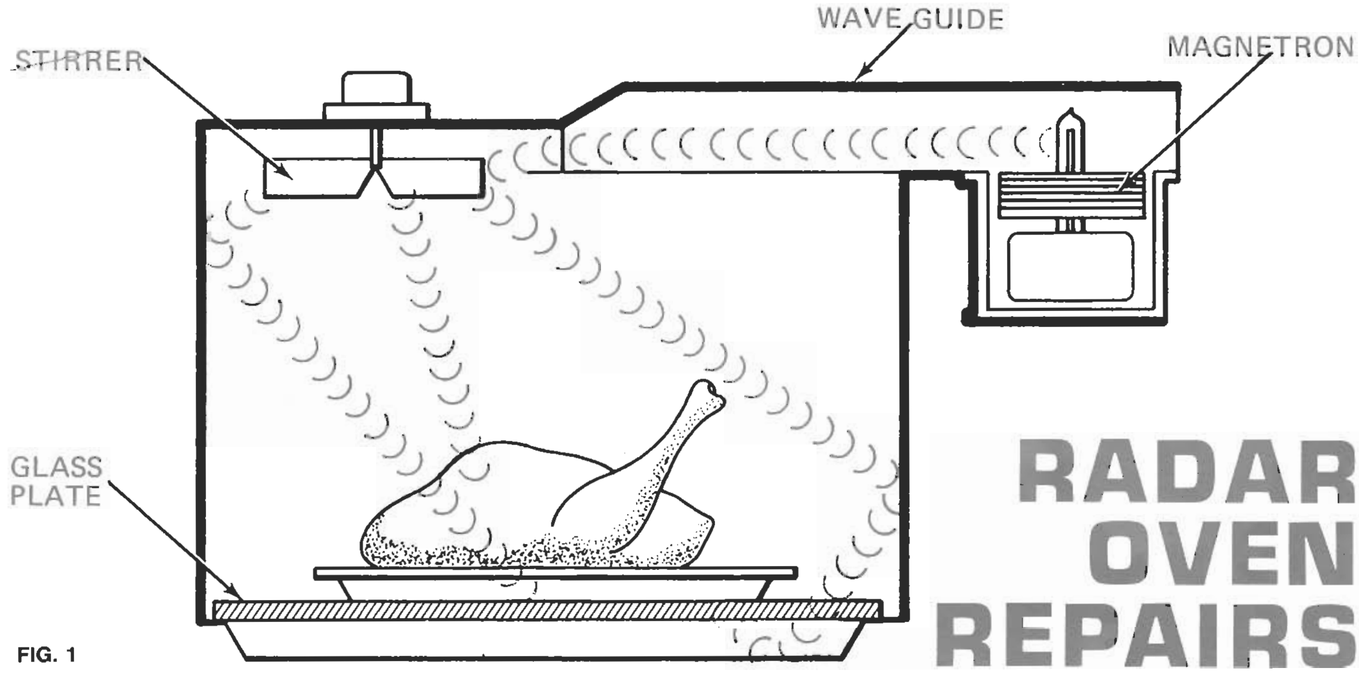

FIG. 1

RADAR OVEN REPAIRS

Microwave ovens are comparatively simple and easy to service. Be prepared when you're called to fix one.

by D. R. MACKENROTH

MICROWAVE OVENS ARE NOW USED IN trains, on airplanes and ships, in restaurants, and are proliferating in private homes as well. If a microwave oven fails to operate correctly, most consumers rely on appliance servicemen to repair them, when in fact, the devices contain electronic circuitry that should more properly be maintained by qualified electronic technicians. TV and other consumer electronics service technicians should become familiar with the principles involved in microwave ovens, as well as the specialized service techniques which they require.

How it works

About twenty-five years ago, so the story goes, Dr. Percy Spencer of Raytheon walked past a radar device with a chocolate bar in his pocket. The chocolate became very warm and melted. Intrigued, Dr. Spencer and his associates found that they were able to pop popcorn and heat other foods with the microwave radiation from the radar.

This is the principle used in the modern microwave oven. The oven itself is nothing more than a tightly sealed metal box as shown in Fig. 1. Microwaves are generated in a special type of tube, called a *magnetron,* and fed into the box through a waveguide. A *stirrer* is also placed in the box. This is simply a slow-speed fan with metal blades. As these blades rotate, they reflect the microwave energy, bouncing it around to all corners and areas of the interior of the metal box. Without the stirrer, standing waves would be created in the oven, and some regions would be "hot" and some would be "cold".

