

March 7, 1967

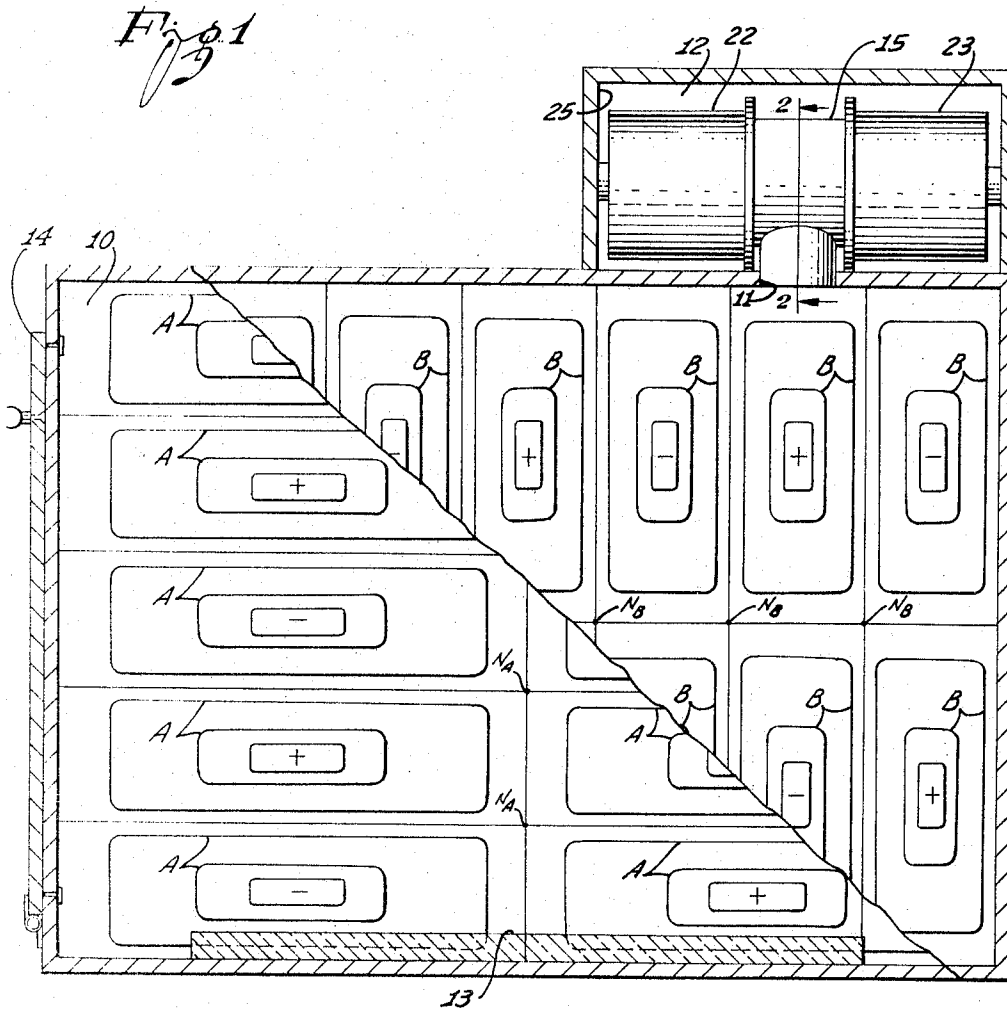
P. W. CRAPUCHETTES

3,308,390

MICROWAVE HEATING APPARATUS AND CIRCUITRY

Filed May 17, 1962

3 Sheets-Sheet 1



INVENTOR:
Paul W. Crapuchettes

By *Henry J. Sprad*
Attorney

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P. W. CRAPUCHETTES

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MICROWAVE HEATING APPARATUS AND CIRCUITRY

