

Sept. 17, 1963

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3,104,305

MICROWAVE FREQUENCY HEATING APPARATUS

Original Filed April 15, 1959

3 Sheets-Sheet 1

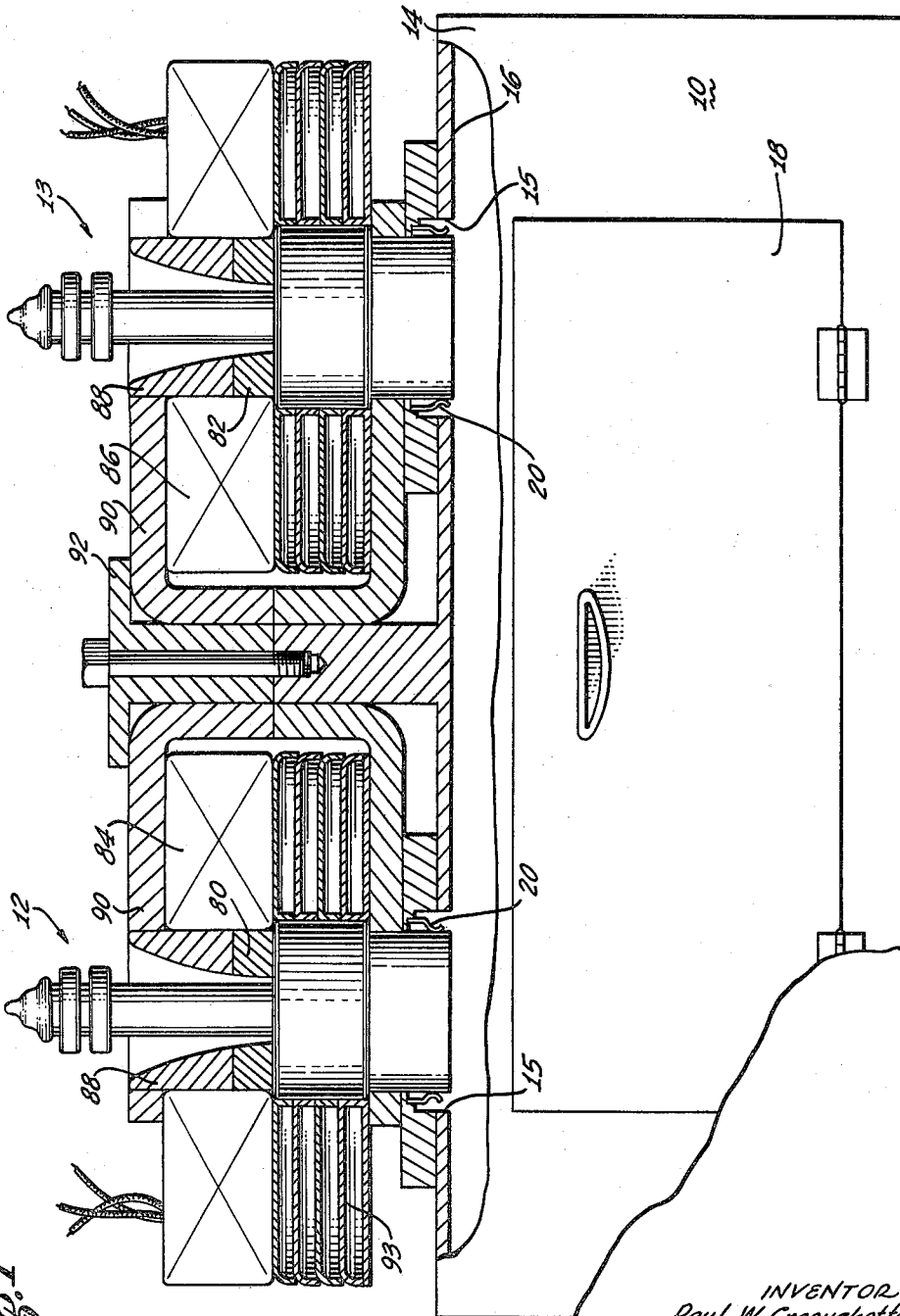


Fig. 1

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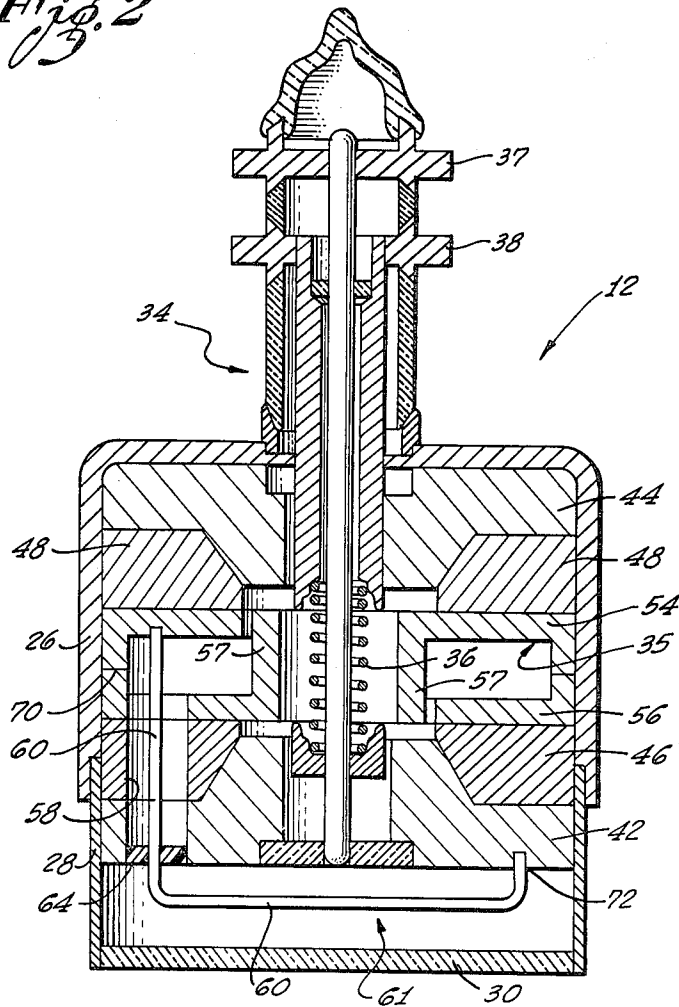