The heart of the oven is the magnetron tube (see Fig. 2). The tube is basically a diode with a cylindrical cathode surrounded by a cylindrical anode. A strong magnetic field is created by a large permanent magnet or electromagnet. This field affects the flow of electrons from anode to cathode.

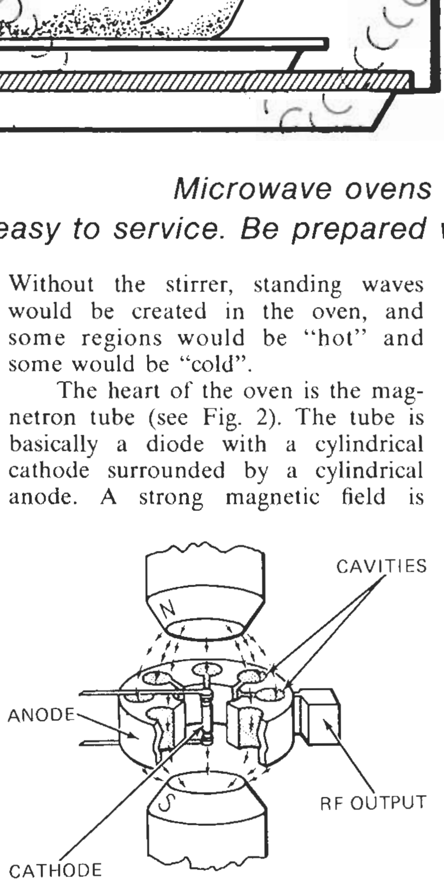

FIG. 2—DIAGRAMATIC REPRESENTATION of a magnetron. Its operation depends on a strong magnetic field developed by a permanent magnet or electromagnet.

A high negative dc voltage is applied to the cathode from a power supply. The magnetic field changes the trajectories of the electrons flowing from cathode to anode, causing them to return toward the cathode. The tube oscillates at a high frequency (2450 MHz is the FCC-regulated operating frequency for microwave ovens), and the cavities of the magnetron act as resonant circuits. Energy is given up to the cavities by the electrons, producing rf power which is coupled into the waveguide by a small "antenna" at one end of the tube.

As can be seen in the typical schematic of Fig. 3, most ovens also have a timer that turns the oven off when cooking is completed, a fan that