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Fig. 4

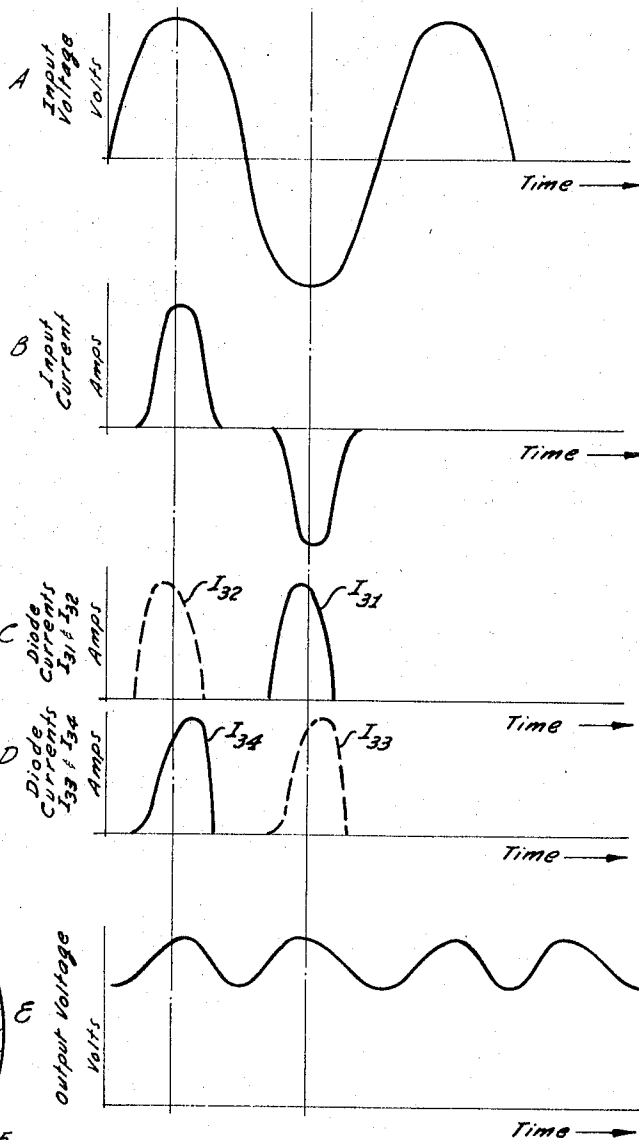
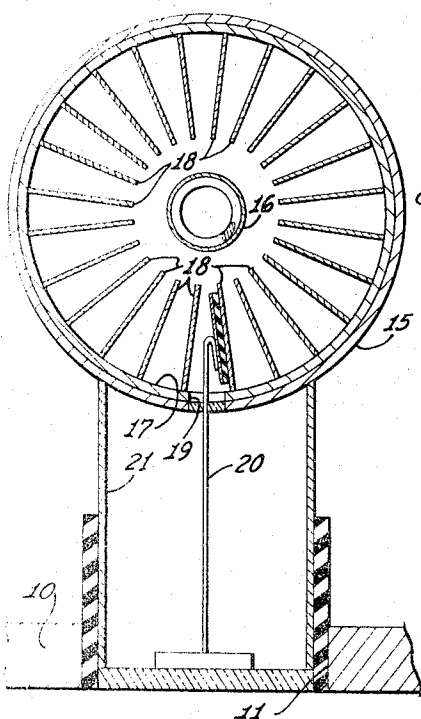


Fig. 2



INVENTOR:
Paul W. Crapuchettes

By *Merwyn D. Young*
Attorney

March 7, 1967

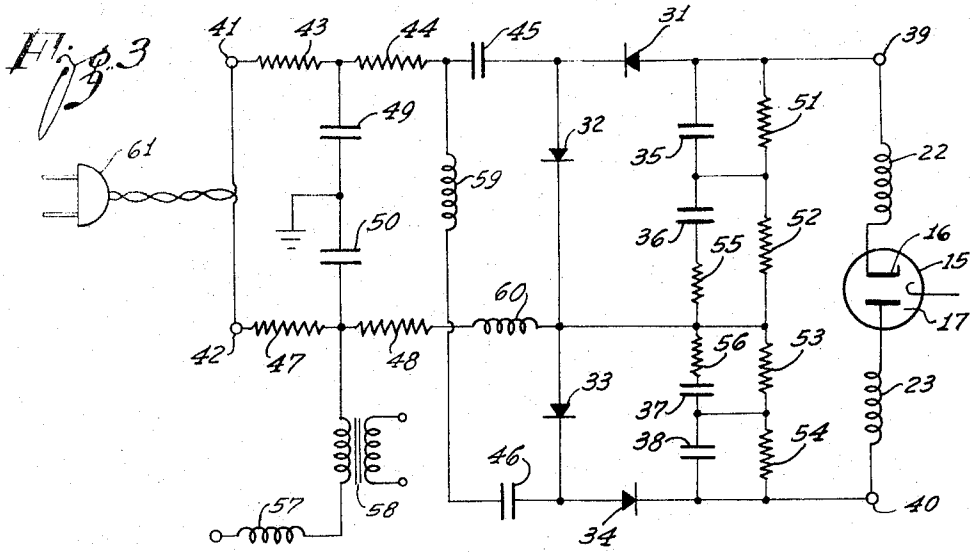
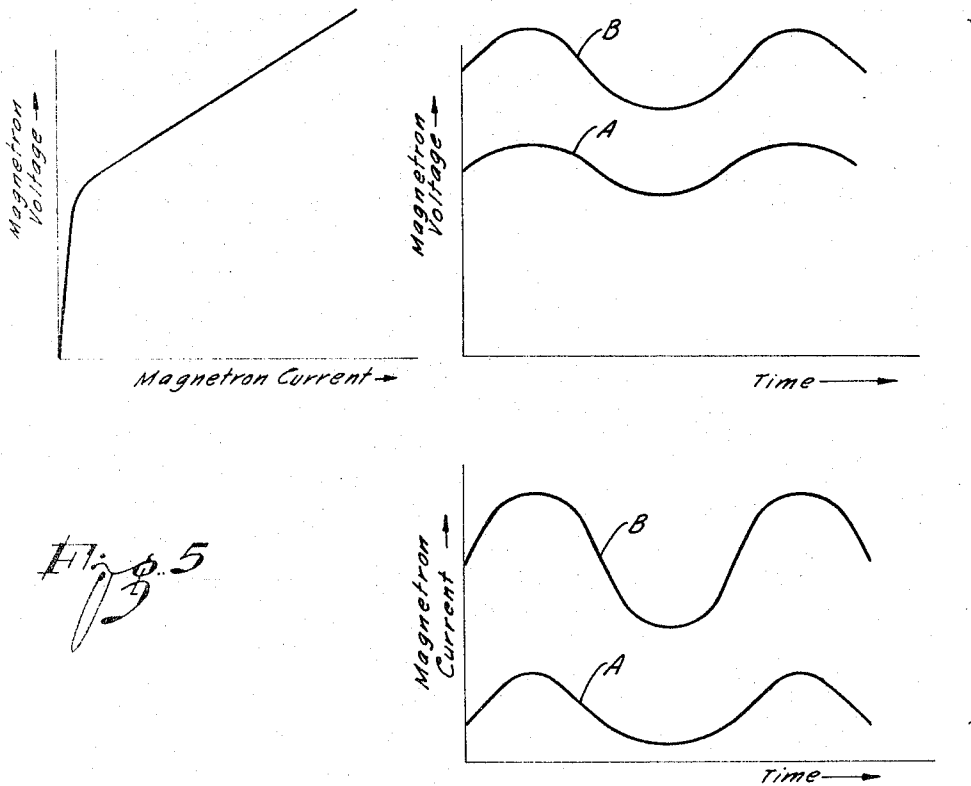
P. W. CRAPUCHETTES

