

Household microwave oven technology

John E. Gerling

Current performance features of domestic microwave ovens, including control systems, uniformity systems, power generation systems, power coupling considerations, and safety features, set the stage for new developments over the next 5-10 years.

Overview

The domestic microwave oven is a phenomenon that is literally reshaping the way America and the world prepare their food for household consumption. From annual sales of a few thousand ovens in the early 1970s, sales of microwave ovens exceeded 11 million units in the United States and 17 million units worldwide in 1989. It is estimated that over 80% of the households in the United States had one or more microwave ovens by the end of 1989. The development of food products to be heated in the microwave oven has dominated the new product development activities of all major food companies.

Because the microwave oven industry is relatively young, it is continuing to show rapid changes in technology resulting in reduced cost and improved performance features. At the same time the food and packaging industry is showing equal ingenuity in creating new products, including ones that overcome the inherent limitations of microwave ovens to brown and crisp.

The major features of current household ovens are shown in Fig. 1.

Control

The operator enters the information necessary to program the control system. In the simplest case the operator enters the time of operation. With many ovens the operator can also enter the desired power level.

Some sophisticated ovens take over the job of oven control through the use of various sensors which determine when the product to be heated is ready for serving. Such sensors utilize the temperature of the product, the initial weight of the product, moisture evaporated from the product, temperature of the exit air, aromatic gases given off by the product, color changes, weight loss, cavity field change, and audible sounds in the cavity. In these cases, the operator enters the type and amount of food being heated and the desired end results. The control circuit measures the output of the sensor and establishes a cooking

protocol based on an internal algorithm. Some ovens incorporate more than one sensor and employ the sensor most appropriate to the type of food being heated.

Many ovens employ sources of thermal energy in addition to the microwave energy to improve the cooking performance with particular food types. The most popular (10% of the 1989 market) is the use of recirculating hot air within the microwave oven cooking cavity.

Other thermal systems include infrared radiation units such as found in toaster ovens and a system for filling the microwave oven with a steam atmosphere for combination steam-microwave cooking.

The control system, in conjunction with the basic information provided by the operator, determines and controls these auxiliary thermal systems.

Power generation

The control system uses the operator-furnished directions or the program from an internal algorithm to operate the microwave power generation system. This system consists of a magnetron, which generates microwave energy at a frequency of 2.45 GHz, and a power supply, which provides the voltages necessary to permit the magnetron to operate. This power supply must be designed to stabilize the output of the magnetron against line voltage changes. This last requirement is necessary because of the magnetron's extreme sensitivity to voltage fluctuations.

The line-voltage regulating circuitry prevents the power supply from varying the level of microwave power by raising it and lowering it. Consequently, designers have incorporated circuitry in the power supply that turns the microwave power on and off and which causes the average energy to be delivered to the food to be reduced by the percentage of time the oven is in the "off" mode. The time-base, or the interval between successive "on" cycles, varies from oven to oven and can range from as short an interval as 1 s to as long an interval as 60 s. The most commonly encountered interval is 20 s. In an oven with this time-base, 50% power means that the oven is switched on for 10 s and switched off for 10 s, with the cycle repeating until the oven completes the program time.

The rated power output of household microwave ovens

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ranges from 350 W to 750 W. It is unlikely that higher powered ovens will be produced for household use because of the power limitations associated with the ordinary electrical outlet. A 750-W oven consumes all the power permitted to be drawn under existing electric codes.

The rated power is the power that is delivered to a large load in the microwave oven cavity, for example, 1 L of water. The power delivered to a small load such as a bag of popcorn or a single food item serving can be much less, down to one-half the rated power. Because of the overwhelming importance of understanding this feature to package design, it will be discussed more thoroughly later.

Power introduction

The microwave power is introduced into the oven cavity through or in association with a mechanism that improves heating uniformity.

The heating uniformity problem basically stems from the fact that the wavelength of the microwave energy (12.24 cm or 4.82 in.) is large compared to oven cavity dimensions. This means that the oven cavity has standing wave mode patterns where there are areas of high microwave heating and adjacent areas of low microwave heating. To make the heating more uniform, some ovens have a rotating mechanism at the point where the microwave energy enters the cavity, causing the mode patterns to occupy different positions and providing for more uniform heating of the product over a period of time. Other ovens have a rotating product platform, which causes the product to be moved through the regions of high and low microwave heating so it will be more uniformly heated over a period of time.

While the microwave power generally comes into the top of the oven cavity, newer designs have it coming in from the sides, rear, or bottom of the oven cavity; in some cases, it is introduced in two places simultaneously.

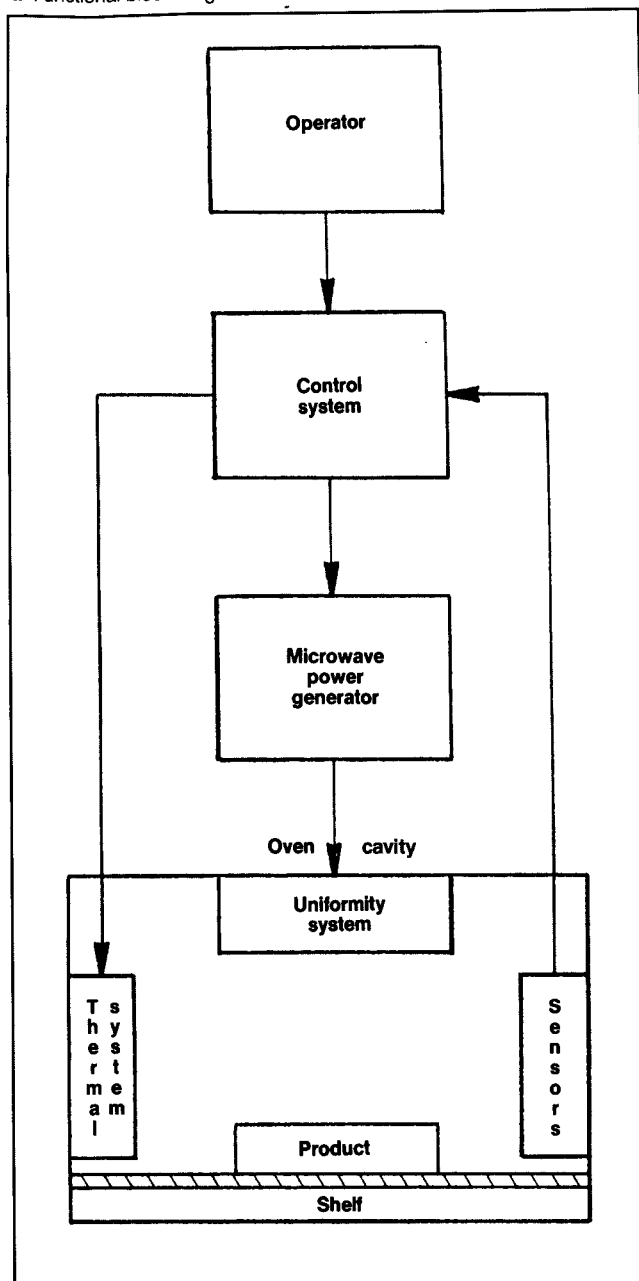
Oven designs differ with respect to the shelf that the product rests on. For a long period of time, shelves were always microwave transparent and were made either of glass or ceramic. Newer oven designs incorporate wire racks or metal shelves or turntables. The type of shelf has an effect on the heating characteristics of different types of food products, with the metal rack and metal shelves giving relatively poor performance with frozen products and products that use interactive packaging such as those with partial shielding and special inserts which cause crisping or browning.