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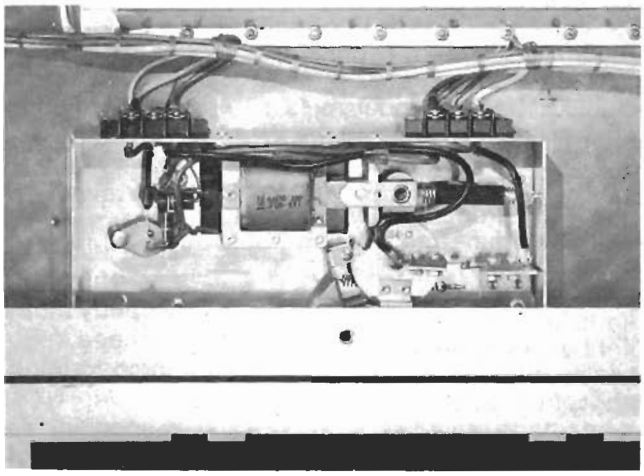
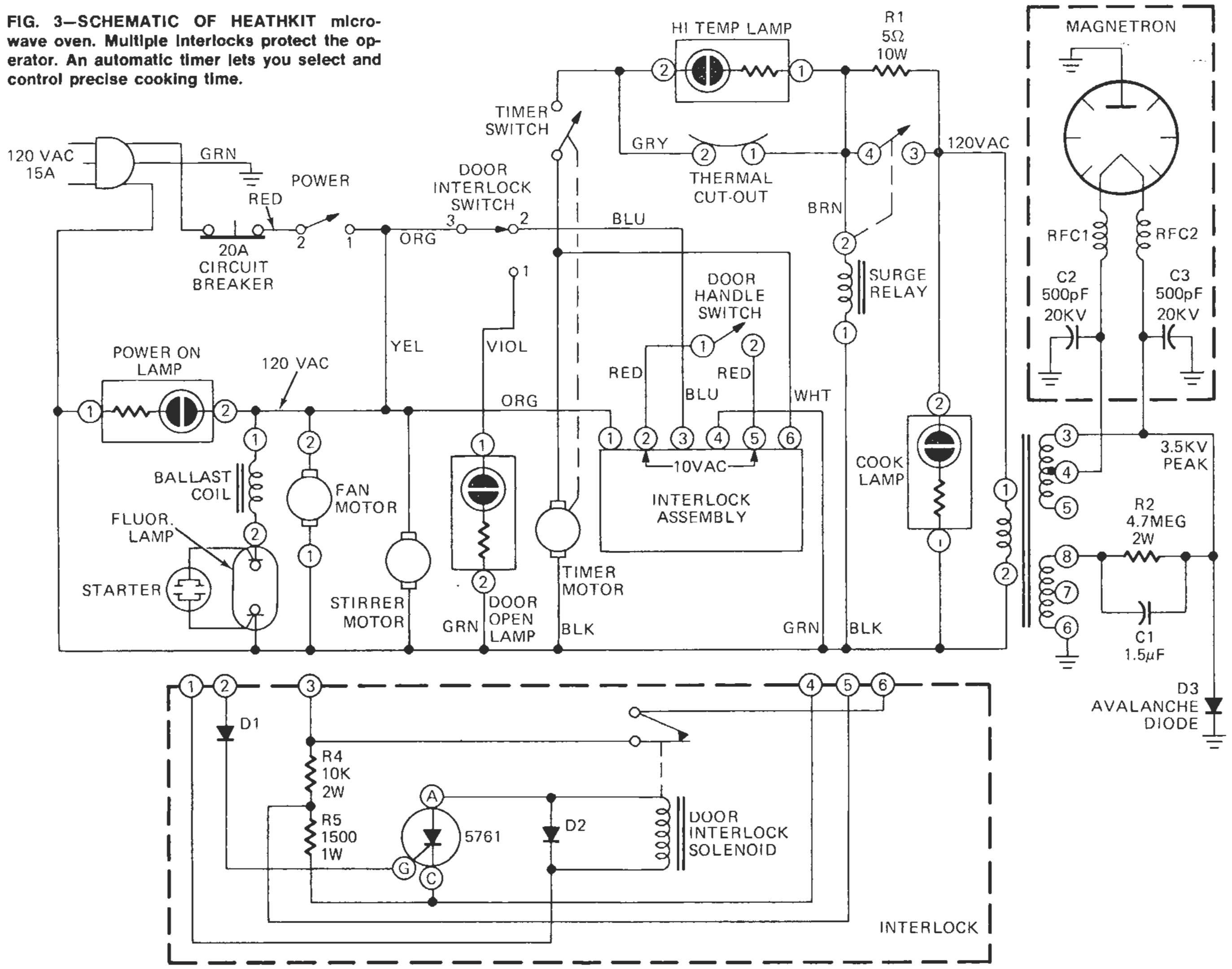


DOOR INTERLOCK on Heathkit oven prevents the door from opening until high-voltage to the magnetron is turned off.

FIG. 3—SCHEMATIC OF HEATHKIT microwave oven. Multiple interlocks protect the operator. An automatic timer lets you select and control precise cooking time.



cools the magnetron assembly, and a series of interlocks and thermal relays designed to shut down the oven when the door is opened or the magnetron temperature climbs too high. Microwaves can be dangerous—they make no distinction between heating food or heating flesh, and we know that microwave energy is particularly damaging to delicate areas of the body, such as eye tissue.

Testing the control circuitry

A microwave oven *never* should be operated completely empty. If it is, you can get arcing within the oven and a damaged magnetron may be the result. Always place a load in the oven when it is on. A good load, as well as a test of the oven, is to place a cup of water into the oven. Then set the timer for five minutes. If the oven is operating correctly, the water should be boiling in 1½ to 3 minutes. Don't use metal utensils, pots, or foil in the oven—this can also cause arcing, since metal surfaces reflect the microwaves and do not absorb them.

For a more accurate measure of the output power (in watts) of the oven, measure the temperature rise of a specific amount of water in one minute in the oven. Measure 500 milliliters of tap water into a ceramic or china dish, heat the water in the oven and measure the temperature rise. Use the formula:

$$P = (T2 - T1 \times 35)$$

where

P = power in watts

T2 = temperature in °C after heating

T1 = temperature in °C before heating

Don't leave the thermometer in the oven when it's on, since the mercury is a metal and will reflect microwaves, perhaps damaging the oven.

If the oven doesn't go on at all, check the interlock and timer switch loop. Clean the oven door and make sure that it will close completely, since small particles of food can work themselves into the seals and keep the door from activating the interlock switch. If food does not heat evenly in the oven, check the operation of the stirrer.