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MICROWAVE HEATING APPARATUS AND CIRCUITRY

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3 Sheets-Sheet 3



INVENTOR:
Paul W. Crapuchettes

By *Manly D. Young*
Attorney

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3,308,390

MICROWAVE HEATING APPARATUS AND CIRCUITRY

Paul W. Crapuchettes, Atherton, Calif., assignor to Litton Precision Products, Inc., a corporation of Delaware
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4 Claims. (Cl. 328-216)

This invention relates to a microwave oven and apparatus, and more specifically to an improved microwave oscillator and circuitry to be used with a resonant cavity oven for the heating of food and various industrial products.

In prior art ovens and resonant cavities which are employed for the heating of various types of lossy materials, the oven or cavity resonator has been designed so that standing waves or resonant modes are set up therein. Such resonant modes will have one or more null points at which there will be substantially no microwave energy and this results in loss of heating efficiency should food or other industrial products be placed in the cavity such that one of these null points coincides with a portion of the material.

Various means have been discovered which overcome, at least in part, this loss of efficiency due to null points in the resonant cavity. For example, in the applicant's co-pending application for "Microwave Frequency Heating Apparatus," Serial No. 806,621, filed April 15, 1959, now Patent No. 3,104,303, there is disclosed a microwave oven which is provided with two or more spaced apart microwave oscillators to generate two or more overlapping resonant modes in the cavity such that one mode presents energy to at least some of the null points of a second mode. Other means of providing microwave energy at a null point of a resonant mode within such a cavity include the provision of two or more microwave oscillators which operate at different frequencies and still other means include the provision of a mechanical stirrer in the resonant cavity the motion of which shifts or moves the resonant mode pattern with a resulting blurring of any null points existing in such standing waves or resonant modes.

While each of the above-described apparatus achieves greater heating efficiency within a microwave oven, it will be appreciated that in each case more components and apparatus are involved than is desirable with a resultant increase in the cost of the respective heating unit. In view of the ever increasing market for microwave ovens, there becomes a demand for more efficient and yet inexpensive microwave ovens. Such microwave ovens should be inexpensive not only from the standpoint of manufacturing costs, but also from the standpoint of cost of operation to the ultimate user. A practical criterion for inexpensive operation is the power utilization efficiency of such a heating unit which is especially of concern to the ultimate user of such a unit since electric power companies are becoming more and more interested in selling electrical energy measured in terms of kilovolt amperes (which implies a characteristic power factor of approximately unity) as opposed to selling electrical energy measured in terms of watts (where the power factor may be substantially less in unity).

It is, then, a major object of the present invention to provide an improved microwave heating unit having a minimum of components and which is inexpensive but highly efficient.

Another object of the present invention is to provide an improved microwave oscillator that does not require additional mechanical apparatus to create a plurality of resonant modes within an oven.

It is still another object of the present invention to provide an improved microwave heating unit having a

single microwave oscillator to provide a plurality of resonant modes in an oven.

It is still a further object of the present invention to provide an improved microwave oscillator and circuitry therefor to generate microwave energy having a range of frequencies such that energy is coupled into the resonant cavity oven to establish a plurality of resonant modes therein.

