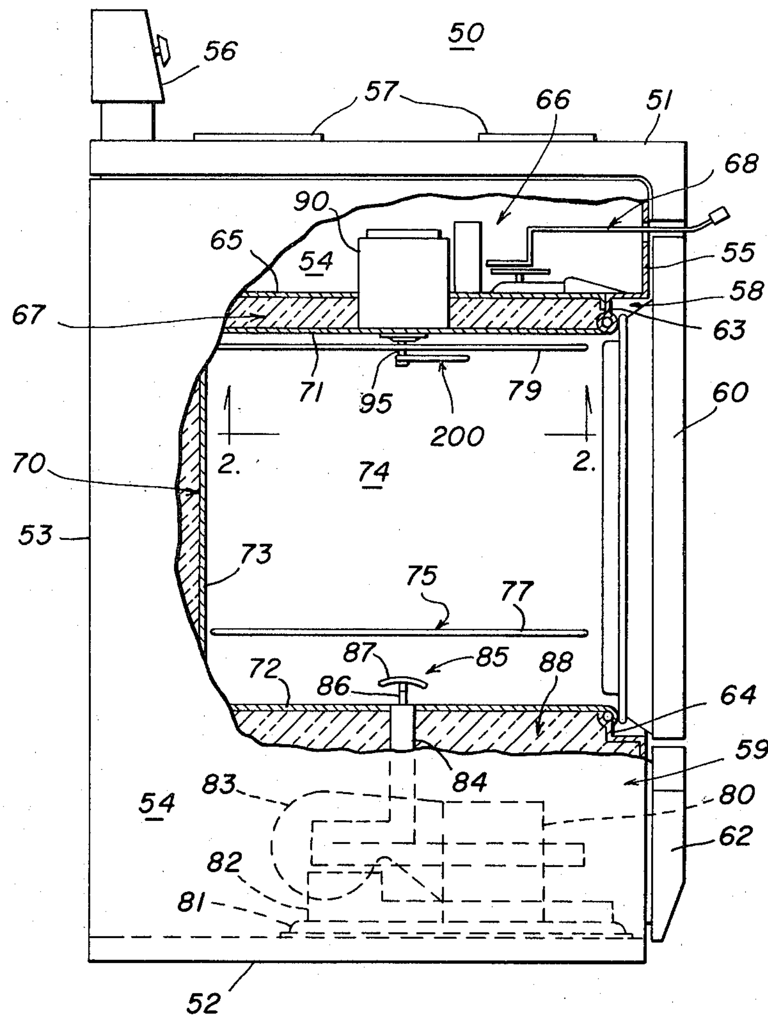

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FIG. 1

FIG. 2

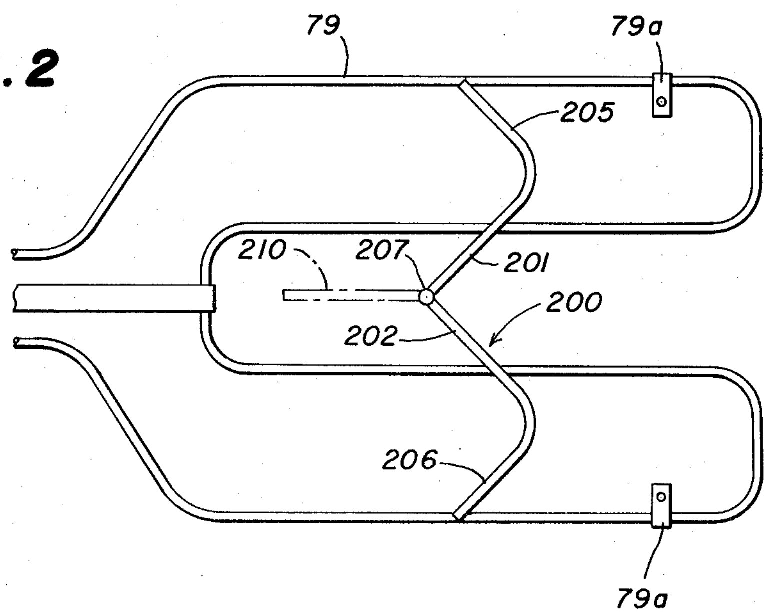
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FIG. 3