Magnetron and high-voltage tests

If the oven appears to operate normally (the stirrer turns, the timer works, etc.), but there is poor or no heating, the trouble is probably in the magnetron or its power supply. If you are checking these circuits, make sure the unit is unplugged and you've bled the filter capacitors first.

Check the magnetron for loose or dirty connections. It may be a good idea to clean the contacts of the magnetron and the waveguide with metal polish, then remove any residue with alcohol. Dirt or corrosion can severely cut down the efficiency of microwave circuitry. Be careful working around the magnetron, though, since most magnetron tubes have a warranty and

MICROWAVE OVEN is Heath's GD-29 kit. Four panel lamps show operating status at all times.

they are expensive—typically well over $100 each.

To check the magnetron and associated circuitry, the first step is a simple resistance check. The heater of the magnetron should read about one or two ohms, and the resistance from the cathode to the anode of the magnetron should be infinite.

A good check to make is to read the anode current of the magnetron. Some manufacturers have placed a 10 ohm, 5 or 10-watt resistor in series with the rectifier diode, and reading across this resistor with a dc voltmeter gives a reading for the anode current. If, for example, the voltage drop across the 10-ohm resistor is 3.0 volts, the anode current is 300 mA. If the manufacturer, as in the diagram in Fig. 3, has not inserted this resistor, you can put one in the circuit for test purposes. Place the resistor, a healthy 10-ohm, 10-watt wirewound type, between ground and the cathode of rectifier diode D3. Remove the resistor when tests are completed.

Although manufacturer's specifications should be checked to make sure, anode current in most magnetrons used in microwave ovens will usually range from 250 to 320 mA. A small fluctuation, 5 to 10 mA on either side of the reading is normal, but wide changes of anode current indicate that the magnetron tube has an internal short or is moding (oscillating at a frequency other than the designed frequency of operation). Although anode current is normally not adjustable, the circuit in Fig. 4, from the Westinghouse microwave oven, includes a coil for the electromagnet of the magnetron and a 5000-ohm 25-watt, adjustable wirewound resistor. This resistor is used to set the magnetron current to its optimum value (300 mA in the case of this Westinghouse oven).

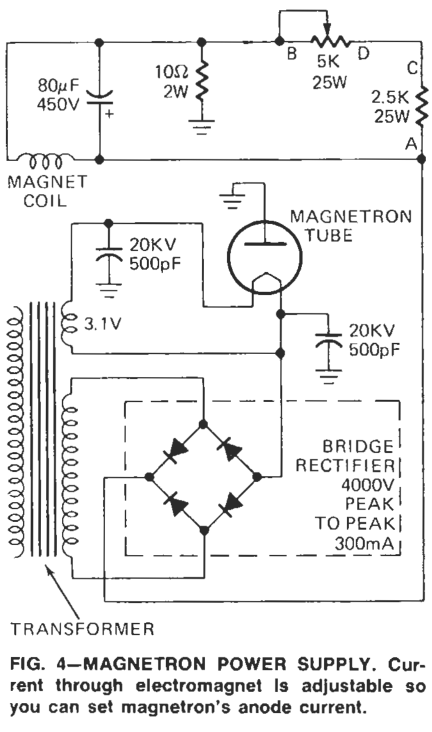


FIG. 4—MAGNETRON POWER SUPPLY. Current through electromagnet is adjustable so you can set magnetron's anode current.