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Fig. 2



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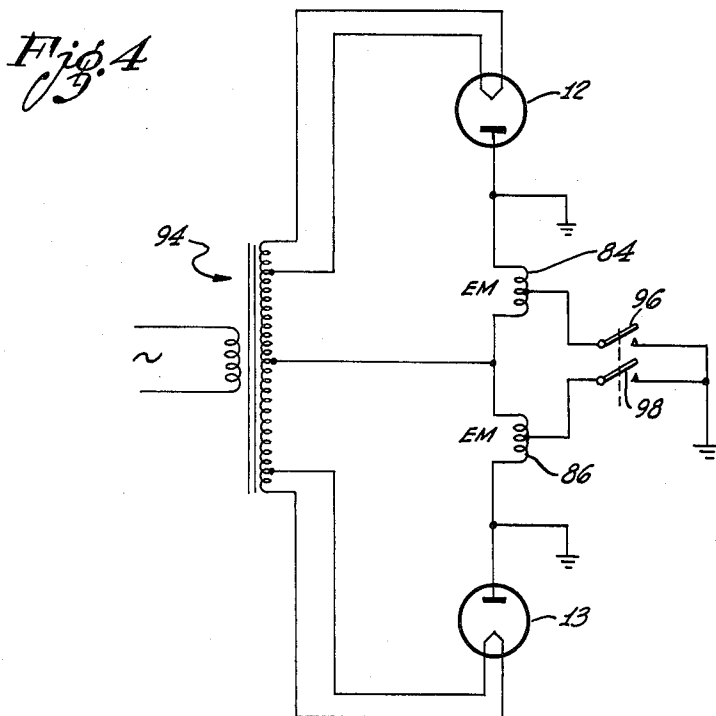
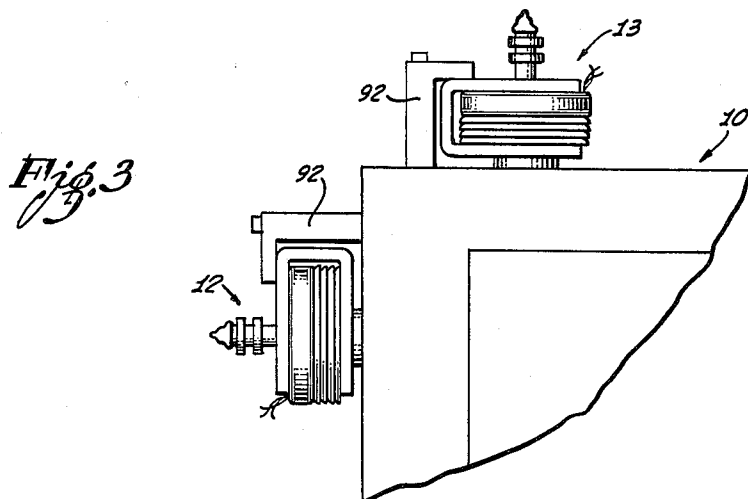
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3 Sheets-Sheet 3