The size of the oven cavity also has an influence on performance characteristics, particularly uniformity of heating. Oven cavities at the present time range in size from 0.4 ft³ to 1.5 ft³ for countertop microwave ovens and up to 3.5 ft³ for wall-type built-in ovens. The larger the cavity, the larger the number of mode patterns that can exist within the cavity, and, generally speaking, the easier it is to achieve uniform heating.

Safety features

All ovens have special interlock circuitry to ensure that the oven cannot be operated with the door open. By federal regulation, this interlock circuitry includes a backup interlock which senses whether or not the primary interlock is operating properly. If an attempt is made to

1. Functional block diagram of a household microwave oven

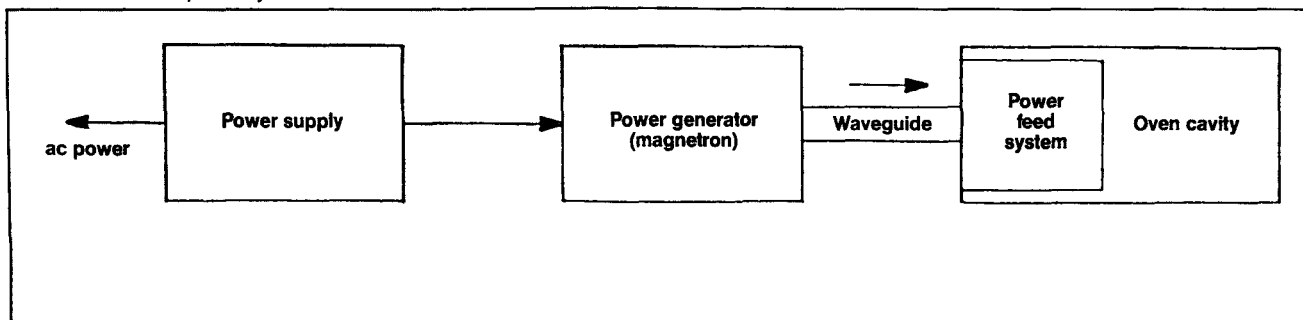


operate the microwave oven with the primary interlock disabled or damaged then the interlock monitor will cause a fuse contained within the oven to fail, preventing further operation until the oven has been serviced.

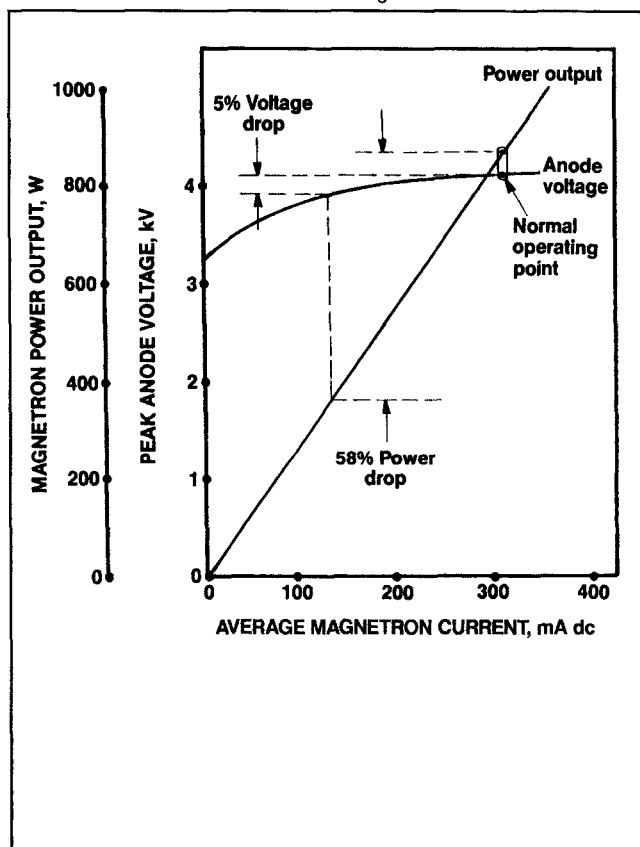
The door of the oven is subject to a special set of design requirements and contains microwave circuits which control the leaking of microwave energy between the surface of the door and the microwave oven cavity to safe levels. The door and its interlock circuitry must also be designed to withstand 100,000 operations without maintenance and without failure.

The safety features of a microwave oven are regulated by three different agencies: the Center for Devices and Radiological Health (an agency of the Food and Drug Administration), which imposes standards to prevent the operator from being exposed to harmful radiation; the

2. Microwave oven power system



3. Performance curves for a 2M107A magnetron



Federal Communications Commission, which imposes regulations to prevent the oven from interfering with other electronic equipment; and the Underwriters Laboratory (UL), which has established a set of standards designed to keep the oven from being a fire or electrical hazard. Consequently, the modern microwave oven is one of the most reliable and safe appliances available on the market today.

Microwave oven power

Now let's talk about microwave power produced by domestic microwave ovens and how it is generated, regulated, and made variable. I'll also discuss factors that affect the power delivered to materials placed in the microwave oven and considerations such as manufactur-

ing variations, measurement techniques, and standards.

Basic system

Figure 2 shows a basic power block diagram for the home microwave oven. A power supply delivers the necessary voltages to a magnetron, which generates the microwave power. This power is delivered to the oven cavity through a power feed system which may be associated with the provisions to achieve heating uniformity.

Magnetron characteristics. Before we can examine the power supply we need to understand the basic electrical characteristics of the magnetron as they influence the design of the power supply.

Figure 3 contains performance curves for a typical home microwave oven magnetron showing the anode voltage and the power output as a function of the magnetron current. The anode voltage is flat at the operating point, and for a 5% voltage drop the power output will drop from 850 W to 350 W (a 58% drop). Since line voltages in the home vary much more than 5% both up and down, clearly the power supply must have some form of regulation stabilizing the power output of the magnetron.