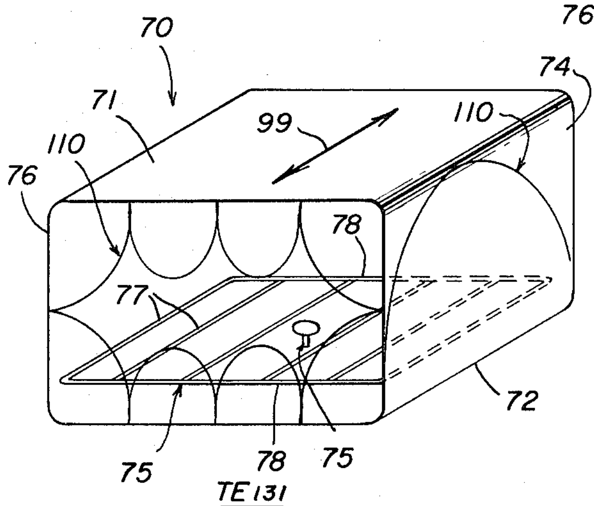


FIG. 4

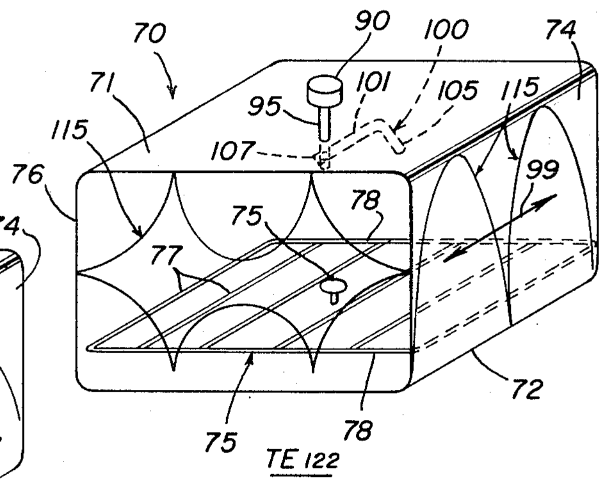


FIG. 5

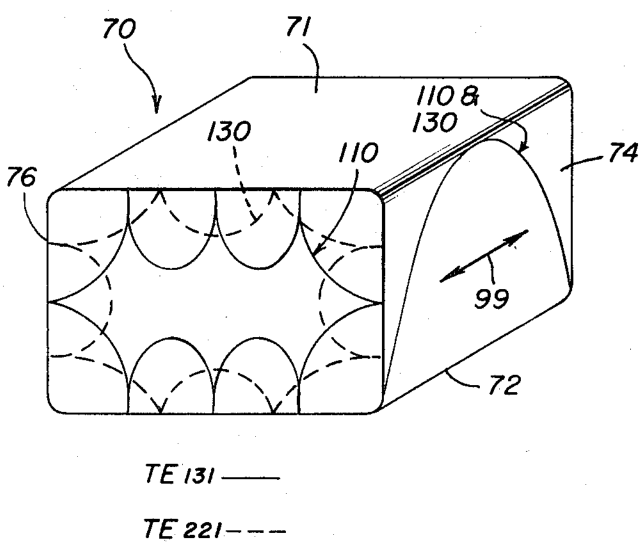


FIG. 6

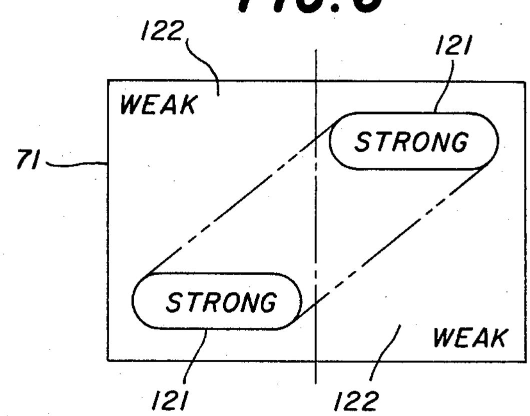


FIG. 7

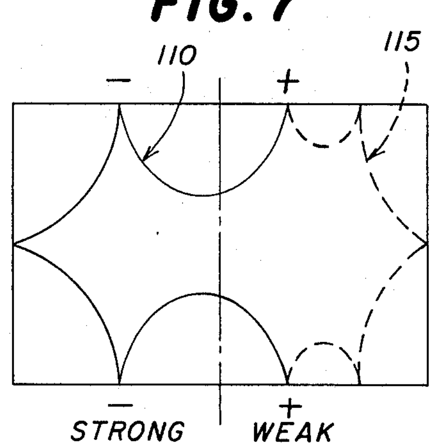


FIG. 8

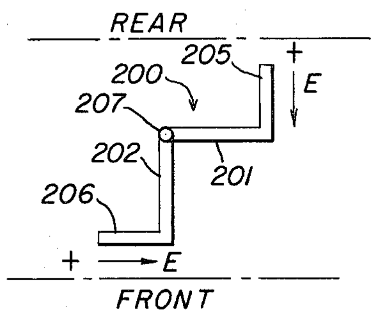


FIG. 11

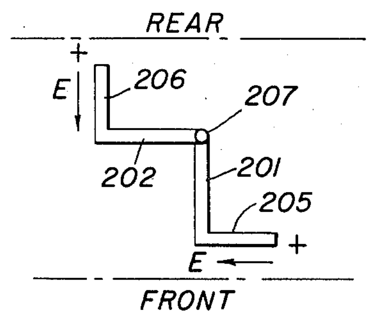


FIG. 9

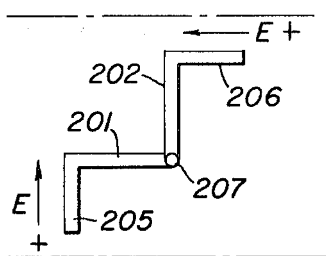


FIG. 12

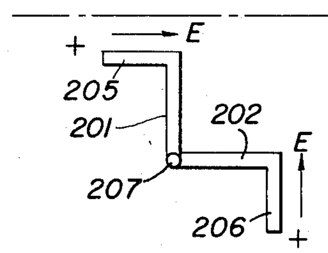


FIG. 10

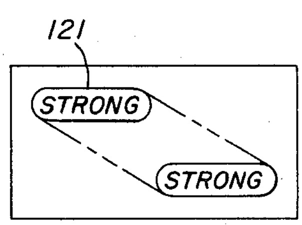


FIG. 13

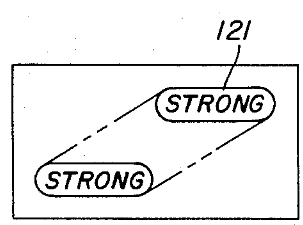


FIG. 14

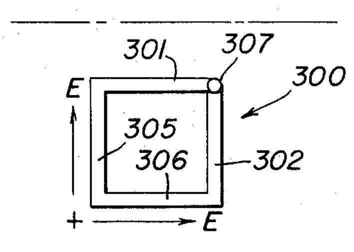


FIG. 16

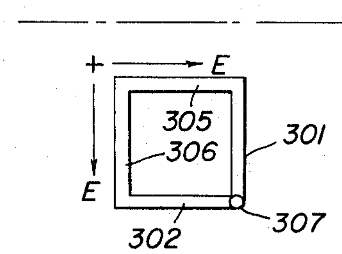


FIG. 15

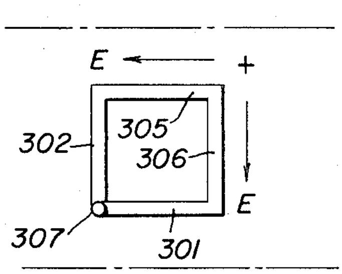
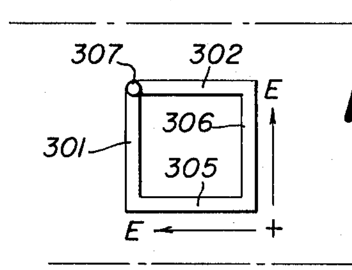


FIG. 17



ELECTRONIC OVEN WITH MODE EXCITER

The present invention relates to an electronic oven and, more particularly, to a device for providing a substantially uniform time-averaged electric field distribution in the oven cavity to facilitate uniform heating of material placed in the oven.

It is a general object of this invention to provide an electronic oven operating at approximately 915 MHz and having novel rotatable mode exciting elements therein for exciting predetermined secondary modes complementary to the primary mode.

It is an important object of this invention to provide electronic heating apparatus comprising an enclosure including two opposed parallel walls and defining a heating cavity for receiving therein a body to be heated, an antenna disposed adjacent to one of the opposed walls and projecting into the cavity along an axis substantially perpendicular to the one wall, the antenna being adapted for coupling to an associated source of electromagnetic energy of a predetermined ultra-high frequency for transmitting the energy into the cavity to excite therein a predetermined primary electromagnetic field mode, a grounded conductive member disposed in the cavity adjacent to the other of the opposed walls, and drive means coupled to the conductive member for effecting rotation thereof about the axis of the antenna for exciting in the cavity a predetermined secondary mode complementary to the primary mode, whereby there is established within the cavity a substantially uniform time-averaged field distribution thereby to facilitate uniform heating of the associated body.

Another object of this invention is to provide an electronic heating apparatus of the type set forth, wherein the drive means includes a rotatably driven grounded conducted shaft extending into the cavity with the longitudinal axis thereof disposed substantially parallel to the electric field component of the primary mode, the conductive member being generally L-shaped and having two interconnected leg portions disposed in the cavity in a common plane substantially normal to the axis of the shaft, the shaft being connected to the conductive member at the free end of one of the leg portions thereof for effecting rotation thereof by the axis of the shaft.