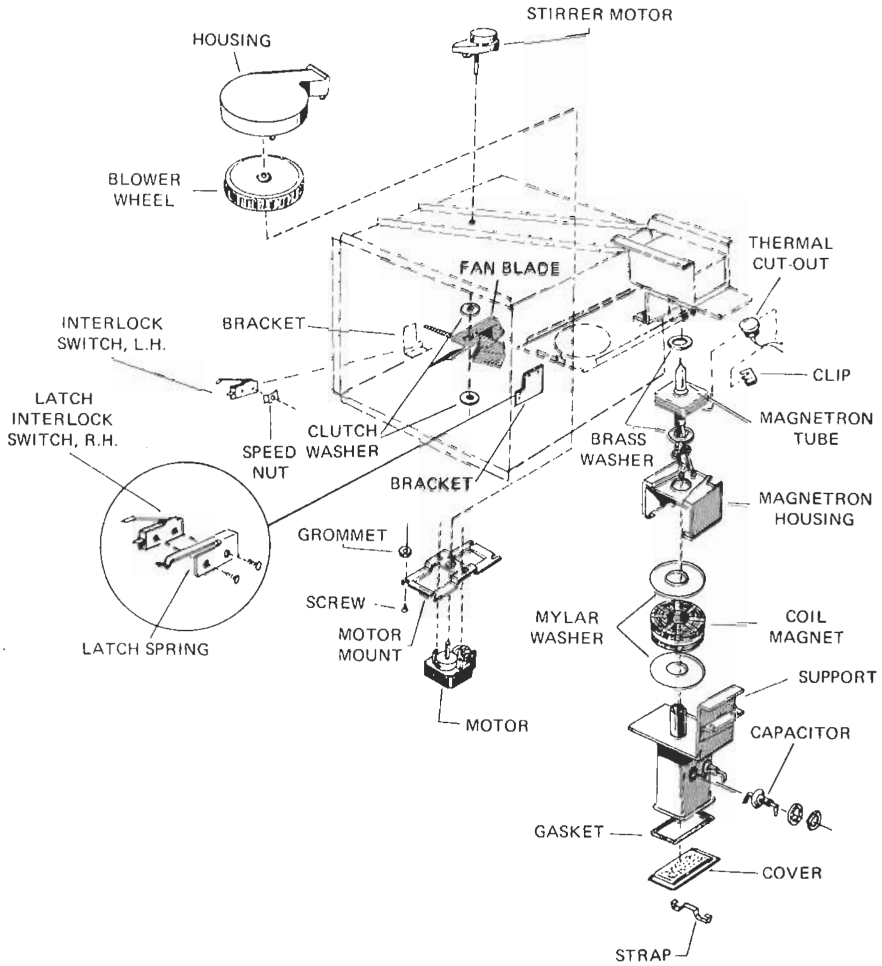
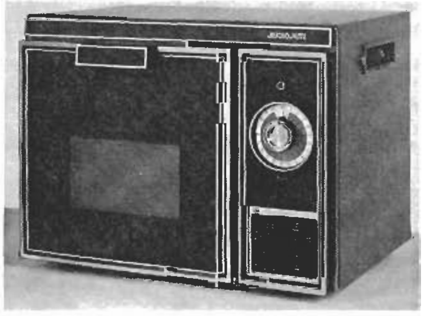


FIG. 5—EXPLODED VIEW of typical microwave oven and magnetron assembly. You'll need this sort of information when removing a defective magnetron and installing a new one.

If anode current is nonexistent or very low, all components in the power supply should be eliminated before the magnetron is changed. With a high-voltage probe, measure the anode voltage, but remember that it will normally be in the 2500-4000 Vdc range. If you have to change the magnetron, be very careful to get all seals and gaskets back in the way they came out. Lay them out on the bench in the order they are removed to facilitate reassembly. Fig. 5 shows a typical magnetron installation, as well as a partial interior of a microwave oven.



THIS MICROWAVE OVEN, Micromite model 2000 has timer dial and see-through oven door.

A visual inspection of the magnetron may reveal faults. A crack in the glass envelope around the antenna, for example, may indicate excessive vibration or rough handling, or possibly that the magnetron was installed incorrectly. The interior of the tube will take on a milky, whitish color if air has gotten into the tube. If a sunken place or a bubble has developed on the glass envelope, it means that the magnetron probably has been overheated by operating it without a load in the oven.

When a new magnetron is installed, the old one should be kept, and the serial numbers of both tubes recorded. For the warranty to be valid, the old magnetron must be sent back to the factory, along with the serial number of the tube that was newly installed.

Leakage, seals and testing

The Bureau of Radiological Health of the Department of Health, Education, and Welfare, regulates the permissible radiation that can emanate from a microwave oven. Under these Federal standards, radiation leakage

(continued on page 47)

RADAR OVEN REPAIRS

(continued from page 37)

from a microwave oven cannot exceed 1 mW per square centimeter prior to factory release and 5 mW per centimeter measured at a distance of 2 inches from the oven at any time thereafter.

Oven doors are usually sealed primarily by a choke section, a quarter-wave slot around the inside of the door. As you can see in Fig. 6, this is backed up by a secondary, Teflon-covered metal-to-metal seal. Particles of food or grease, or wear on the seals themselves, can cause leakage, and an unconnected neon bulb held next to the edges of the door, will indicate leakage. If the edge of the door feels warm to a finger run around it while the oven is operating, leakage is probably excessive.