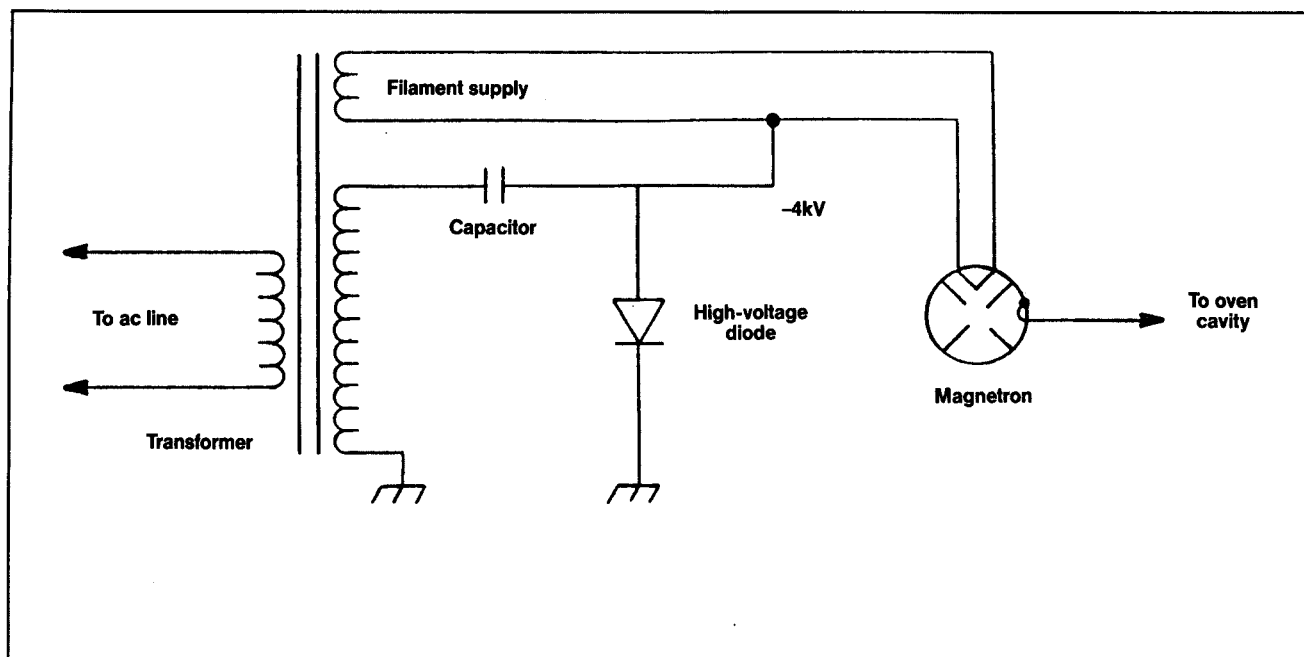
Power supply. In the middle 1960s, there was a development by Feinberg of Advance Transformers (U.S. pat. 3,396,342) that resulted in a magnetron power supply that provided the necessary regulation at a reasonable cost. This design consists of a transformer having a high-leakage reactance operating in concert with a series capacitor. This combination caused a constant current to be delivered to the magnetron over the normal range of line voltages. The basic Feinberg design is used in essentially all domestic microwave ovens. The fundamental constituents of this supply are shown in Fig. 4.

There is a "filament supply" shown in this figure. The filament supply furnishes the necessary power to the magnetron to cause the filament, or source of electrons, to come to the temperature necessary for electrons to be emitted. Until the filament has come to its operating temperature, the magnetron will not produce any power since no current can be drawn. In a new magnetron it takes approximately 1.5 s for the filament to come to temperature.

Magnetron load effects. The exact operating point of the magnetron is partially determined by the impedance of the power feed system and the oven cavity with whatever load might be in the cavity.

The interrelationship between these elements is

4. Basic microwave oven power supply



predicted by the use of a diagram called a "Rieke" diagram, which shows what the power output and frequency of a magnetron will be under various conditions of output load. The output load in this case is the delivery waveguide, feed system, and oven cavity with load. A typical Rieke diagram is shown in Fig. 5. The particular point at which the magnetron operates is determined by the amount of power reflected back to the magnetron and the phase of the reflected power. The reflected power is measured in relationship to the delivered power as a voltage standing wave ratio; this ratio is shown on the Rieke diagram as the various diameter circles starting from closest to the center at 1.1 to the outer diameter at 5.0. The center of the diagram represents no reflected power. The phase is indicated by the particular point on the voltage-standing-wave-ratio circle with 360 degrees of the circle being equal to one-half of a wavelength. The power output from the magnetron can be increased, decreased, or not affected and the frequency from the magnetron can be increased or decreased or not affected depending on the exact nature of the load.

Basic power equation

The basic power equation for the microwave oven is simply stated as follows:

$$P_g = P_r + P_a + P_d$$

where

P_g = power generated by the magnetron

P_r = power reflected back to the magnetron

P_a = power absorbed by the microwave oven cavity and feed system

P_d = power delivered to the load placed within the microwave oven capacity.

To fully understand the power characteristics of a microwave oven, we need to examine each one of the statements and see what affects it and how it relates to the other statements.

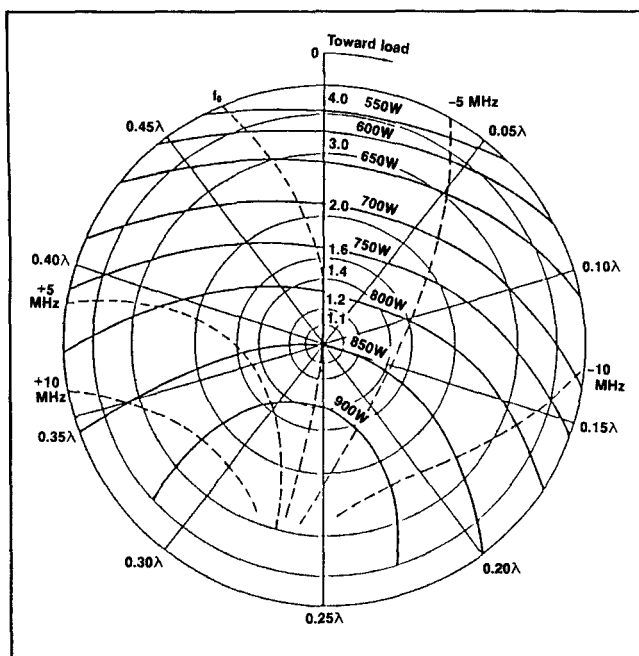
Power generated

The power generated by the magnetron is determined by the line voltage, by the amount of time the magnetron has been operated, and by the power reflected back to the magnetron from the oven cavity.

Magnetron power-line voltage. Figure 4 shows a power supply design which causes a constant current to be delivered to the magnetron under conditions of varying line voltage. The design is not perfect. An actual magnetron power supply does cause the power output of the magnetron to vary with line voltage, and the degree of variation depends quite a bit on the particular selection of component parameters. It is possible to create a ferro-resonant power supply which has excellent regulating characteristics. However, this adds cost to the power supply and in the current market, which is price driven, this is usually not one of the design choices. Consequently, we have power supply designs which permit appreciable variations in the output of the magnetron with line-voltage changes. The amount of change varies from manufacturer to manufacturer and can be as low as $\pm 5\%$ for a $\pm 5\%$ line-voltage change to as high as $\pm 20\%$ for a $\pm 5\%$ line-voltage change.