In connection with the foregoing object, it is still another object of this invention to provide electronic heating apparatus of the type set forth, wherein the conductive member is generally W-shaped, and includes two interconnected identically constructed L-shaped sections all disposed in a common plane substantially normal to the axis of the shaft, the conductive member being responsive to continuous rotation thereof by the drive means for periodically reversing the phase relationships between the electric field components of the primary and secondary modes.

In connection with the foregoing object, yet another object of the invention is to provide an electronic heating apparatus of the type set forth, wherein the conductive element is generally rectangular in shape, comprising four interconnected straight segments all disposed in the cavity in a common plane substantially normal to the axis of the shaft.

Further features of the invention pertain to the particular arrangement of the parts of the electronic heating apparatus whereby the above-outlined and additional operating features thereof are attained.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings in which:

FIG. 1 is a side elevational view in partial section of an electric range incorporating therein an electronic heating apparatus constructed in accordance with and embodying the features of the present invention;

FIG. 2 is an enlarged fragmentary bottom plan view of the oven broil unit and mode stirrer, taken along the line 2—2 in FIG. 1;

FIG. 3 is a reduced front perspective view of the oven enclosure showing the electric field pattern of the primary mode excited in the cavity by the microwave antenna;

FIG. 4 is a view similar to FIG. 3, showing the mode stirrer in accordance with a first embodiment of the invention, and illustrating the electric field pattern of one of the secondary modes excited by the stirrer;

FIG. 5 is a view similar to FIG. 4, showing superimposed the primary mode electric field pattern of FIG. 3 and another one of the secondary modes excited by the mode stirrer of FIG. 4;

FIG. 6 is a diagrammatic representation of the relative composite field strength pattern established in the cavity by the stirrer of FIG. 4, as viewed from the top of the cavity;

FIG. 7 is a diagrammatic front elevational view of the composite field pattern established in the oven cavity by the stirrer of FIG. 4;

FIG. 8 is a top plan diagrammatic representation of a mode stirrer according to a second embodiment of the invention, and illustrating the phase orientation of one of the secondary modes with respect to the primary mode;

FIG. 9 is a view similar to FIG. 8, showing the mode stirrer in a position rotated 180° from the position illustrated in FIG. 8;

FIG. 10 is a diagrammatic representation of the relative composite field strength pattern in the oven cavity as viewed from the top thereof when the mode stirrer of FIG. 8 is disposed in the positions illustrated in FIGS. 8 and 9;

FIG. 11 is a view similar to FIG. 8 showing the mode stirrer in a position rotated 90° clockwise from the position illustrated in FIG. 8;