Another aspect of the invention also involves reduction in the cost of microwave cooking apparatus. Power supplies for magnetrons have characteristically included a heavy and expensive step-up transformer to provide the high voltage required for magnetron operation. The elimination of this transformer constitutes another object of the invention.

In the prior art microwave oscillators, and more specifically magnetrons, care is taken to stabilize the frequency at which energy is generated by the oscillator. It is because of this stability that such an oscillator will produce only certain resonant modes when coupled to a resonant cavity oven, and, thus, other means are required to provide additional resonant modes in the microwave oven to increase the heating efficiency thereof. However, a major feature of the present invention resides in a microwave oscillator adapted to generate a range of frequencies, and in means to activate the oscillator such that a microwave energy is coupled to the resonant cavity oven to excite the oven in a plurality of resonant modes. Additional features of the present invention reside in the particular circuitry employed to activate the magnetron and which includes inductive, capacitive and resistance means to insure proper phase relations between the input voltage and current and between the magnetron plate voltage and current such that, in each case, the power factor is close to unity for greater power efficiency. In accordance with another feature of the present invention, the heavy transformers may be eliminated by the use of an inexpensive voltage syncopated double doubler power supply which may be connected directed to commercially available alternating current power lines.

In considering the implications of the present invention, it may be noted that microwave cooking units are still quite expensive. The remarkable advantages of high speed microwave cooking are therefore not yet available to the general public. By eliminating the need for mode mixing devices and for the expensive transformer in the power supply, the cost at the manufacturing level can be greatly reduced, and microwave stoves may be made available to many more people.

Other objects, advantages and features of the present invention will become apparent from the following description which is to be read in conjunction with the appended drawings wherein:

FIGURE 1 is a cross sectional view of an oven and the microwave generator unit that includes a representation of the respective modes in which the oven is resonant as a result of the manner in which the magnetron oscillator is activated;

FIGURE 2 is a cross sectional view of the magnetron unit including the magnetron and showing the manner in which it is coupled to the oven;

FIGURE 3 is a schematic drawing of the voltage quadrupling circuit employed in the present invention to activate the magnetron;

FIGURE 4 is a set of wave forms illustrating the current signals supplied to the magnetron by various portions of the circuitry of FIGURE 3 including the resultant sum of the respective signals; and

FIGURE 5 is a curve representing the dynamic voltage-current characteristics of a typical magnetron of the type employed in the present invention.

In order to more fully describe the major features of the present invention, reference is now made to FIGURE 1 in which is shown the boundaries of a resonant cavity consisting of the reflective top, bottom and side walls of microwave oven 10. Aperture 11 in the top of oven 10 is aligned with the output window of the magnetron of microwave generator unit 12 mounted on the top of microwave oven 10. Oven 10 may include support 13, which is permeable to microwave radiation, to receive food and various industrial products inserted through oven door 14. The dimensions of oven 10 are so chosen that when the magnetron is operating at a particular frequency, a resonant mode will be established in oven 10 which is represented generally by the contour lines A. Contour lines A may be interpreted as defining respective equipotential electric field lines of an electromagnetic standing wave extending throughout microwave oven 10. When the magnetron of microwave generator unit 12 is operated at a different frequency, a different resonant mode pattern will be set up in microwave oven 10 as generally indicated in FIGURE 1 by contour lines B which are similar in nature to contour lines A.

Within microwave generator unit 12, magnetron oscillator 15 is of the vane type, as shown in FIGURE 2, and includes cathode element 16 disposed with a horizontal axis and anode 17 is disposed coaxially about cathode 16 with a plurality of vanes 18 extending from the inner surface of anode 17 radially inwardly toward cathode 16 so as to define a plurality of resonant chambers within magnetron 15. As shown in FIGURE 2, the lower portion of anode 17 is provided with aperture 19 through which extends loop coupling antenna 20 from the lowermost resonant cavity of magnetron 15 to chamber 21, the walls of which are designed to engage aperture 11 of microwave oven 10 as shown in FIGURE 1. The axial magnetic field is supplied to the magnetron by two electromagnetic coils 22 and 23 mounted coaxially with cathode element 16 and disposed on either side of magnetron 15 as shown in FIGURE 1. The axial magnetic field is perpendicular to the radial electric field between the cathode and anode, thus providing the crossed fields necessary for magnetron like action. The tube and coil arrangement is mounted in housing 25 to complete the structural combination forming the microwave generating unit 12 as shown in FIGURE 1. The respective magnet units may include permanent magnets as well as electromagnets excited by the magnetron plate current.