Magnetron power—heat effects. The amount of time the magnetron is operated affects the power output in two different ways. First, there is the problem of the heating of the magnetron. As the magnetron heats, the permanent

5. Rieke diagram for the 2M107A magnetron



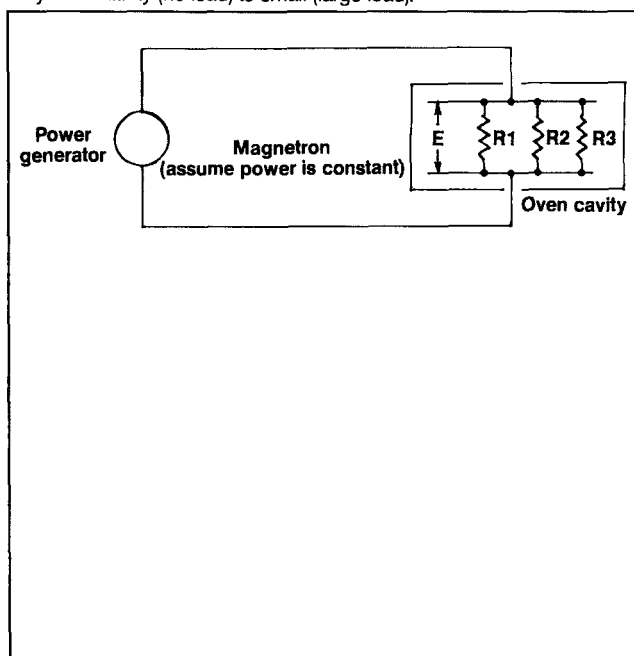
magnets (which are a part of the magnetron and establish the operating voltage of the magnetron) will heat, causing a reduction in the magnetic field within the magnetron. This reduction in magnetic field causes the operating voltage to reduce which, in turn, causes the power output to reduce.

The power output of the magnetron changes for another reason with time. This has to do with the heating of the plate transformer in the power supply. As a cost and weight reduction feature, the iron in the transformer has been reduced as much as possible, which increases the losses in the transformer. To enable this cost reduction to be carried as far as possible, new insulation classes have been created. Based on these new classes, UL has permitted the temperature of the transformer to go as high as 165°C. At this temperature, the power loss in the transformer is significant. The temperature rise of the transformer decreases power to the magnetron because of increases in the series resistance of the transformer windings.

The sum of these two effects is to reduce the power to the oven by as much as 10% as these components come to operating temperature.

Magnetron power—load effects. Power that is reflected back to the magnetron depends on the nature of the load within the oven cavity. If the oven is operated without a load, then a great deal of the power is reflected. If the oven is operated with a rather large load, then very little of the power is reflected. The size and the phase of the power reflected will, in turn, change the performance of the magnetron as explained previously. In some oven designs, the power output is less in a lightly loaded oven than it is in a heavily loaded oven. In other designs, the reverse is true. There is no consistency from manufacturer to manufacturer or even within different oven designs for

6. Simple equivalent circuit (E = average field strength in cavity. R_1 = reflected power equivalent load. R_2 = cavity losses equivalent load. R_3 = load placed in cavity by user.) R_1 and R_2 are fixed by design. R_3 can vary from infinity (no load) to small (large load).



a given manufacturer.

Magnetron power—actual values. The actual amount of power that can be generated in a domestic microwave oven is limited by the amount of electric power that is available to the power supply.

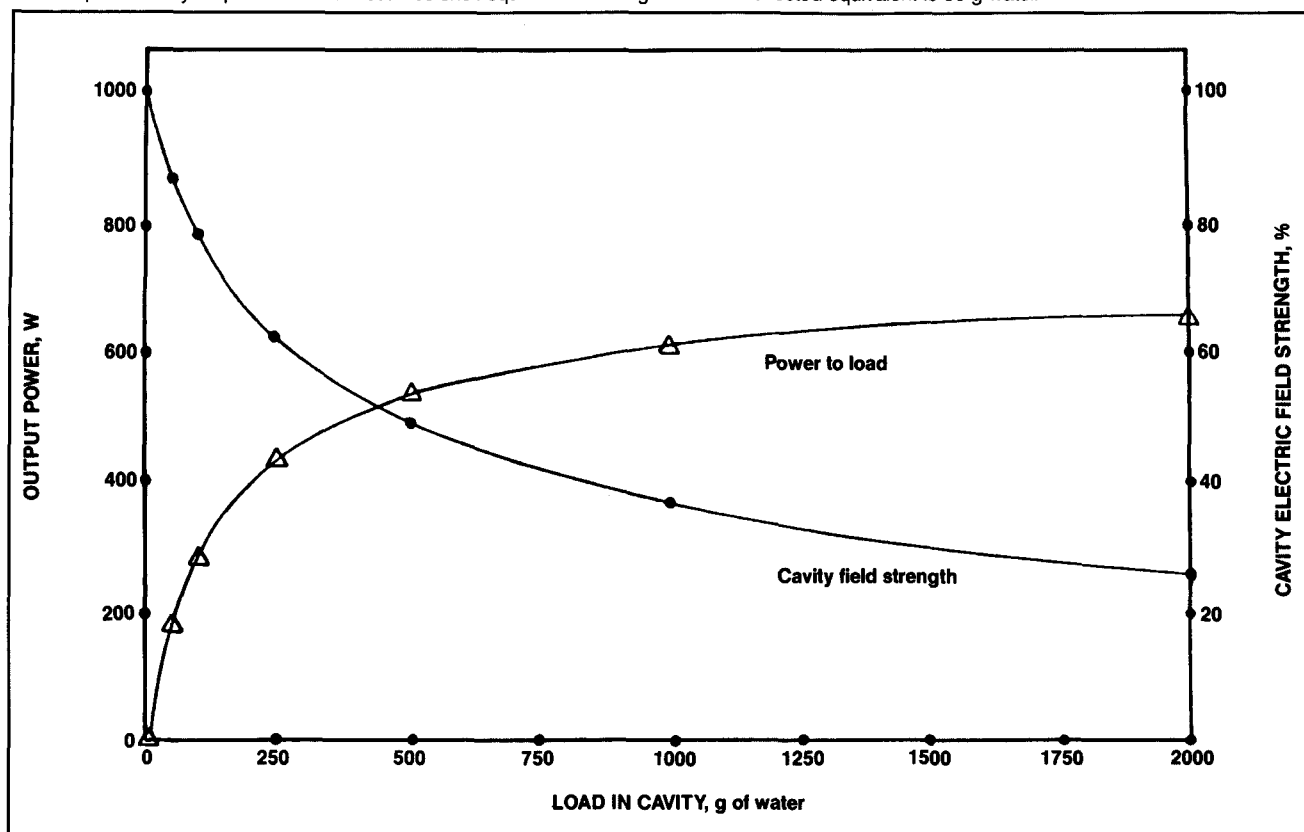
Countertop microwave ovens, designed to be plugged into a convenience outlet, are limited in the amount of power that can be drawn by the limitations imposed by the National Electric Code and its adoption by local building authorities.