FIG. 12 is a view similar to FIG. 8 showing the mode stirrer illustrated in a position rotated 270° from the position shown in FIG. 8;

FIG. 13 is a diagrammatic representation, similar to FIG. 10 showing the relative composite field strength pattern when the mode stirrer of FIG. 8 is in the positions illustrated in FIGS. 11 and 12;

FIG. 14 is a top plan diagrammatic representation of a mode stirrer according to a third embodiment of the invention, and shown in a position which produces the field strength pattern illustrated in FIG. 10;

FIG. 15 is a view similar to FIG. 14 showing the mode stirrer in another position which produces the field strength pattern of FIG. 10;

FIG. 16 is a view similar to FIG. 14 showing the mode stirrer in a position which produces the field strength pattern of FIG. 13; and

FIG. 17 is a view similar to FIG. 14 showing the mode stirrer in another position which produces the field strength pattern of FIG. 13.

Referring now more particularly to FIGS. 1 and 2 of the drawings, there is illustrated an electric range, generally designated by the numeral 50. The detailed construction of the electric range 50 is disclosed in the copending U.S. application Ser. No. 256,093 of Roland V. Fowler et al., filed May 23, 1972, entitled MULTIPLE POSITION DOOR LATCH MECHANISM, and assigned to the assignee of the present invention. Accordingly, only so much of the structure of the range 50 will herein be described as is necessary for an understanding of the present invention.

The range 50 is generally box-like in shape and includes a top wall 51, a bottom wall 52, an upstanding rear wall 53, a front wall 55, and a pair of opposed upstanding side walls 54. Mounted on the top wall 51 of the range 50 is a plurality of standard electrical resistance heating units, these units and the other heating apparatus of the range 50 being controlled by a set of controls carried by a control panel 56 mounted on the top wall 51 at the rear end thereof. The front wall 55 has a relatively large rectangular upper opening 58 and a relative small rectangular lower opening 59 therein for providing access to the interior of the range 50. Connected to the front wall 55 and extending inwardly therefrom at the upper and lower edges of the opening 58 are two angle mounting flanges 63 and 64 which cooperate with similar flanges (not shown) at the sides of the opening 58 for defining a doorway.

A door 60 is mounted on the front wall 55 for movement between an open position (not shown) providing access to the interior of the range 50 and a closed position illustrated in FIG. 1 disposed in the doorway for closing the opening 58. In like manner, a door 62 is mounted on the front wall 55 adjacent to the opening 59 for movement between an open position (not shown) providing access to the interior of the range 50 and a closed position, illustrated in FIG. 1, for closing the opening 59. Connected to the upper mounting flange 63 and extending rearwardly therefrom substantially normal to the front wall 55 is a rectangular partition 65 for dividing the interior of the range 50 into an upper machinery compartment 66 and a lower open compartment 67. Mounted in the upper machinery compartment 66 upon the partition 65 is a latch assembly 68 for latching the front door 60 in the closed position thereof.

Mounted in the lower oven compartment 67 a slight distance below the partition 65 is a generally boxlike metallic oven enclosure, generally designated by the numeral 70, the oven enclosure being substantially in the shape of a rectangular parallelepiped and including a top wall 71, a bottom wall 72, an upstanding rear wall 73, and a pair of opposed upstanding side walls 74, the front end of the oven enclosure 70 being open at the front end thereof and communicating with the opening 58 of the front wall 55 of the range 50. The top and bottom walls 71 and 72 and the side walls 74 of the enclosure 70 are connected at the front edges thereof to the mounting flanges 63 and 64 for supporting and positioning the oven enclosure 70 in the compartment 67.

Preferably, the side walls 74 of the oven enclosure 70 are provided on the inner surfaces thereof with mounting means (not shown) for supporting a rack 75, the

rack 75 comprising a plurality of laterally spaced-apart parallel rods 77 extending parallel to the side wall 74 and interconnected at the front and rear ends thereof by end rods 78 disposed substantially parallel to the rear wall 73 (see FIGS. 3 and 4). Disposed within the oven enclosure 70 closely adjacent to the top wall 71 and substantially parallel thereto is a broil unit 79 secured to the top wall 71 by means of mounting clips 71a, the broil unit 79 preferably being a resistance heating element arranged in the serpentine configuration illustrated in FIG. 2.

The bottom wall 72 of the oven enclosure 70 is spaced a predetermined distance above the bottom wall 52 of the range 50 and cooperates therewith to define there-between a lower machinery compartment 88, access to which is provided through the front opening 59. Mounted in the lower machinery compartment 88 on the bottom wall 52 is a component tray 81 having mounted thereon a magnetron generator 80 for generating electromagnetic energy of a predetermined ultra-high frequency, preferably 915 MHz. The magnetron 80 is energized by a power supply unit 82 which is also mounted on the component tray 81. The magnetron 80 and the power supply unit 82 may be of the type disclosed in the copending U.S. Pat. application Ser. No. 181,144 of James E. Staats, filed Mar. 20, 1962, entitled Control and Power Supply Systems for Magnetron Devices, and assigned to the assignee of the present invention.