In addition to the structure thus far described, the microwave generator unit 12 includes a voltage quadrupling rectifier circuit which is shown schematically in FIGURE 3. This circuit, in essence, includes four power diodes 31, 32, 33 and 34 in series, which series combination is placed in parallel with capacitors 35, 36, 37 and 38 with the entire combination being adapted to provide an output voltage across the anode and cathode of magnetron 15 as will be more fully described. The A.C. input to this power supply is received across terminals 41 and 42 and alternately across power diode 32 and power diode 33. Terminal 41 is connected through resistances 43 and 44 and capacitor 45 to the junction between power diode 31 and 32 and from resistor 44 through capacitor 46 to the junction between power diodes 33 and 34. Terminal 42 is connected through resistances 47 and 48 to the junction between power diodes 32 and 33. Resistances 43, 44, 47 and 48 along with capacitors 49 and 50 are provided to filter out any commutating noise from the rectifier so as to prevent any television or telephone interference. Resistors 43, 44, 47 and 48 also serve to limit the peak current to capacitors 45 and 46 during those portions of the cycle when diodes 32 and 33 respectively are conducting. It will be appreciated that the respective diodes act as rectifiers with the respective diodes 31 and 34 acting to complete the voltage doubling circuit of each half of the quadrupling circuit which may be viewed as a syncopated double doubler. The

use of syncopation reduces the capacitance requirements of capacitors 35, 36, 37 and 38 for a given degree of ripple in the output voltage which will be more thoroughly discussed.

To supply the proper plate voltage and current to the magnetron from output terminals 39 and 40, the respective power diodes act as rectifiers to store the appropriate charge in respective capacitors 35, 36, 37 and 38. While in prior voltage quadrupling circuits there are normally but two capacitors in parallel with the series of power diodes, four capacitors may be used in the present circuit where the voltage drop thereacross, in a no load situation, can be as high as 1400 volts which is greater than can be sustained by but two commercially available capacitors. Resistors 51, 52, 53 and 54 in series are placed across output terminals 39 and 40 and are respectively connected in parallel across each of capacitors 35, 36, 37 and 38 to insure the proper division of the output voltage across the respective capacitor parts in each doubling portion of the quadrupling circuit.

While it is the purpose of the circuitry of FIGURE 3 to provide as uniform an output voltage as practical, it is also the purpose of the circuitry of FIGURE 3 to drive the magnetron in a predetermined manner so that the magnetron will generate a range of frequencies. To this end, resistors 55 and 56 in series are inserted between capacitors 36 and 37 with the junction between resistors 55 and 56 being connected to the junction between power diodes 32 and 33. In this arrangement, resistors 55 and 56 reduce the current which flows through the capacitors thereby reducing heating in the capacitors and encourage current flow directly through the magnetron. When the rectifier charge cycle is completed, the voltage drop across this resistance series reduces the affected voltage across the respective capacitors and in this way reduces the current drawn from the capacitors. As a result thereof, the current through the magnetron varies over a wider range than would otherwise be the case and thereby produces more "pushing" and contributes to the generation of a range of frequencies and to the elimination of the need for additional mode mixing means in the oven resonant cavity as will be more thoroughly described below.

Also shown in FIGURE 3 is the magnetron filament power supply to be employed during the warm-up period of the magnetron operation. This supply circuit includes radio frequency choke 57 in series with transformer 58, the secondary of which is coupled to the magnetron filament leads. Power may be supplied by this circuit only during the warm-up period, since the heating efficiency of the magnetron cathode can be made to be of such a magnitude that all the filament power during the operation of the magnetron is supplied by back heating. In such an embodiment, the filament transformer 58 can be operated by a timer (not shown) for the first few seconds of operation. It will be noted that input terminals 41 and 42 may be connected to a standard power outlet by plug 61.

Two other components may be included in the circuit of FIGURE 3 and are phase shifting inductors 59 and 60 which may be inserted respectively between resistor 48 and the junction between power diodes 32 and 33 and between resistor 44 and capacitor 46. The purpose of such inductances is to produce a lagging current to offset the leading current produced by the capacitive components of the circuit such that the input to the circuit has a power factor of unity or substantially unity as will be more fully discussed below.

While the ripple of the output voltage should be reduced as much as possible, a complete elimination of such a ripple is not feasible. With the circuitry of the type shown in FIGURE 3 a ripple will have a frequency of one hundred-twenty cycles even though a power input thereto is taken off a standard sixty cycle electrical source. In FIGURE 3, the respective power diodes 31, 32, 33

and 34 serve to supply unidirectional currents to the respective capacitors which are discharged through the anode-cathode circuit of the magnetron. Thus, during one half of the cycle, positive current flow will be from input terminal 41 through resistors 43 and 44, capacitor 45, power diode 32 and then to input terminal 42. At this time, positive current flow will also occur from terminal 41 through resistors 43 and 44, capacitor 46, power diode 34 and through capacitors 38 and 37 and then back to terminal 42. During the other half of the cycle, positive current flow will be from input terminal 42 through resistors 47 and 48, power diode 33 and capacitor 46 back to terminal 41 and also through resistance 55, capacitors 36 and 35, power diode 31 and then back to terminal 41. During the first half of this cycle, power diode 32 and capacitor 45 serve to place the junction between diodes 31 and 32 at a potential above that of the junction between diodes 32 and 33 which potential is equal to the potential of the input voltage. During the second half of the cycle, power diode 31 and capacitors 35 and 36 in a similar manner serve to place output terminal 39 at a higher potential by the same amount with respect to the junction between diodes 31 and 32. Similarly, diodes 33 and 34 serve to place terminal 40 at a negative potential of a magnitude twice that of the input potential such that the average potential difference between terminals 39 and 40 is approximately four times that of the input potential. It will be noted that current flow through diode 34 occurs during the first half of the cycle while diode 33 conducts during the second half of the cycle.