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MICROWAVE FREQUENCY HEATING APPARATUS

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Original application Apr. 15, 1959, Ser. No. 806,621.
Divided and this application Oct. 11, 1962, Ser. No. 229,804

6 Claims. (Cl. 219—10.55)

This invention relates to microwave frequency heating apparatus, and more particularly to an improved microwave frequency heating apparatus which employs a microwave oven which is excited in one or more predetermined modes by at least one magnetron oscillator mounted flush within the walls thereof, and to the magnetrons therefor.

This patent application is a division of my copending patent application Serial Number 806,621, entitled "Microwave Frequency Heating Apparatus," filed April 15, 1959.

In existing ovens of the type which operate at microwave frequencies the heating thereof is achieved through the use of one or more high frequency energy sources which communicate energy to the oven through the use of a transmission network such as coaxial line or waveguide. In the prior art it has been found preferable to use magnetrons almost exclusively as the source of energy for the illumination of the oven, the microwave energy being extracted from the magnetron usually by means of an output coupling antenna which then forms the inner conductor of the output transmission line. More specifically, the coupling antenna usually consists of a coupling loop which has one end connected to the wall of the magnetron's resonant system, while the other end extends from the loop externally through the side wall of the magnetron along a path perpendicular to the axis of the magnetron tube. The coaxial output line is then used to either illuminate the oven directly through the use of conventional coaxial probes inserted into the oven through openings provided in the walls thereof, or to excite a hollow waveguide connected to the oven walls at some specific location where openings are provided for physically terminating the waveguide.

While such prior art configurations will function to supply the required energy to the associated oven cavity, there are nevertheless several serious disadvantages attendant their use. Firstly, from an economic standpoint the magnetrons generally envisaged for use with microwave ovens are of the type formerly associated almost exclusively with military applications, and are therefore relatively expensive to fabricate. Moreover, the utilization of high power coaxial lines and waveguide runs for introducing energy into the oven provides an additional cost factor which must be considered and also introduces electrical losses and reflections which effectively decrease the amount of power deliverable to the oven from any given tube. Secondly, from an operational point of view these coaxial lines and waveguide runs are known to operate as a resonant load when connected between the magnetron and the oven cavity, thereby presenting mismatches or standing waves to the magnetron which may cause it to oscillate unstably at a plurality of output frequencies. As a consequence, the oven cavity is excited with a plurality of unpredictable mode patterns corresponding to the spurious frequencies at which the magnetron oscillates. Thirdly, the use of additional waveguide runs and transitions decreases substantially the volumetric efficiency of the overall oven while simultaneously adding to the weight thereof.

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In the prior art it has also been found through experience that certain undesirable difficulties arise when a system of two or more magnetrons operating at substantially the same frequency are employed for exciting an oven, these difficulties arising from the fact that when such magnetron devices each have substantially the same output frequency, one of the devices tends to act as a low impedance across the output of the other due to slight dissimilarities between them, so that one of the magnetrons tends to absorb the microwave power of the other, or stated differently, acts as an additional load across the other instead of supplying microwave power to the common load of the cavity.

In the prior art, attempts have been made to avoid this latter limitation by the use of magnetrons which produce output signals at appreciably different frequencies, the theory behind this concept being that the tendency of one of the magnetrons to absorb microwave power from the other may be reduced to a level that is inappreciable. Although this method has been used with minor success, it has proven impractical for many applications, and requires that two different tube types be manufactured and stocked to insure adequate servicing.