Also mounted in the lower machinery compartment 88 is a blower 83 for directing a stream of cooling air over the magnetron 80 and the power supply 82 for effecting cooling thereof in a well-known manner. Coupled to the RF output terminals the magnetron 80 is a waveguide 84, the upper end of which is received in a complementary opening disposed centrally of the bottom wall 72 of the oven enclosure 70 and is coupled to an antenna, generally designated by the numeral 85, for radiating the microwave 70 and the closed front door 60. The antenna 85 preferably includes a cylindrical metal post 86 extending vertically upwardly into the oven cavity substantially perpendicular to the bottom wall 72 and coaxially connected at the upper end thereof to a circular slightly concave disk-like capacitive member 87. Preferably, the post 86 has an electrical length approximately equal to 1/8 of the wavelength λ of the microwave energy generated by the magnetron 80, the total electrical length of the antenna 85 being approximately equal to $\lambda/4$.

Mounted in the upper machinery compartment 66 is an electric drive motor 90 having a grounded conductive output shaft 95 extending vertically downwardly through a complementary opening disposed centrally in the top wall 71 of the oven enclosure 70. The output shaft 95 is preferably disposed substantially coaxially with the post 86 of the antenna 85 and extends a predetermined distance into the oven into the heating cavity. Preferably, the shaft 95 has an electrical length approximately equal to $\lambda/8$.

Connected to the shaft 95 at the bottom end thereof is a mode stirrer or exciter according to one of the embodiments of this invention, generally designated either by the numeral 100, 200 or 300, the embodiment 200 being illustrated in FIGS. 1 and 2. In order to facilitate the description of the structure and operation of the mode exciters of this invention, however, the mode exciters **100, 200** and **300** will be described in numerical order.

Referring now also to FIGS. 3 through 7 of the drawings, there is illustrated in FIG. 4 the mode exciter **100** according to the first embodiment of the present invention. The mode exciter **100** is generally L-shaped and is preferably integrally formed of a single piece of conductive material such as metal, the mode exciter **100** including a relatively long leg **101** and a relatively short leg **105**, the leg **105** being disposed substantially normal to the leg **101**. Preferably, the mode exciter **100** is formed of a relatively thin flat piece of metal having a width and thickness sufficient to provide appropriate mechanical strength and current-carrying capacity, the width however preferably being less than or equal to $\lambda/8$. In the preferred embodiment of the invention, the mode exciter **100** is disposed in a plane substantially parallel to the top wall **71** of the oven enclosure **70** and is connected at the free end of the leg **101** to the bottom end of the shaft **95** for rotation therewith by the drive motor **90.** The leg **101** preferably has an electrical length approximately equal to $3\lambda/8$, while the short leg **105** preferably has an electrical length approximately equal to $\lambda/4$, whereby the total electrical length of the shaft **95** and the mode exciter **100** is approximately equal to $3\lambda/4$.

The length, width and height of the heating cavity defined by the oven enclosure **70** are all preferably greater than λ. Thus, in operation, the dimensions of the heating cavity and the dimensions of the antenna **75** are such that when the microwave energy is radiated into the cavity by the antenna **75**, the heating cavity acts as a cavity resonator and there is established therein the $TE_{1,3,1}$ mode at approximately 920 MHz, the electric field component of which is diagrammatically illustrated in solid line in FIGS. **3** and **5** and is generally designated by the numeral **110**, the direction of propagation of the electromagnetic waves being indicated by the double-ended arrows in FIGS. **3** through **5.** It can be seen that the electric field component **110** of the $TE_{1,3,1}$ mode is maximum at the middle of the heating cavity and is minimum at the front and rear ends thereof, with the direction of the field **100** being substantially parallel to the axis of the grounded shaft **95.**

As the mode exciter **100** is rotated through the electric field **110**, the mode exciter **100** is itself excited by the electric field **110** and in turn excites secondary modes in the heating cavity. More particularly, when the short leg **105** of the mode exciter **100** is disposed in positions parallel to the rear wall **73**, it excites in the oven heating cavity the $TE_{1,2,2}$ mode at approximately 930 MHz, the electric field component of which is diagrammatically illustrated in FIG. **4** and is generally designated by the numeral **115**. It can be seen from FIG. **4** that the electric field **115** is maximum adjacent to the front and rear ends of the cavity and is minimum at the center thereof. Similarly, when the long leg **101** of the mode exciter **100** is disposed in positions substantially parallel to the back wall **73**, it excites in the cavity the $TE_{2,2,1}$ mode at approximately 960 MHz, the electric field component of this mode being diagrammatically illustrated in broken line in FIG. **5** and generally designated by the numeral **130.** As can be seen from FIG. **5,** the electric field **130**, like the electric field **110** is maximum at the center of the heating cavity and is minimum adjacent the front and rear ends thereof.

As is apparent from FIGS. **4** and **5** of the drawings, both the $TE_{1,2,2}$ and the $TE_{2,2,1}$ secondary modes are complementary to the primary $TE_{1,3,1}$ mode and cooperate therewith to equalize the electric field pattern in the heating cavity. More particularly, it will be appreciated that, as the secondary modes $TE_{1,2,2}$ and $TE_{2,2,1}$ are periodically excited as the mode exciter **100** is rotated in the heating cavity, the electric fields of the several modes add so that the resultant time-averaged electric field distribution in the oven cavity will be equalized, thereby facilitating more even heating of food placed in the oven cavity to be cooked.