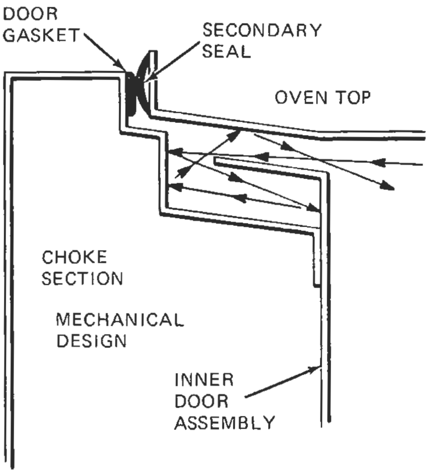


FIG. 6—RADIATION FROM INSIDE OVEN is prevented by a quarter-wavelength slot or trap section around the door perimeter.

More accurate tests of leakage are performed with commercially-made leakage testers, such as International Crystal Corporation's Microlite 287 and Microdek 310. The 287 is a simple bulb that glows when radiation levels exceed 5 mW/cm^2. The Microdek 310 has a meter that reads 0.4 mW to 23 mW in two scales.

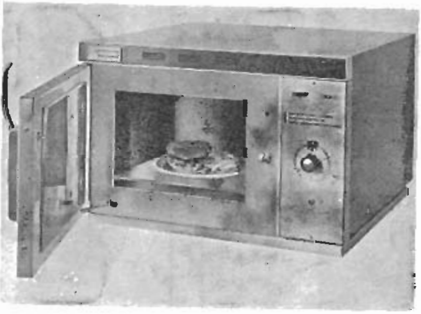
To test an oven for leakage, place a measuring cup or bowl filled with water in the oven. Close the door, turn on the oven, and set the timer for the longest available time. The meter probe usually has a spacer that places the antenna of the leakage detector at the proper distance from the oven. Place the tip of the probe into one of the cracks where the door contacts the oven and slide it back and forth all along the door. At the point where maximum indication is obtained on the meter, the level should be recorded and the meter turned 90° and another reading taken. The sum of the

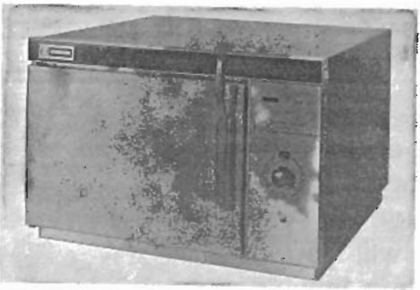
(continued on page 90)

RADAR OVEN REPAIRS
(continued from page 47)

two readings is the leakage level of the oven at that particular point.

Leakage measurements should be taken along all edges of the door, and at the grille in the door, if the oven has a viewing window. In addition, leakage tests should be performed at all points on the oven case where leakage could possibly occur—at the slot between the timer panel and the oven, along the top and sides of the oven, and at the rear of the oven. Excessive leakage at the rear or top and sides of the oven may indicate that the magnetron and rf gaskets are not seated properly.





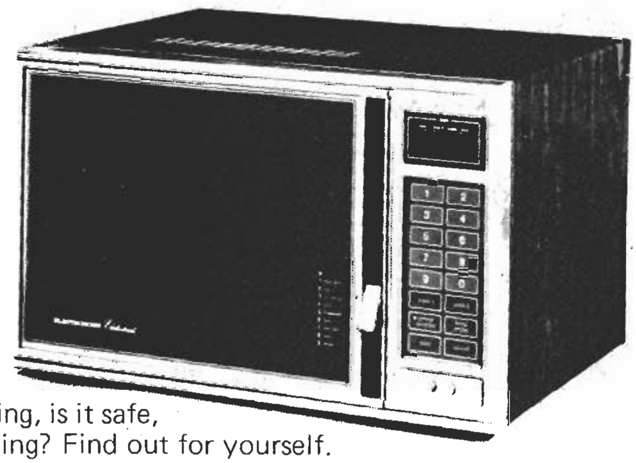
INTERNATIONAL CRYSTAL makes this electronic oven. Two views show both the exterior and interior of the quick-cooking machine.

Also check the oven door with shims placed between the door and the oven. The thickness of the shims should be such that the oven door interlock switch is just *barely* defeated. If leakage on this test is excessive, the interlock switch should be adjusted so the oven will not turn on unless the door is adequately sealed.

If you find excessive leakage around the door, clean all surfaces and seals with a damp rag and a mild detergent. If microwave leakage is still excessive, the Teflon or metal seals may have to be changed.