The present invention obviates the foregoing and other disadvantages of the prior art by providing a microwave oven which is excited by one or more magnetrons mounted at preselected points in the oven walls, each of the magnetrons having an output window disposed substantially flush with an oven wall for launching energy directly into the oven. More particularly, in accordance with one of the basic features of the invention there is provided a magnetron having a resonant system which exhibits substantially uniform impedance from tube to tube and whose output energy waves are transmitted from the magnetron through an axially positioned output window suitable for mounting in the oven walls to directly excite the oven cavity. Moreover, as will be disclosed in more detail hereinbelow, the advantages derived through the utilization of an axially mounted output window are obtained through the use of a relatively simple magnetron structure which should provide an economic impetus to the manufacture and sale of microwave ovens in general.

In accordance with another of the basic concepts of the invention, there is provided a microwave oven which is excited directly by a pair of magnetrons whose inputs to the oven are positioned relative to each other so as to illuminate the oven alternately in two different modes without appreciable intercoupling, thereby providing means for obtaining relatively uniform energy distribution throughout the oven while simultaneously permitting the magnetrons to function at the same or relatively close frequencies of operation.

It is, therefore, an object of the invention to provide an improved microwave heating apparatus which employs direct excitation of a microwave oven.

Another object of the invention is to provide a metallic microwave oven which is excited by one or more magnetrons mounted within the walls of the oven to provide direct microwave illumination of the oven.

A further object of the invention is to provide a magnetron tube from which energy is extracted through an output window in a direction parallel to the axis of the tube.

Still another object of the invention is to provide a magnetron which employs an output window mounted coaxially with respect to the axis of the magnetron to provide direct coupling between the magnetron and an associated microwave oven into a wall of which the magnetron is mounted.

A further object of the invention is to provide a microwave oven wherein energy is coupled into the

cavity alternately from a pair of magnetrons operating at or near the same frequency and positioned to provide excitation in two different modes for producing a relatively uniform power density within the oven.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which several embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings are intended for the purpose of illustration and description only, and are not intended to limit the scope of the invention.

FIGURE 1 is a fragmentary view, partly in cross section, of a microwave oven illustrating the manner in which a pair of magnetron oscillators constructed in accordance with the invention may be mounted within one wall of the oven to provide uniform excitation thereof;

FIGURE 2 is an enlarged cross sectional view of one of the magnetron oscillators shown in FIGURE 1 illustrating the structural details thereof;

FIGURE 3 is a fragmentary view, partly in cross-section, of a microwave oven which includes two associated magnetrons mounted within different oven walls, in accordance with the present invention, to provide uniform excitation thereof; and

FIGURE 4 is a schematic diagram of one form of power supply unit which may be employed for exciting two magnetrons in accordance with the teachings of the present invention.

With reference now to the drawings, wherein like or corresponding parts are designated by the same reference characters throughout the several views, there is shown in FIGURE 1 a microwave oven, generally designated 10, only a portion of which is shown, and a pair of associated magnetron oscillator tubes 12 and 13, constructed in accordance with the teachings of the invention, which are mounted directly in the oven wall and energized alternately to provide microwave energy to heat any lossy dielectric body which may be placed within the oven. As shown in FIGURE 1, oven 10 comprises two basic elements, namely, a metallic conductive enclosure 14 having a pair of spaced apertures 15 passing through one wall 16 for permitting the magnetron oscillators to be mounted therein, and an enclosure door 18 to provide a communicating passage for placing objects within the oven or for removing objects previously placed therein. It will be seen from FIGURE 1 that the oven is illuminated directly from the magnetrons 12 and 13 without the use of any additional microwave transmission components.

Considering now the specific elements of the microwave oven of the invention, enclosure 10 is preferably rectangular in form comprising six metallic walls. In the specific embodiment of FIGURE 1 enclosure door 18 is located in one of the side walls, while the top wall 16 includes apertures 15, the configuration of the apertures depending upon the outline of the magnetrons utilized therewith. In actual practice each aperture 15 has associated therewith a suitable grounding mechanism, such as a plurality of spring fingers 20, to insure good electrical contact between the oven wall and the magnetron. It will be seen, therefore, that the boundary walls of the enclosure and enclosure door present to the magnetrons a cavity resonator which is capable of resonating in any one of a plurality of modes and at a plurality of microwave frequencies. As will be disclosed in more detail below, the oven may be made to support oscillations in preferred mode configurations through proper selection of the dimensions of the enclosure, the position of each magnetron in the oven wall, and the frequency of operation of the magnetrons.