It will be observed that, as the long leg **101** of the mode exciter **100** rotates, the phase orientation of the $TE_{2,2,1}$ mode excited thereby, with respect to the primary $TE_{1,3,1}$ mode, is automatically continually changed to provide optimum equalization of the resultant electric field pattern. However, the $TE_{1,2,2}$ mode excited by the short leg **105** maintains the same phase orientation with respect to the primary mode $TE_{1,3,1}$ as the mode exciter **100** is rotated. Thus, there will be a distortion of the resultant field of the $TE_{1,3,1}$ and $TE_{1,2,2}$ modes as is more clearly illustrated in FIGS. **6** and **7.** When the $TE_{1,2,2}$ mode is being excited, the resultant field pattern as viewed from the front of the oven enclosure **70** may be as diagrammatically illustrated in FIG. **7,** which indicates that the front end of the field is strong in the left front half of the cavity where the electric fields **110** and **115** add and is weak in the right front half of the cavity where the electric fields **110** and **115** subtract. However, in the rear portion of the cavity, this relationship is reversed, with the field in the left half of the cavity being weak and the right half of the cavity being strong, as is illustrated diagrammatically in FIG. **6.** In order to eliminate this distortion in the resultant field of the superimposed $TE_{1,3,1}$ and $TE_{1,2,2}$ modes, it is necessary to effect a periodic phase reversal of the mode orientation of the electric field of the $TE_{1,2,2}$ mode with respect to the electric field of the $TE_{1,3,1}$ mode.

Referring now to FIGS. **8** through **13** of the drawings, a second embodiment of the mode stirrer of this invention, generally designated by the numeral **200,** is illustrated for effecting this phase reversal. The mode exciter **200** is generally W-shaped and comprises two identically constructed L-shaped sections, each of which is substantially identical to the mode exciter **100.** More particularly, the mode exciter **200** includes a first long leg portion **201** being integral at one end thereof with a first short leg portion **205** disposed substantially normal thereto. Connected to the first long leg portion **201** at the other end thereof is one end of a second long leg portion **202** extending from the first leg portion **201** substantially normal thereto and in a direction opposite to the direction of the short leg portion **205.** Integral with the second long leg portion **202** at the other end thereof and extending therefrom substantially normal thereto in a direction opposite to the direction of the first long leg portion **201** is a second short leg portion **206.** Preferably, the leg portions **201, 202, 205** and **206** of the mode stirrer **200** are all disposed in a common plane substantially parallel to the top wall **71** of the oven enclosure **70,** with the mode exciter **200** being connected at a point **207** at the junction of the long leg portions **201** and **202** to the lower end of the shaft **95** for rotation therewith by the motor **90.**

In operation, the mode exciter **200** acts in the same manner as two of the L-shaped mode exciters **100.** More particularly, the short leg portions **205** and **206** excite the secondary $TE_{1,2,2}$ mode when they are disposed substantially parallel to the front and rear walls of the oven cavity, while when the long leg portions **201** and **202** are disposed parallel to the front and rear walls, the secondary $TE_{2,2,1}$ mode is excited. The interaction between these two modes effects a periodic phase reversal of the orientation of the $TE_{1,2,2}$ mode with respect to the $TE_{1,3,1}$ mode, thereby evening out or equalizing the diagonal distortion of the field as illustrated in FIG. **6.**

The polarity of the mode exciter **200** is determined by the $TE_{1,3,1}$ electric field, as indicated by the "+" signs in FIGS. **8, 9, 11** and **12.** When the mode exciter **200** is disposed in the positions illustrated in FIGS. **8** and **9,** which positions are 180° apart, it will excite the $TE_{1,2,2}$ mode with the electric field E as shown. The field strength pattern of the resultant electric field in the oven cavity will be as indicated diagrammatically in FIG. **10,** with the strong field regions being located at the left rear and right front portions of the cavity. On the other hand, when the mode exciter **200** is disposed in the positions illustrated in FIGS. **11** and **12,** the field strength pattern of the resultant electric field in the oven cavity will be as indicated in FIG. **13,** with the strong field regions being at the left front and right rear portions of the heating cavity. Accordingly, it will be appreciated that as the mode exciter **200** is rotated through the electric field **110,** the phase relationship between the electric fields of the $TE_{1,2,2}$ and $TE_{1,3,1}$ modes will be continuously reversed, thereby maximizing the equalization of the time-averaged field distribution in the heating cavity and canceling out the field distortion which resulted with the mode exciter **100.**

Referring now to FIGS. **14** through **17** of the drawings, there is illustrated a third embodiment of the mode exciter of the present invention, generally designated by the numeral **300,** the mode exciter **300** affording an alternative structure for effecting the periodic reversal of the phase relationship between the $TE_{1,2,2}$ and $TE_{1,3,1}$ mode electric fields. The mode exciter **300** is generally rectangular in shape and includes four interconnected straight segments **301, 302, 305** and **306.** While the mode exciter **300** is illustrated in the drawings as having a substantially square configuration, it will be understood that other rectangular configurations could also be used. Preferably, the segments **301, 302, 305** and **306** are all disposed in a common plane substantially parallel to the top wall **71** of the oven enclosure **70,** with the mode exciter **300** being connected at one corner **307** thereof to the lower end of the shaft **95** for rotation therewith **90.**

Preferably, the total electrical length of the segments **301** and **305** is approximately equal to $5\lambda/8$, whereby the total electrical length of the segments **302** and **306** is also equal to approximately $5\lambda/8$. Thus, the total electrical length of the shaft **95** plus the distance along the mode exciter **200** from the point **307** to the opposite corner thereof is approximately equal to $3\lambda/4$. The mode exciter **300** operates essentially the same way as the mode exciter **200,** with the segments **301** and **305** acting in essentially the same manner as one of the L-shaped mode exciters **100** for exciting the $TE_{1,2,2}$ and $TE_{2,2,1}$ modes, with the segments **302** and **306** operating as another of the L-shaped mode exciters **100.** When the mode exciter **300** is disposed in the positions illustrated in FIGS. **14** and **15,** the field strength pattern of the resultant electric field of the $TE_{1,2,2}$ and the $TE_{1,3,1}$ modes will be as indicated diagrammatically in FIG. **10,** while when the mode exciter **300** is disposed in the positions illustrated in FIGS. **16** and **17,** the field strength pattern of the resultant field of the $TE_{2,2,1}$ and $TE_{1,3,1}$ modes will be as indicated diagrammatically in FIG. **13.** Thus, it will be appreciated that there will be effected a periodic reversal of the phase orientation of the $TE_{1,2,2}$ mode electric field with respect to the $TE_{1,3,1}$ mode electric field as the mode exciter **300** is rotated in the heating cavity, thereby maximizing the time-averaged equalization of the resultant field distribution.