The nominal voltage delivered by a convenience outlet in the United States is usually 120 V (some locations have 110 V or 115 V), at least under conditions of no power being drawn. A convenience outlet delivers this voltage and has a regulatory limitation on the absolute maximum amount of current that can be delivered of 15 A and a design maximum of 13 or 14 A. These figures, 120 V and 14 A, dictate the maximum power that can be delivered by the magnetron to the oven cavity. This power is approximately 750 W.

Ovens can be made to have lower power outputs by changing the component values of the transformer and capacitor. Ovens can be made to have any value of low power for which there is an economic justification. If a use could be found for a 50-W oven, then it could easily be produced.

Ovens with power outputs higher than 750 W (up to 2000 W) are available in commercial service where 208-240-V lines or 20-A current outlets are installed. Such ovens also could be made for domestic use; one company (Amana) marketed a 1 kW domestic microwave oven which required that the convenience outlet be changed to a configuration that permitted 20-A current. Unfortunately, Amana and its dealer network were unable to convince a sufficient number of households to make the necessary

7. Computed cavity response curves. Assumes shelf equivalent to 100 g water and reflected equivalent to 50 g water.



conversion, and Amana withdrew this oven from the market.

Common cavity ovens which are built into the wall and have available to them 208-240-V circuits could be made to have higher power output. But as far as is known, manufacturers of such ovens have not taken advantage of this capability and supply microwave systems based on countertop designs.

Power utilized

Reflected power. The power reflected back to the magnetron is generally determined by the size of the load placed in the oven cavity. The larger the load placed in the oven cavity, the smaller the field strength in the cavity and the less power delivered to the reflected power mechanism.

Power absorbed by the cavity. The microwave oven designer wants to maintain maximum power in the cavity and avoid the prohibited regions specified by the magnetron manufacturer. He must achieve these goals under all conditions of position of the uniformity system and oven cavity load.

The most onerous of these circumstances is an empty oven, which causes the maximum amount of reflected power. To meet magnetron manufacturers warranty requirements, some oven manufacturers choose to place material in the cavity that will absorb some power. This is usually done by formulating the glass shelf or ceramic shelf to absorb power. The presence of such a shelf is necessary to achieve the design performance of the oven. It is for this reason that use and care manuals for

microwave ovens prohibit oven operation without the shelf in place.

When microwave power is transmitted into any enclosure, the power is reflected by the metallic surfaces, and in the reflection process, current is caused to flow. This current will cause some slight heating due to the electrical resistance of the metallic elements involved and will mean some power being absorbed.

If the oven walls or the space underneath the shelf become contaminated with grease or filled with water, then the power absorbed by the oven cavity will increase, having a corresponding effect on the power delivered to the load.

Power absorbed by the load. The amount of power delivered to the load is determined by the size and placement of the load, the power reflected, and the power absorbed within the cavity.

Figure 6 gives a simple equivalent circuit for the microwave oven. The diagram is an electrical representation of the basic power equation stated earlier.

Looking at it this way we can see more clearly the interaction between the three elements that take up the power delivered by the magnetron. These three elements can be considered load resistors, which are connected in parallel and placed across the power generator. The first two resistors, R1, which represents the power reflected back to the magnetron, and R2, which represents the power absorbed within the oven itself, are determined by oven design and are fixed. The resistor, R3, represents the load placed in the cavity by the user. It has a value of infinity or is electrically not there when there is no load

and has a small value if a large load is placed in the cavity.

The power delivered to each of the resistors is simply the voltage squared divided by the resistance value. In the case of the microwave oven, where the power produced by the magnetron is assumed to be constant for this simple analog, the voltage (or cavity field strength) is influenced by the size of the load placed in the oven cavity. As the load increases (or the value of R_3 decreases), the field strength reduces, causing the power consumed by the first two resistors to be reduced and the power consumed by the load resistor to be increased. The manner by which these factors change is shown in the simple graph in **Fig. 7**, which shows how the power to R_3 changes as R_3 is decreased from an infinite value to a very small value and shows how the field strength in the cavity decreases.

This is a rather roundabout way to say that the power absorbed by the load placed in the oven cavity is determined by the size of the load. The reason for this relationship is explained in the diagrams and curves in **Figs. 6 and 7**.

Figure 8 shows cavity power as a function of load size for six different microwave ovens where the load sizes are various amounts of water contained in laboratory beakers. These curves generally follow the shape predicted by the simple analog circuit.

Power output measurement

The measurement of power output of a microwave oven is done by using calorimetric principles, that is, the change of temperature of a known mass of water in a known period of time.

The basic equation is:

$$P_w = 4.17 (L \times \Delta T / T_m)$$

where

P_w = measured power output of the microwave oven, W

L = the amount of water heated, g

ΔT = the temperature rise of the load of water, °C

T_m = the time the microwave power was on, s.

The problem with such a measurement is that details of the measurement have a pronounced effect on the result.

The most obvious one is the size of the load. As can be seen in **Fig. 8**, changing the size of the load has a rather dramatic effect on the microwave power measured. Another parameter is the allowed temperature rise. If the temperature rise is held so the temperature of the water never exceeds 50°C or so, then the measurement is not compromised. But if the temperature rise is permitted to go much above 50°C then evaporation will occur, and the energy used to support the evaporation will not be taken into account in the measurement.

The shape of the vessel holding the water has an effect. A flat shallow dish will generally tend to give a higher power measurement than will a vessel that holds the water in a compact mass. This is because a larger surface area will couple more efficiently.

The initial water temperature also has an effect because the loss factor of water changes significantly with temperature. The lower the temperature, the higher the loss factor.

Finally, there is the question of the thermal mass of the container.

In a typical measurement procedure, 1000 g of water is placed into a Form 1000 Corning Pyrex® beaker and the water heated for a time to cause it to rise 20°C. The power output is computed from the exact temperature rise and elapsed time measurement. This measurement does not take into account the fact that a certain amount of energy was utilized to heat the beaker. The beaker started at the same temperature as the water and ended at the same temperature as the water, thereby experiencing a temperature rise. It required a certain amount of power to heat the beaker. The beaker described has an equivalent thermal mass of about 70 g of water. The power output measurement would be 7% higher if this factor were taken into consideration.