Consider now the construction of the magnetrons mounted in the microwave oven of FIGURE 1 and the manner in which they function to provide flush mounting capabilities. Referring now to FIGURE 2, there is shown a detailed view of a magnetron oscillator constructed in accordance with the teachings of the present invention, which includes means for directly transferring microwave energy from the resonant system of the magnetron to the oven along a path concentric with the axis of the magnetron. As shown in FIGURE 2, the magnetron includes two cylindrical housing members 26 and 28 forming a tubular envelope which is enclosed at one end by an output window 30 and at the other end by a cathode terminal assembly generally designated 34. As further shown in FIGURE 2, mounted within the envelope is a cylindrical anode structure, generally designated 35, which surrounds a cathode 36 which is in turn electrically and mechanically connected to a pair of terminal members 37 and 38 which form part of cathode assembly 34. In addition, the magnetron includes a pair of pole pieces 42 and 44 which are disposed on opposite ends of the anode structure and are spaced therefrom by a pair of pole piece spacers 46 and 48 fabricated from a non-magnetic material, such as copper.

It should be noted at this point that the configuration of housing element 26 and the placement of the various structural elements therein, in accordance with the invention, greatly facilitates construction and assembly of the magnetron. More specifically, it will be noted that housing member 26 has a general cup shaped configuration with an aperture for receiving the cathode assembly. In assembling the magnetron, therefore, there are successively placed within the housing 26 the pole piece 44, spacer 48, anode 35, spacer 46 and pole piece 42, thereby providing a sandwich type construction.

Considering now in more detail the construction of anode 35, it will be noted that the anode is basically a hybrid form of interdigital structure comprising a pair of cup-like conjugate members which when placed together form a cavity enclosed at its ends by a pair of conductive end plates 54 and 56 positioned adjacent the opposite ends of the cathode 36 and perpendicular to the axis thereof. Each of the end plates has an aperture 55 in the central region thereof coaxial with the cathode, and a group of anode fingers 57 mounted about this aperture at uniformly spaced points and extending perpendicular from the plane of the associated end plate toward the other end plate. As further shown in FIGURE 2, the two cup-like anode members are positioned with respect to each other so that the two groups of anode fingers respectively associated with the two end plates are interleaved to form the anode interaction structure of the interdigital anode 35.

Considering now the novel output structure employed in the magnetron of this invention, energy is extracted from the magnetron's resonant system through a communicating passage 58 which extends through end plate 56, spacer 46, and pole piece 42 into the region 61 between pole piece 42 and output window 30. More particularly, as viewed in FIGURE 2, the communicating passage is formed by an aperture eccentrically located in each of the foregoing elements, the apertures being drilled or otherwise formed to register with each other and thereby provide a passage substantially parallel with the tube axis, which extends from the inductive region of the magnetron anode to the region of the output window.

It should be noted at this point, that if desired, energy may be extracted directly from the magnetron through passage 58 by using the passage as a cylindrical waveguide into which the output energy propagates. However, in accordance with the preferred embodiment of the invention the output structure further comprises a conductor 60 which extends from the anode resonator, through passage 58 and into the region 61 adjacent out-

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put window 30 whereat it is terminated at a point 72 on the pole piece 42 to provide an output antenna for radiating energy through the output window. The other end of conductor 60, on the other hand, is affixed to anode end plate 54 and functions as an energy pick-up or receiving antenna in the inductive region of the cavity resonator, the output energy thus produced being transmitted to the output antenna by the coaxial link formed by passage 58 and the central region of the conductor 60. It will be understood, of course, that if desired the central region of conductor 60 may be further supported within passage 58 through the use of a suitable insulating spacer, such as the spacer designated 64 in FIGURE 2.

In the operation of the magnetron the RF electric field set up in the resonant system functions to generate a current in conductor 60, and energy is extracted through the coaxial link formed by passage 58 and is presented to the output antenna portion of conductor 60 in the region 61. At this point, therefore, the conductor 60 functions in conjunction with the reflective back surface of pole piece 42 to produce a radiated field in response to the current flowing in the conductor. It should be noted, incidentally, that the process by which microwave oscillations are generated in the magnetron of the present device is substantially the same as that of conventional magnetrons, and therefore further discussions of the phenomena occurring in the electron interaction gap is considered unnecessary.