In the event of fast rotation (60 to 300 r.p.m.) of the W-shaped mode exciter **200,** it may be necessary to mechanically balance the mode exciter. This may be accomplished by providing a straight balance leg **210** extending from the junction **207** away from the legs **201** and **202** and substantially bisecting the angle therebetween, as illustrated in broken line in FIG. **2.** The balance leg **210** has an effective electrical length of approximately $\lambda/2$, whereby the mode exciter **200** is not electrically affected, since the $\lambda/2$ leg will exhibit a high impedance at the junction **207.**

It is an important feature of the present invention that the orientation of the rods **77** of the rack **75** is such that the rack **75** does not interfere with the excitation of the several modes in the heating cavity and the propagation of the electric field waves therein. More particularly, since the rods **77** are disposed substantially parallel to the direction of propagation as indicated by the arrow **99,** the rack **75** will not interfere with the primary $TE_{1,3,1}$ mode or with the excitation of the secondary $TE_{1,2,2}$ and $TE_{2,2,1}$ modes.

It will be appreciated that if it were desired to excite only the primary $TE_{1,3,1}$ mode and the secondary $TE_{2,2,1}$ mode, only a single straight mode exciter would be necessary, comprising a single length of material corresponding to the long leg portion **101** of the mode exciter **100,** this single straight portion preferably having an electrical length of between $\lambda/4$ and $3\lambda/8$. It will also be understood that, while in the preferred embodiments of the invention there has been provided a separate antenna and mode stirrer disposed at opposite ends of the oven cavity, the primary and secondary mode excitation could also be achieved by utilizing only a rotating antenna in the shape of one of the mode exciters **100, 200** or **300.** With that configuration, a separate mode exciter would not be necessary. In addition, the grounded conductive shaft **95** may be provided with an equivalent electrical ground such as a choke joint in place of the actual ground described.

From the foregoing, it will be seen that there has been provided a novel and improved electronic heating apparatus and, in particular, an improved mode exciter therefor to excite predetermined secondary modes of the electrical field in the heating cavity.

In particular, there has been provided a rotating mode stirrer disposed at one end of the heating cavity and arranged substantially coaxially with a radiating antenna disposed at the opposite end of the cavity.

In addition, there have been provided three preferred embodiments of the mode stirrer for exciting in the oven cavity two predetermined secondary modes, two of these embodiments also providing for periodic reversal of the phase relationship between the primary mode electric field and the secondary mode electric field to optimize the field equalization in the heating cavity.

While there have been described what at present are considered to be the preferred embodiments of the invention, it will be understood that various modifications may be made therein, and it is intended to cover in the appended claims all such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. Electronic heating apparatus comprising an enclosure including two opposed parallel walls and defining a heating cavity for receiving therein a body to be heated, an antenna disposed in said cavity adjacent to one of said opposed walls and having a longitudinal axis substantially perpendicular to said one wall, said antenna being adapted for coupling to an associated source of electromagnetic energy of a predetermined ultra-high frequency for transmitting said energy into said cavity to excite therein a predetermined primary electromagnetic field mode, a grounded conductive member disposed in said cavity adjacent to the other of said opposed walls, and drive means coupled to said conductive member for effecting rotation thereof about said axis of said antenna for exciting in said cavity a predetermined secondary mode complementary to said primary mode, whereby there is established within said cavity a substantially uniform time-averaged field distribution thereby to facilitate uniform heating of the associated body.

2. The electronic heating apparatus set forth in claim **1,** wherein said enclosure includes six walls arranged substantially to form a rectangular parallelepiped, said antenna being disposed centrally of the bottom wall of said enclosure and said conductive member being disposed centrally of the top wall of said enclosure.

3. The electronic heating apparatus set forth in claim **1,** wherein said antenna includes a cylindrical post having the longitudinal axis thereof disposed substantially normal to said one wall, and a capacitive disk-like member connected to said post at the inner end thereof substantially coaxially therewith.

4. The electronic heating apparatus set forth in claim **1,** wherein said antenna includes a cylindrical post having the longitudinal axis thereof disposed substantially normal to said one wall, and a capacitive disk-like member connected to said post at the inner end thereof substantially coaxially therewith, said drive means including a grounded shaft extending inwardly of said other wall substantially coaxially with said antenna post, said shaft being connected to said conductive member for effecting rotation thereof.

5. The electronic heating apparatus set forth in claim **1,** and further including a rack mounted in said cavity for supporting an associated body to be heated, said rack including a plurality of spaced-apart parallel rods interconnected at the opposite ends thereof, said rods being disposed in use substantially parallel to the direction of propagation of said primary and secondary mode electromagnetic energy thereby freely to accommodate excitation of said primary and secondary modes without interference therewith.