Because he has the test equipment and electronic skills needed to repair microwave ovens, this venture can be a profitable undertaking for the electronic service technician. But he must be aware of the potential hazards to himself when working on this type of equipment, and also of his responsibility to his customer to limit radiation leakage. **R-E**

FEATURE



Microwave Cooking

Much has been said lately on the subject of Microwave Cooking, is it safe, are they cheaper and quicker than ordinary methods of cooking? Find out for yourself. Dr. B. Minakovic takes the lid off the world of microwaves.

The main advantage of cooking by microwaves is speed — anything from two to four times faster than by conventional means. This does not mean that one can improve very much on an electric kettle to boil water, but certainly it will cook a chicken faster than a gas or an electric cooker, despite its lower power rating.

Cooking by microwaves requires some change in cooking habits. For instance, there is no need to warm up a microwave oven before food is put into it, as it is often done with an ordinary oven. Also, there are no more temperature settings to worry about because all cooking is controlled by time.

In contrast to radiant heat, microwaves penetrate almost instantaneously into food and produce heat by agitating the atoms and molecules. The result is fairly uniform heating through the food, but without a crust or surface browning. This may be a desirable feature in some cases, for instance, when warming up or preparing pre-cooked food. When, however some crust or surface browning is necessary the cooking has to be finished off in an ordinary oven.

Browned Off

To obviate the necessity of transferring the food from one oven to another some ovens are fitted with radiant electric elements. In others one can now use a so-called "browning-dish" which is designed to absorb microwaves and hence produce sufficient radiant heat to cause some browning. It should be noted that ordinary glass and pyrex dishes are not heated, being poor absorbers of microwaves. The oven, usually made of stainless steel, is also not heated because metal walls are good reflectors of microwaves. Metal utensils or dishes behave similarly and must not be used in a microwave oven. Apart from screening food from microwaves, they could produce spurious reflections which could adversely affect operation of the microwave source (magnetron) and even damage it.

Condensation on the cold oven walls is prevented by ducting into the oven the hot air from the magnetron cooling circuit, so the vapours are blown out as quickly as they are formed. As a result an oven never gets really dirty and occasional wiping with a soapy cloth is all that is usually necessary to keep it clean.

Defrosting of frozen food is possible, too. This process, however, must not be regarded just as warming up. Ice, unlike water is a poor absorber of microwaves so will take somewhat longer to heat up. If heating is too rapid, water pockets which are formed will enhance local heating, causing hot spots or even burning. This can be prevented by switching the microwave power off and on, so that the heat has time to diffuse from hot spots into the frozen region and there produce more thawing. Typical times are 7-15 sec for "off" and 5-10 sec for "on," the exact timing being determined by the power rating of the oven. The switching sequence is controlled electronically and all that a user has to do is to set the timer according to the quantity of food and depress the defrost button.

Bacteria

The practice of defrosting food by letting it stand overnight at room temperature is rather dangerous, because, once a certain temperature is reached bacteria will start to multiply and food poisoning is possible. This cannot happen with microwave defrosting simply because the time is too short. In any case, there is some evidence that in fact microwaves tend to kill bacteria as most of them are good microwave absorbers. It is important to remember that any kind of food processing involves a certain degree of risk from bacteriological infection, so all food should only be handled in scrupulously clean conditions.

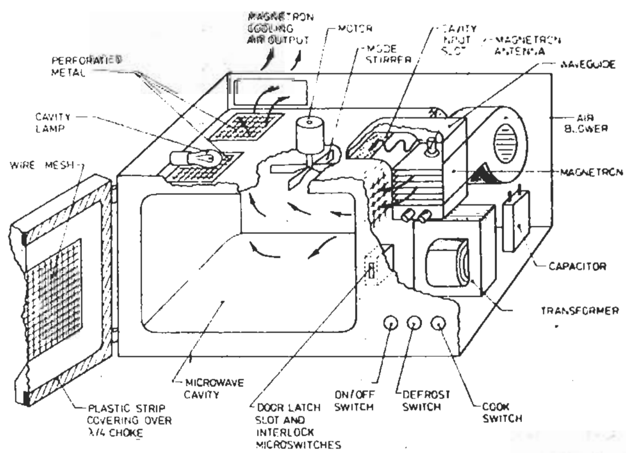


Fig 1. Basic feature of a microwave oven.