To further illustrate the syncopated matter in which this quadrupled voltage is built up and also to illustrate the current flow in the respective portions of the circuit, reference will now be made to FIGURE 4 which illustrates the respective wave-forms. Wave-form A in FIGURE 4 represents the input voltage of the form $e \sin \omega t$ where e is just the maximum voltage amplitude and ω represents the frequency in radians per second which, in practical applications of circuit, will just be power line frequency of the standard electrical source. As mentioned above, during the first portion of the cycle (although not the entire first half thereof) current will flow through diode 32 and this current wave shape is illustrated in wave-form C as I_{32} . It will be noted in wave-form C that the peak of curve I_{32} leads the peak input voltage due to capacitor 45 in FIGURE 3. In a similar manner, the current flow through diode 34 will be as illustrated in wave-form D and denoted as I_{34} . Again it will be noted that the peak of curve I_{34} lags the peak of the input current due to the phase shifting inductor placed in the circuit as described above.

Curve B of FIGURE 4 illustrates the input current to the circuit and a comparison of curve A with curve B illustrates the relation between the input voltage and the input current where it is anticipated that the line current will have an open angle of one hundred-thirty to one hundred-fifty degrees.

During the second portion of the cycle, positive current flow will be through diode 31 and will have the form as depicted as I_{31} in wave-form C and again it will be noted that the peak of this form leads the input voltage and input current peak while the current through diode 33 will have the form indicated as I_{33} in wave-form D of FIGURE 4 and again it will be noted that this current lags the peak of input current.

While phase shifting inductors 59 and 60 may be placed in both legs of the circuit as indicated in FIGURE 3, the placing of such an inductor in but one leg of the circuit will suffice to correct the capacitive phase shift and in fact increases the angle of line current. For example, while current wave-forms I_{32} and I_{34} represent currents in different portions of the circuit, both currents are derived from the input terminals and thus may be added to determine the total current input and its contribution to

the input power efficiency where the power factor is made substantially unity.

It will be noted that the current through diode 31 and the current through diode 34 are out of phase by approximately one hundred-eighty degrees such that the rectifying output voltage of the circuitry as seen at output terminals 39 and 40 will have a ripple of a frequency twice that of the power input to the circuit. Such a ripple which would be at one hundred-twenty cycles for a sixty cycle input and is illustrated by wave-form E in FIGURE 4.

To achieve the particular results which are important objects of this invention, namely that of exciting the magnetron to resonate over a range of frequencies, resistances 55 and 56 are inserted in series between capacitance 36 and 37 as illustrated in FIGURE 3 with the junction of the respective resistances being connected to the junction between diodes 32 and 33 and hence to input terminal 42. As described above, one of the effects of the adaptation of these resistances to the circuit of FIGURE 3 is that of reducing the voltage drop across the respective capacitances of the output portion of the circuit in FIGURE 3 with the result that less current is drawn by the magnetron from the respective capacitors and more current is drawn from the input portion of this circuitry. Furthermore, the total output voltage is increased.

Referring to FIGURE 5 of the drawings, there is shown therein the voltage current characteristics of a typical magnetron such as might be employed in the present invention. In addition to the voltage current characteristic curve, FIGURE 5 also depicts a set of typical current time wave-forms and the relation thereof to the applied voltage time wave-form for a typical magnetron. It will be noted from the voltage current characteristic curve that, for an initial applied voltage, very little current flows and this curve rises to a knee above which the dynamic resistance of the tube is greatly reduced, thus allowing for a large current to be drawn for a small additional applied voltage.

In general, the average operating voltage applied across the magnetron is in the vicinity of the curve above this knee and it will be appreciated that there will be a large variation of the current drawn by the magnetron, relative to operation below the knee, for a given voltage variation. However, if the applied voltage variation is increased during operation above the knee of this curve, there results even greater variation of the current drawn by the magnetron. This increase in current variation is illustrated in FIGURE 5 where the voltage curve A represents the output voltage of the circuitry of FIGURE 3 when resistances 55 and 56 are not in a circuit. On the other hand, when resistances 55 and 56 are placed in the circuit as disclosed above, the output voltage curve for the circuit will be as indicated by voltage curve B in FIGURE 5 and the resultant current variation will be as indicated by current curve B in FIGURE 5.