General American practice is to use 1000 g of water and to make the measurement in such a way as to not take into account the thermal mass of the container. Japanese practice is to use 2000 g of water for the measurement and to follow a procedure that eliminates the thermal mass of the container. Removing the thermal mass of the container from the computation and using a larger load size results in the Japanese measurement typically being 10–15% higher than the American measurement for the same microwave oven.

The International Electrotechnical Commission (IEC) has adopted a standard procedure which calls for a measurement using 1000 g of water but otherwise following the Japanese procedure.

Unfortunately, there is no government administrative agency in the United States which requires the use of a standard procedure for power output measurement. This means that each manufacturer is at liberty to choose the method of his choice in measuring and reporting power output. The trend seems to be for American manufacturers to adopt Japanese measurement practices since this results in a higher power output measurement. In time, there will probably be a de facto standard, that being the method that gives the highest number, either the Japanese method or, by mutual agreement, the IEC method.

Variable power

Variable power was introduced during the early 1970s with the first electronically variable microwave oven produced by Litton Industries.

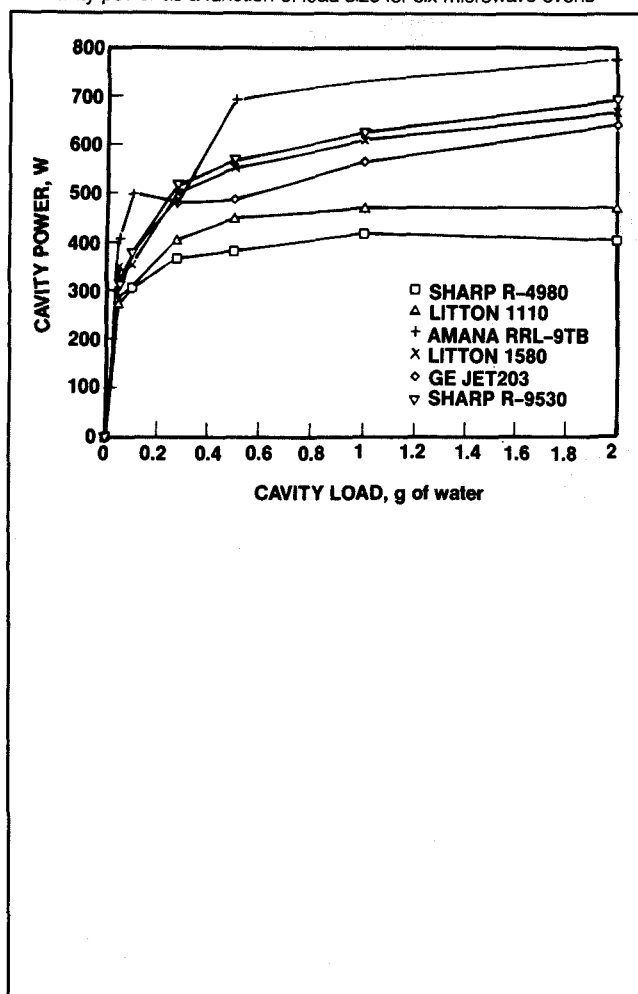
Varying the power output of a microwave oven is not simple because of the electrical characteristics of the magnetron and the design of the associated power supply.

Because the supply is regulated against line-voltage changes and is designed to deliver a constant current to the magnetron (**Fig. 4**), it cannot be easily made to adjust the current and still provide regulation.

The solution has been to stay with the basic power supply and its regulating characteristics and use a time-based sequence of switching the power supply off and on to change the amount of average power delivered to the load.

If the power supply is turned off and on repeatedly so the magnetron is on only half of the time, then it will deliver only half of the power it should have delivered if the power supply had been operating continuously. This is the principle of the variable-power system now used virtually universally by oven manufacturers.

8. Cavity power as a function of load size for six microwave ovens



9. Variable power waveforms

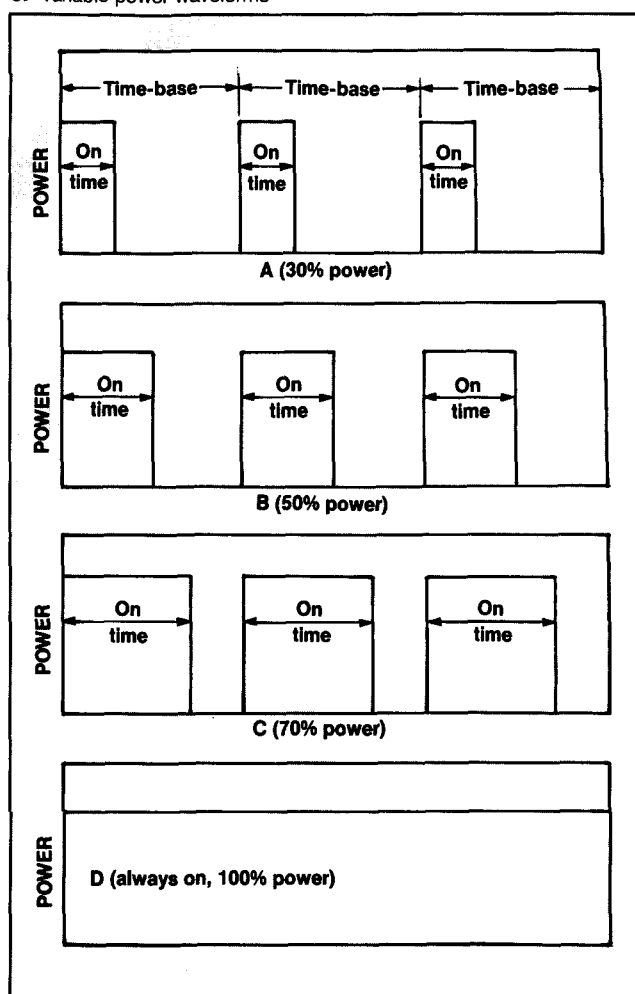


Figure 9 shows the waveforms that exist for a microwave oven that operates using an off-on cycle. Figure 9A shows it operating at 30% power, 9B at 50% power, 9C at 70% power, and 9D at 100% power. When the power is less than 100% there is an interval between successive pulses, which is referred to as the time-base, and that the on-time is made a percentage of the time-base to achieve the desired power level. In any given oven with variable power, the time-base remains fixed and the on-time is changed until it is the desired percentage of the time-base.

The time-base is a factor of some variability between oven designs. It can be as short as 1 s or as long as 60 s.

To determine how the time-base is selected, we need to review again another facet of magnetron performance. A magnetron functions by having a filament, which, when heated to the proper temperature, gives off electrons that ultimately produce the microwave power. Unless the filament is at the operating temperature, the magnetron cannot function. Figure 10 shows three methods used in current microwave ovens to achieve variable power. See how the treatment of filament power determines the design and the time-base.