Consider now the advantages of the construction of the magnetron of FIGURE 2 with respect to its use in magnetron ovens and the manner in which it provides flush mounting capabilities. In accordance with the invention the microwave energy generated within each magnetron is oriented uniquely by the antenna-like conductor 60 in such a manner that it may be launched in an output wave through the output window along a path which is coaxial with the axis of the magnetron. This novel feature of orientating the output energy wave differs substantially from that of the prior art devices and is utilized advantageously as described herein, to permit the magnetron to be mounted in the walls of the oven, thus eliminating the need for conventional lossy and inefficient transmission circuits and microwave plumbing traditionally associated with the microwave ovens of the prior art. A further advantage is derived from the fact that the novel construction of the magnetron output structure functions to permit the magnetron to be placed readily in any one of various locations within the oven walls to produce whatever mode pattern has been selected for the operation of the oven.

Returning now to the description of FIGURE 1, the static magnetic field requisite for magnetron operation is provided in part by a pair of annular permanent magnets 80 and 82 respectively associated with magnetrons 12 and 13, and in part by a pair of electromagnets comprising two electromagnet coils 84 and 86 and associated magnetic return structures. It will be noted that each of the magnetic return structures includes an annular member 88 which engages the associated permanent magnet, and a yoke 90 which communicates magnetically with the opposite ends of the evacuated envelope of the associated magnetron, the yokes 90 further providing a surface for fastening the magnetrons in position with a suitable clamp 92.

It will be further noted from FIG. 1 that in addition to the elements described previously, each of the magnetrons further comprises a plurality of annular cooling fins 93 which are preferably formed of a good heat conductor, such as copper, the fins being stacked together and affixed to the tubular body portion 26 of each of the magnetrons. While an air cooled system of this nature will be found satisfactory in most applications, it will of course be appreciated by those skilled in the art that an equivalent liquid cooling system could be

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employed with the basic magnetron construction shown in FIG. 2 without departing from the basic concept of the invention.

Consider now the factors which determine the position of the magnetrons in the oven wall 16 as shown in FIGURE 1. It will be recognized by those familiar with resonator design that the dimensions of the oven and the frequency of operation of the magnetrons both contribute to establish the number of mode patterns of the type TE_{1wh} which may be excited in the oven, and that the excitation of a preselected mode within the oven by a particular magnetron is also dependent upon the excitation energy therefrom being introduced into the oven at a given point such that it has a particular space relationship to the fields of the mode pattern to be excited. Furthermore, it may be demonstrated that to achieve a relatively uniform power density throughout the oven it is preferable to excite the oven alternatively in two different modes whose field configurations overlap, and that to minimize any coupling between the two magnetrons each of the tubes should be located preferably at a point in the oven wall which appears substantially as a null in the mode pattern produced by the other tube.

In general the frequency range in which frequency of operation of the magnetrons must fall is preordained by the Federal Communications Commission. Accordingly, after the specific frequency at or around which the magnetrons will operate has been selected, it is only necessary to select two mode configurations for exciting the oven which are consistent with the criteria outlined above and which provide overall oven dimensions compatible with the size of conventional ovens for use in environments similar to that for which the microwave oven is intended. In addition, once the mode patterns of the type TE_{1wh} which are to be utilized in the oven are selected, the locations for placement of the magnetrons can be determined, and the magnetrons placed in space relationship to the fields of the mode to provide proper excitation of the oven. Since there are many possible modes in which the oven may operate for a given frequency, it is important that placement of the magnetrons be relatively accurate to insure proper coupling to the oven so that excitation occurs in the particular modes selected to provide uniform heating within the oven. Thus, as an added feature of the invention, the use of flush mounted magnetrons as shown in FIG. 1 facilitates placement of the magnetrons for coupling energy into the oven directly at the desired points through the use of the apertures 15 described hereinabove.

It is to be expressly understood, of course, that the invention may be practiced in manners other than that shown in the embodiment of FIGURE 1 by employing a plurality of magnetrons of the general form shown in FIGURE 2. With reference now to FIGURE 3, for example, there is shown a microwave cooker in accordance with the invention which includes an oven 10 and two magnetrons 12 and 13 for the illumination thereof, the magnetrons being positioned in adjacent walls of the oven. In this embodiment of the invention the magnetrons function in substantially the same manner and provide the same advantages as in the embodiment of FIGURE 1, one further advantage of the invention illustrated in FIGURE 3 being that the magnetrons may be placed in the various walls of the oven for special applications.