It will be appreciated, from the above discussion of the basic operation of the voltage quadrupling circuitry, that the function of either doubling portion thereof is to develop a potential drop across either diodes 31 and 32 or diodes 33 and 34 which is twice that of the input voltage; and it is this doubled voltage which is impressed across either the combination of capacitors 35 and 36 and resistance 55 or across the combination of capacitors 37 and 38 and resistance 56. However, because there is current flow through either leg during only approximately thirty to forty percent (30-40%) of the cycle due to the current rectification of the circuitry and also because the input line current has an open angle of approximately one hundred-thirty to one hundred-fifty degrees, there will be a charging current flow through either of resistances 55 and 56 for only approximately forty percent (40%) of the time and the remainder of the time the respective output capacitors will tend to

maintain the total quadrupled voltage. Thus, current flow through resistances 55 and 56 results in an added voltage across the output terminals 39 and 40 with the resulting increase of the voltage output during the charging cycle and a proportional increase of the output voltage variation. This increase can be adjusted by the selection of the respective resistances 55 and 56.

As a result of this increase of the plate voltage variation, the magnetron will experience a greater current variation as illustrated by current curve B of FIGURE 5. Furthermore, there results more efficient power output from the power supply since resistances 55 and 56 act to reduce the effect of the capacitive phase shift and there also will be more variation of current flowing to the magnetron during the voltage cycle. This latter effect may be viewed as an increase of the open angle of the magnetron current flow.

With the power supply circuitry of the type described above, it will be appreciated that not only is the input power efficiency increased, but the power factor improvements cited above result in further reduction of line current required for a fixed input power to the magnetron. More importantly, however, when in combination with the power supply of the type described above, a magnetron will be driven so as to generate microwave energy of a range of frequencies for reasons which will now be described.

That an increase in the plate current variation results in an increased range of frequencies generated by the magnetron is due to the fact that the output frequency thereof is, among other things, current dependent. This may be explained as a phase shift being experienced by the electron space cloud as it moves from the magnetron cathode to the anode which shift is due to a change in the plate current and results in an effective change of the capacitive and inductive characteristics of the magnetron resonance circuit. Thus, a periodic variation of the plate current will result in a periodic variation of the output frequency of the magnetron. Such a frequency variation is commonly referred to as the "pushing characteristic" of a magnetron and is measured in terms of a frequency per ampere anode current change. While "pushing" is known to those skilled in the art, this effect is generally considered to be undesirable and magnetrons are normally designed to reduce such "pushing" in order to stabilize the frequency output thereof.

Referring again to FIGURE 1, the establishment of a plurality of resonant modes within the oven resonant cavity due to the range of frequencies radiated by the microwave generator will now be explained. Consider that, as illustrated in FIGURE 1, a series of standing waves will be set up within the oven cavity resonator depending upon the frequencies radiated into the chamber from the magnetron. For example, contour lines A represent, in a general way, the various potential values of a standing wave mode for a given frequency with null points indicated by N_A . Contour lines B represent the potential values of a second wave in the chamber set up for a higher frequency with null points indicated by N_B . While these patterns are represented as being two-dimensional, it will be understood that FIGURE 1 represents a cross section of a three-dimensional cavity. Thus, contour lines A may be considered as representing the cross section in an x-y plane of a mode pattern of the form TE_{523} and contour lines B represent a cross section of the mode TE_{273} such that the respective patterns in the z direction are not shown. Additional standing waves will exist depending upon the various frequencies generated by the magnetron and it will be appreciated from viewing FIGURE 1 that should null points exist in any one of the respective standing waves, microwave energy will nevertheless be supplied at such points by at least one other standing wave.

While the frequency spectrum of the magnetron output will be continuous over the range of frequencies being

generated, there nevertheless will exist only a discrete number of modes within the microwave oven depending upon the integral number of half wave lengths that can be accommodated by the dimensions of the oven cavity for each of the respective frequencies. While many of the frequencies will not present standing waves that can be accommodated by the cavity dimensions, such frequencies may nevertheless contribute energy to the standing wave patterns of adjacent frequencies where there is a low ratio of energy input to energy absorption by the cavity for each of the respective frequencies. While this ratio will always be greater than 1 for each frequency as required for resonance, it is nevertheless desirable that this ratio be made as low as possible so as to provide a more even distribution of energy throughout the cavity. Thus, as the input frequency to the oven periodically varies, the energy input to each of the discrete modes will have a similar periodic variation, although each mode may be said to continually exist so long as the oven is being excited to resonance. It is to be understood that any means of periodically varying the magnetron frequency may be employed within the scope of the present invention. Thus, while a particular embodiment of this invention may employ the power supply circuitry of FIGURE 3, other embodiments may include periodically variable magnetron tuning means.

It will be understood that the respective null points N_A and N_B represent the intersections of null planes and microwave energy should not be introduced into the cavity along such a null plane. Thus, magnetron 15 and aperture 11 are to be positioned at a point in the resonant cavity wall adjacent to a substantial coincidence of maximum potentials of each of the resonant modes. It is to be noted in FIGURE 1 that aperture 11 is adjacent to a maximum potential of mode B and also adjacent to a maximum potential of mode A.