Figure 10A describes the top-of-the-line design capable of creating a very short time-base. In this design, the filament is powered by a separate transformer which is always connected to the power line. This means that the

filament is always at its operating temperature. The power control can then switch the high voltage as rapidly as the circuit constants will permit. In this design, the shortest time-base in use is a 1-s time-base found in some Hardwick ovens and 1.67 s (100 line pulses) found in some Amana ovens. This design is the most expensive because it requires a separate transformer.

Figure 10B shows a design that uses a vacuum reed relay to switch the high voltage. This permits the filament transformer to be incorporated with the plate transformer, but since it is always on, the filament is always at the operating temperature. The limitation on time-base relates to the life of the reed relay and is usually about 5 s. As far as I know, only Matsushita has used this design in some of its Panasonic and Quasar models.

The most common system is shown in Fig. 10C and is the so-called "self-start" system. In this system, the filament transformer is part of the plate transformer and the power control causes both the filament power and the plate power to be switched. Each time the power control turns the transformer on, the filament must come up to temperature before the magnetron can deliver power. This is extremely hard on the magnetron, and life tests conducted under these conditions have indicated that the time-bases shorter than 12 s can cause the magnetron to have a shorter than desired life. This is the least expensive

of the systems and the one most commonly used. It is used in designs from 12 s and up. Most of the electronically controlled systems are in the 12 s to 20 s range. Systems using electromechanical means (e.g., clock motors with cams to operate the switch) are usually at 30 s and 60 s, either for cost reasons or because they deliberately want a longer time-base to have enhanced defrosting capabilities.

Oven to oven variations

There is a variation in power output from oven to oven because of variations in the component values of the capacitor and differences in the performance characteristics of the magnetron. (The transformer and high-voltage diode are manufactured in such a way as not to introduce any oven to oven variations.) The capacitor has the greatest effect because there can be considerable variation from lot to lot for a given capacitor manufacturer and even more variation from manufacturer to manufacturer. With all factors taken into account it is not unusual to see the power output of a series of identical models have a range of output from 575 W to 675 W, with a 625-W specified value.

Future developments

Here I will describe some of the features I predict will be developed and made available sometime within the next 5-10 years in home microwave ovens.

I am not going to discuss the implications of these developments; I leave that to you.

Basic oven

Plastic cavity. There is active work now to develop a plastic cavity and door for the microwave oven, and there have been several patents issued that describe a plastic microwave oven. The primary reason for bringing out a plastic cavity is to reduce manufacturing costs. As far as I know, making a microwave oven with a plastic cavity does not improve any of its performance characteristics. There are a number of safety-related factors that must be handled before a plastic cavity can be approved for sale, but I am certain that these problems will be overcome and that we will see a microwave oven with a plastic cavity. A product announcement was recently made about a plastic door.

Plastic cabinet. For the same reason that there is an investigation of plastic cavities, there is also an investigation of utilizing a plastic cabinet for the microwave oven. The utilization of a plastic cavity will reduce the manufacturing cost of the unit. The safety-related problems with the plastic cabinet are somewhat less than those with a plastic cavity and are primarily concerned with insulation class, grounding, and electrical shock hazards. An effort has already been started, by at least one Japanese manufacturer, to have such a microwave oven regarded as a "double insulated" device, which requires only a two-prong power plug and can therefore use a plastic cabinet. This is analogous to the approval and method of manufacture of home power tools.

Inverter power supply. The inverter or high-frequency power supply for the magnetron is a type of power supply that has technically been available but not introduced for reasons of cost and reliability. I have seen

announcements that two Japanese manufacturers, Panasonic and Sharp, have introduced microwave ovens with inverter-type power supplies in Japan, and so it appears that the time of the inverter power supply is now here. The inverter power supply permits the microwave oven to have less weight, occupy less volume, and have superior performance characteristics as far as line-voltage regulation and variable power features are concerned. It is a development that will be to the benefit of the consumer if the reliability problems are solved. The inverter power supply is more expensive than the present power supply and will undoubtedly be found only in multi-featured, more expensive ovens.

Heating uniformity. While the consumer is not generally aware of many of the more subtle performance factors such as time-base and line power regulation, he or she is generally aware of heating uniformity or the lack thereof. For this reason, and because oven manufacturers generally recognize that if they can bring out an oven with improved heating uniformity it will give them an edge in the marketplace, they devote a significant percentage of their engineering resources to this problem. While I have no inside information about any new development, I have to believe that there will continue to be improvement in the heating uniformity of microwave ovens simply as a result of the massive engineering effort devoted to this problem.