It will be recognized, of course, that numerous electrical circuits may be devised for energizing magnetrons 12 and 13 alternately in time. With reference to FIGURE 4, for example, there is shown a magnetron power supply which comprises a power transformer 94 having a center-tapped secondary which is connected to the anodes of magnetrons 12 and 13 through a pair of respectively associated electromagnet windings 84 and 86. The cathodes of the magnetrons, in turn, are each con-

nected to the ends of the transformer secondary by a pair of associated conductors, the ends of the secondary further providing filament transformers for energizing the magnetron cathodes. In addition, as shown in FIGURE 4, the circuit further includes a pair of switch contacts 96 and 98 which are selectively operable in unison to short circuit a portion of electromagnet coils 84 and 86 to thereby provide means for varying the output power presented by the magnetrons through variation of the magnetic field applied to the associated tubes. It will be recognized by those skilled in the art that maximum power will be presented when the switches are in the small coil position since the transverse magnetic field in the tubes is then held to a specified minimum, whereas a smaller amount of power will be presented when the full transverse magnetic field is applied to the tubes.

It is to be understood, of course, that alterations and modifications may be made in the structure and circuits shown without departing from the spirit and scope of the invention. For example, it is clear that the concepts disclosed herein are equally applicable for use with a pair of magnetrons placed in opposite walls of the oven, for operation of the magnetrons at substantially different frequencies, or for the use of more than two magnetrons as an energy source. It should be emphasized, therefore, that the spirit and scope of the invention is to be limited only by the spirit and scope of the appended claims.

What is claimed as new is:

1. The combination comprising: a microwave oven having a plurality of boundary walls defining a cavity resonator resonant in a plurality of modes; means for opening said chamber to insert material to be heated; a pair of microwave oscillators each of which generates microwave energy of the same frequency as the other, each of said oscillators having a respective output impedance and an output window for presenting a microwave output signal; means for mounting said oscillators to directly excite the cavity resonator defined by said oven in at least two of said plurality of modes, each of said oscillators being positioned at a pre-selected point along one of said boundary walls at which said point the impedance characteristic of the resonant mode of the other of said oscillators and of said oven matches said respective output impedance such as to prevent absorption by either of said oscillators of energy delivered to said oven by the other of said oscillators; and means for energizing said pair of oscillators to excite said oven in said two modes for producing a relatively uniform average energy density at substantially all points within said oven.

2. The combination defined in claim 1 wherein each of said pair of oscillators is mounted along a different boundary wall of said microwave oven.

3. The combination defined in claim 1 wherein said pair of oscillators are mounted along the same boundary wall of said microwave oven.

4. In a microwave oven unit, an oven chamber, means

for opening said chamber to insert material to be heated, first means for exciting said oven chamber in a first electromagnetic mode having a field pattern with nulls adjacent predetermined points along the walls of the oven, and second means separate and distinct from said first means for exciting said oven chamber in a second mode having nulls adjacent other spaced points along the walls of the oven chamber, said first excitation means including a magnetron coupled to said chamber substantially at a null point for said second mode, said second excitation means including a magnetron coupled to said oven chamber substantially at a null point for said first mode to substantially prevent electromagnetic coupling between said first and second means.

5. A microwave unit for heating material comprising: an oven resonant chamber; means for opening said chamber to insert material to be heated; first means positioned relative to said chamber to introduce a first microwave energy into the oven at a preselected point to form a first microwave mode having a field pattern with nulls at predetermined points in the oven; and second means separate and distinct from said first means and positioned relative to said first means and said chamber to introduce a second microwave energy into said oven adjacent one of said null points of said first mode to form a second microwave mode having a field pattern with a null adjacent said preselected point to substantially prevent electromagnetic coupling between said first and second means.

6. A microwave unit for exciting a microwave resonant cavity comprising: first means adapted and arranged to introduce a first microwave energy into the cavity at a preselected point to form a first microwave resonant mode having a field pattern with nulls at predetermined points in the cavity; and second means separate and distinct from said first means and adapted and arranged to introduce a second microwave energy into the cavity adjacent one of said null points of said first mode to form a second microwave resonant mode having a field pattern with a null adjacent said preselected point to substantially prevent electromagnetic coupling between said first and second means.

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