As a typical example of the number of modes that may be excited in a resonant cavity, modes of the form TE_{523} , TE_{551} , TE_{462} , TE_{273} and TE_{142} have been established in a cavity having dimensions of 35.5 cm., 45.6 cm., and 38.6 cm. respectively for the n, m and p directions where the input frequency variation is of the order of magnitude described below.

With an oven and a microwave unit employing the power supply circuitry of the type described herein, power can be taken from a standard household electrical outlet of the one hundred-ten volt sixty cycle type or from a commercial outlet of the two hundred-twenty-five volt commercial type outlet and the power supply circuitry can be approximately adjusted to provide the required plate voltage to a magnetron. For example, a particular embodiment which is highly adaptable to commercial useage may be designed to utilized a normal two hundred-twenty-five volt input to the power supply to obtain a minimum of one kilovolt-ampere of power being applied to the oven cavity with the power supply producing a plate voltage of essentially eleven hundred volts D.C.

Such performance characteristics, of course, depend upon the employment of a magnetron which has been designed to operate at a relatively low voltage and a consequent high current. Such a magnetron may have a relatively low input impedance associated therewith, for example on the order of four hundred-fifty ohms. However, such a magnetron can be incorporated in series with coils 22 and 23 of the respective electromagnets described above such that the output impedance of the power supply of the type shown in FIGURE 3 may be on the order of six hundred ohms. The voltage, current and impedance characteristics are determined, of course, by the magnetron design including, among other things, on the number of vanes. As shown in FIGURE 2, the type of magnetron contemplated for use in the present invention has twenty-four vanes and a like number of resonant chambers.

With a magnetron adapted to be activated by a circuit of the type shown in FIGURE 3, the microwave energy output thereof will periodically vary over a range of frequencies, which range is of the order of three to twenty megacycles, when the magnetron is normally tuned to operate in that portion of frequency band prescribed by the Federal Communications Commission for the type of use anticipated by the present invention. As before pointed out, this periodic variation will be at a frequency of one hundred-twenty cycles per second when the input power to the power supply is received from a sixty cycle per second source. While a conventional resonant cavity might be resonant in more than one mode without such a frequency variation, the number of modes excited by this frequency variations will be greatly increased and thus the possibility of the existence of unwanted null points within the resonant cavity is greatly reduced.

As disclosed herein, the present invention includes a microwave oven and power supply therefor which not only achieves greater power efficiency but also achieves greater uniformity in heating because of the plurality of resonant modes present in the oven, and this is accomplished with but a single magnetron or microwave oscillator and without the use of various mechanical devices such as "stirrers." Thus, the present invention is directed not only toward a more efficient microwave oven but also toward a less expensive oven unit as required for the ever expanding commercial market for microwave heating of foods and various types of industrial products.

It will be understood that the above-described embodiments of the present invention are not the only embodiments or arrangements that may be employed within the practice of the present invention. Thus, it should be emphasized that present invention is not to be limited only to the particular arrangements described herein and that it is to include variations by one skilled in the art which nevertheless remain within the spirit and scope of the inventions as recited herein and in the appended claims.

What is claimed is:

1. A microwave resonant cavity unit for the heating of food and industrial products, said unit comprising:
 - a resonant cavity having an aperture in one of the sides thereof;
 - a magnetron mounted outside of the cavity and adapted to supply microwave energy of a given frequency through said aperture into said resonant cavity, said magnetron comprising a reentrant anode member including a plurality of resonant cavities adapted to have standing waves induced therein, and a cathode member coaxial with and immediately adjacent said anode member, said given frequency being variable

over a range of frequencies in response to variation of the magnetron plate voltage; and

power supply means coupled to said magnetron to provide a varying magnetron plate voltage to said magnetron whereby said resonant cavity becomes resonant in a plurality of discrete resonant modes in response to the varying frequency of the microwave energy introduced therein.

2. The microwave resonant cavity unit of claim 3 wherein said power supply means includes a syncopated voltage multiplier.

3. The microwave resonant cavity unit of claim 2 in which said syncopated voltage multiplier comprises a first series arrangement of first, second, third and fourth power diodes, each having the same polarity orientation and a second series arrangement of capacitance and resistance means in parallel with said first series arrangement, the combination being adapted to supply a periodically varying anode voltage to said magnetron, said power supply means also including a pair of input capacitors coupled to the circuit respectively between said first and second power diodes and said third and fourth power diodes to receive and transmit an input voltage and current thereto.

4. The microwave resonant cavity unit of claim 3 wherein said power supply means further includes phase means in response to which the input voltage and current thereto have substantially the same phase.

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ARTHUR GAUSS, *Primary Examiner.*

RICHARD M. WOOD, *Examiner.*

L. H. BENDER, R. H. EPSTEIN,

Assistant Examiners.