6. Electronic heating apparatus comprising an enclosure defining a heating cavity for receiving therein a body to be heated, source means electrically coupled to said heating cavity for transmitting thereinto ultra-high frequency electromagnetic energy of a predetermined wavelength to excite a predetermined primary electromagnetic field mode in said cavity, drive means including a rotatably driven grounded conductive shaft extending into said cavity with the longitudinal axis thereof disposed substantially parallel to the electric field component of said primary mode, a generally L-shaped conductive member disposed in said cavity and having two interconnected leg portions intersecting at an angle and lying in a common plane substantially normal to the axis of said shaft, said shaft being connected to said conductive member at the free end of one of the said leg portions thereof for effecting rotation thereof about the axis of said shaft, said conductive member being responsive to continuous rotation thereof by said drive means for interaction with said primary mode electric field periodically to excite in said cavity predetermined secondary electromagnetic field modes complementary to said primary mode, whereby there is established within said cavity a substantially uniform time-averaged field distribution to facilitate uniform heating of the associated body.

7. The electronic heating apparatus set forth in claim **6,** wherein said source means transmits into said heating cavity electromagnetic energy at a frequency of approximately 915 MHz.

8. The electronic heating apparatus set forth in claim **6,** wherein said enclosure includes six walls arranged substantially to form a rectangular parallelopiped having internal dimensions greater than said predetermined wave length, said source means being disposed adjacent to the bottom wall of said enclosure and said conductive member being disposed adjacent to the top wall of said enclosure.

9. The electronic heating apparatus set forth in claim **6,** wherein the sum of the electrical lengths of said shaft and the leg portions of said conductive member is approximately equal to 3/4 of said predetermined wave length.

10. The electronic heating apparatus set forth in claim **6,** wherein said enclosure includes six walls arranged substantially to form a rectangular parallelepiped having dimensions greater than said predetermined wave length, said source means being disposed adjacent to the bottom wall of said enclosure and said conductive member being disposed adjacent to the top wall of said enclosure, said shaft having an electric length approximately equal to 1/8 of said predetermined wave length, said one leg portion of said conductive member having an electrical length approximatly equal to 3/8 of said predetermined wave length, the other leg portion of said conductive member having an electrical length approximately equal to 1/4 of said predetermined wave length.

11. The electronic heating apparatus set forth in claim **6,** wherein said conductive member is responsive to rotation thereof for exciting in said cavity two secondary electromagnetic field modes.

12. Electronic heating apparatus comprising an enclosure defining a heating cavity for receiving therein a body to be heated, source means electrically coupled to said heating cavity for transmitting thereinto ultra-high frequency electromagnetic energy of a predetermined wavelength to excite a predetermined primary electromagnetic field mode in said cavity, drive means including a rotatably driven grounded conductive shaft extending into said cavity with the longitudinal axis thereof disposed substantially parallel to the electric field component of said primary mode, a conductive member disposed in said cavity and including two interconnected generally L-shaped sections, each of said sections including first and second leg portions intersecting at an angle and lying in a common plane substantially normal to the axis of said shaft, said the first leg portions of said sections being interconnected at the free ends thereof and with said second leg portions of said sections extending in opposite directions, said shaft being connected to said conductive member at the intersection of said first leg portions thereof for effecting rotation thereof about the axis of said shaft, said conductive member being responsive to continuous rotation thereof by said drive means for interaction with said primary mode electric field periodically to excite in said cavity predetermined secondary electromagnetic field modes complementary to said primary mode, said conductive member being further responsive to continuous rotation thereof by said drive means for periodically reversing the phase relationships the electric field components of said primary and secondary modes, whereby there is established within said cavity a substantially uniform time-averaged field distribution to facilitate uniform heating of the associated body.

13. The electronic heating apparatus set forth in claim **12**, wherein the sum of the electrical lengths of said shaft plus either one of said L-shaped sections is approximately equal to 3/4 of said predetermined wave length.

14. The electronic heating apparatus set forth in claim **12**, and further including a balance member connected to said conductive member at the point of interconnection of said first leg portions thereof and bisecting the external angle therebetween, said balance member having an effective electrical length approximately equal to one-half of said predetermined wavelength and mechanically counterbalancing said conductive member during high speed rotation thereof.

15. Electronic heating apparatus comprising an enclosure defining a heating cavity for receiving therein a body to be heated, source means electrically coupled to said heating cavity for transmitting thereinto ultra-high frequency electromagnetic energy of a predetermined wavelength to excite a predetermined primary electromagnetic field mode in said cavity, drive means including a rotatably driven grounded conductive shaft extending into said cavity with the longitudinal axis thereof disposed substantially parallel to the electric field component of said primary mode, a conductive member including four straight segments all disposed in said cavity in a common plane substantially normal to the axis of said shaft and being interconnected to form a hollow rectangle, said shaft being connected to said conductive member at one of the corners thereof for effecting rotation thereof about the axis of said shaft, said conductive member being responsive to continuous rotation thereof by said drive means for interaction with said primary mode electric field periodically to excite in said cavity predetermined secondary electromagnetic field modes complementary to said primary mode, said conductive member being further responsive to continuous rotation thereof by said drive means for periodically reversing the phase relationships of the electric field components of said primary and secondary modes, whereby there is established within said cavity a substantially uniform time-averaged field distribution to facilitate uniform heating of the associated body.

16. The electronic heating apparatus set forth in claim **15**, wherein the sum of the electrical lengths of said shaft plus any two adjacent segments of said conductive member extending from said one corner to the opposite corner thereof is approximately equal to 3/4 of said predetermined wavelength.

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