Control systems

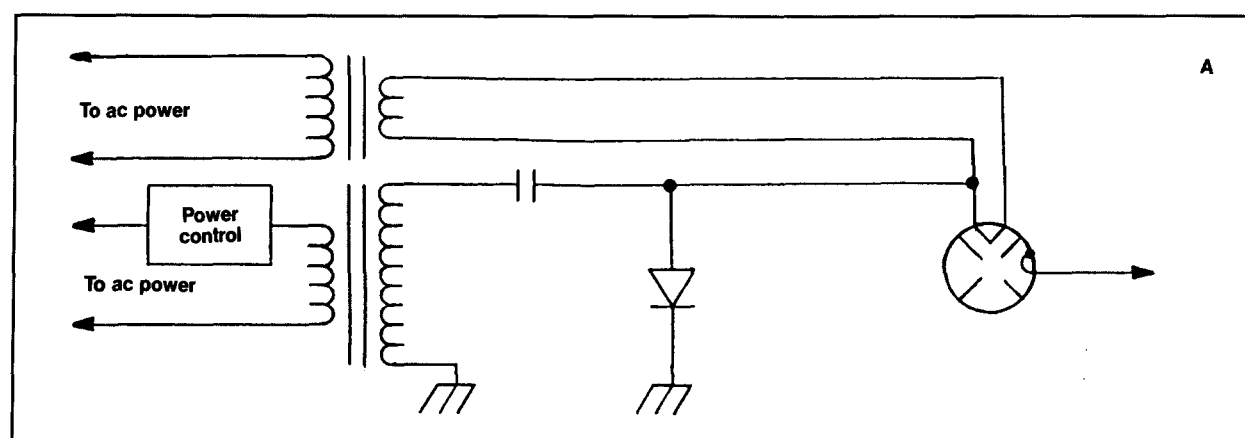
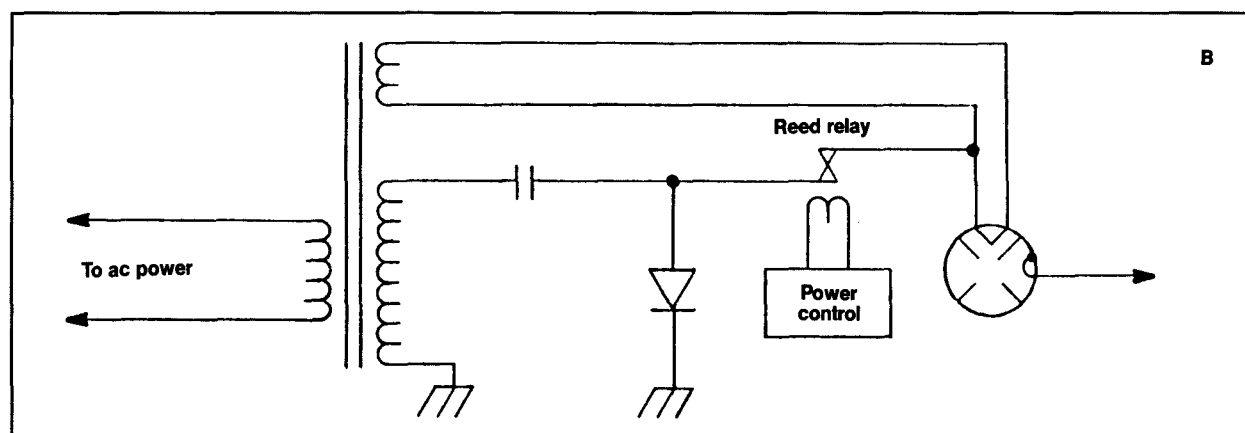
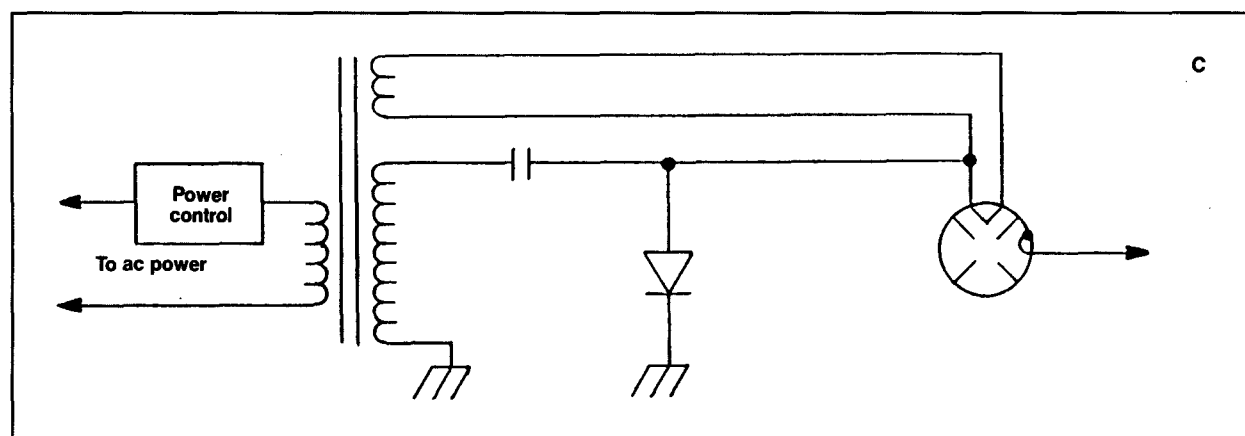
Cookbook scanner. There is now on sale in Japan a microwave oven which has within it a cookbook scanner. In operation, the scanner is withdrawn from the oven and drawn across a bar chart which is printed as a part of a recipe. The scanner is then placed back into its slot in the microwave oven and the data are transferred to the oven. These data consist of the settings necessary for the oven and in addition provide any necessary special information to the operator by means of written information on a special screen. The information gives directions such as covering the product, stirring it half way through the cooking cycle, or giving it a certain number of minutes stand time. These ovens will undoubtedly be offered for sale in the United States.

Cookbook programming. The logical extension of the type of system described above is an oven with a computer display panel and a cookbook contained in its permanent memory. The operator can call up particular recipes, and the panel displays the cooking instructions step by step, starting with a list of ingredients.

Kitchen scale. The weight sensing devices utilized in current ovens to sense the weight of the product being heated and establish oven parameters are accurate enough and sensitive enough to permit them to be used as general purpose, high performance kitchen scales. One patent recently came through in which the door of the oven (the door opened downward) became the platform of such a general-purpose kitchen scale. It requires very little adaptation of the electronics of existing ovens to permit offering this feature.

Kitchen thermometer. The temperature probe of current microwave ovens is an accurate device for measuring temperature and in a manner analogous to that discussed above can become a general-purpose kitchen

10. Variable power and power supply systems



thermometer. All that is needed is an extension cord and some minor modification to the oven electronics to permit it to be used in this mode.

Combination ovens

Recirculating hot air. Recirculating hot air combination ovens are currently available and are priced at the upper end of microwave oven pricing. They currently constitute 5-10% of oven sales. It is anticipated that combination oven pricing will come down, performance will improve, and the market share of such ovens will have increased to at

least 15% by the end of 1989.

Steam atmosphere. There are now for sale in Japan countertop microwave ovens that generate a steam atmosphere inside the microwave oven cavity to assist in the cooking of certain types of food such as fresh vegetables and fish. The technical problems associated with constructing such ovens obviously have been solved, and all that is required now is a desire on the part of the oven manufacturer to bring such products to the American market.

Custom ovens

As the market saturates and the sale of general-purpose microwave ovens begins to drop, it is anticipated that some of the manufacturers will create special-purpose microwave ovens. The following describes just two of the many concepts that come to mind when considering such a concept.

Automobiles. A special-purpose microwave oven for installation in automobiles has long been considered. It is technically not difficult, and the availability of the inverter power supply makes the product even more technically attractive. The capability of the automobile generator probably will limit the power output of such ovens to 200–250 W, but even at this low power level they undoubtedly will serve adequately as coffee heaters and roll warmers for those who wish to partake of their breakfast in their car as they drive to work.

Product specific. It is anticipated that there will be custom microwave ovens which are specific to one manufacturer's food product or line of food products. Such a microwave oven will be designed to have heating uniformity and browning features matched to the product. This means that the product will achieve superior heating packaged in standard packaging which is much less expensive than active packaging. Custom microwave ovens may find their way into specialty markets such as offices and other semi-organized activities where there is no formal food handling or eating arrangement but there is a market for feeding a person away from home. The

reduction in cost of the packaging can pay for the development and placement of the custom oven.

Another type of product-specific oven just announced by a Japanese manufacturer is an oven with bread making capabilities.

The industry

There are presently some 20–22 individual companies manufacturing microwave ovens for sale in the United States. As the market saturates and sales begin to drop, it seems clear, at least to me, that not all of these companies will survive. The next four or five years will be ones in which there will be enormous pressures on the manufacturers to maintain their share of the market. I predict they will attempt to do so both by reducing prices (by such innovations as plastic cabinets and cavities) and improving product performance features (such as inverter power supplies and better heating uniformity).

After this industry consolidation, minimum-performance ovens will tend to disappear, prices will go up, and ovens will have more features.□

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