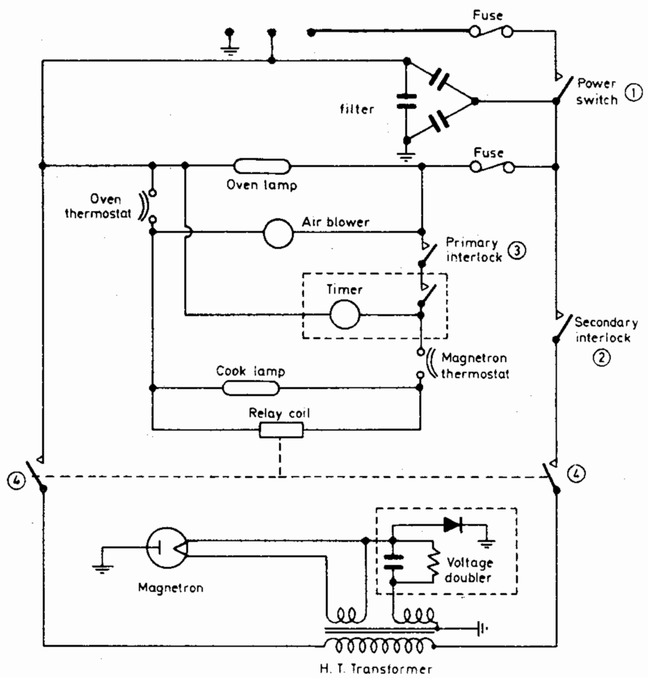


Fig. 2 Simplified circuit diagram of a microwave oven. Magnetron HT of 4.5kV is produced by stepping up the line input to 2.3 kV and a half wave doubling. The doubling circuit, consisting fof a capacitor and a diode, generates a square wave at line frequency. The polariyt is negative so that the anode (magnetron body) can be grounded. The effect of voltage fluctuation is reducedby operating the transformer core near full saturation. the interlock switches 2 and 3 are operated by the door latches and therefore the magnetron is only energized whilst the door is closed.

For clarity, the defrosting circuit has been omitted from the diagram.

How Does It Work?

Radio waves, microwaves, heat, light and X-rays are examples of electromagnetic waves. Although identical by their nature, they exhibit many different properties simply because of their vastly different wavelengths (frequencies). Microwaves, developed during World War II were named so because in comparison with ordinary radio waves, their wavelengths are very small, 100mm or less.

When food or some non-metallic material is placed in a microwave field, the electric field penetrates into it and forces electrons, protons and ions into oscillations along the direction of the field and at the same frequency. Internal friction then produces heating. The rate of heat generation depends on the field strength, its frequency and a parameter tan δ which characterises the "lossiness" of a material. Materials with low tan δ like quartz and PTFE cannot be heated by microwaves. An electric field propagating through a lossy material decays in amplitude at a rate inversely proportional to the square root of frequency.

A microwave field can penetrate several centimetres into the food before it becomes very weak. This distance is known as the depth of penetration. Infra-red radiation (heat), on the other hand, penetrates less than a millimetre and thus heats the surface only and from there the heat spreads inwardly mainly by conduction, a relatively slow process. So, the essential difference between microwave and ordinary heating is that microwaves penetrate deeply into food whereas the ordinary heat radiation is absorbed at the surface.

The internationally allocated frequency band for microwave cooking is centred at 2450 MHz corresponding to a wavelength (λ) of 12.24cm (use $f\lambda = c$, c is the speed of light, 3×10^{10}cm/sec). There is no special reasons why it should be exactly 2450 MHz. A few hundreds of MHz up or down would hardly matter as far as the cooking or the depth of penetration is concerned, and equally the rate of heat generation would be hardly affected. The main reason for this allocation is that this band is not much good for anything else and it does give a reasonable depth of penetration.

Magnetron

The essential features of a typical modern microwave oven are show in Fig. 1. The microwave cavity, as the oven itself is usually called, is a rectangular metal box, large enough to accommodate an oversized chicken. Microwave power is fed in at the top through a large slot via a short waveguide with a magnetron antenna at the other end.

On entering the cavity microwaves spread out in all directions and undergo a series of reflections from wall to wall, passing through the food on each transit. The situation is analogous to a beam of light in a closed box with mirror walls.

Furthermore, as in the case of light, destructive or constructive interference will take place between the overlapping waves and providing the cavity dimensions are the multiples of the cavity half-wavelengths, there will be set up a three-dimensional standing wave pattern. In technical terms, the cavity is said to be resonant. Fig. 3 shows such a standing wave pattern of the electric lines of force.

Food or any other object in the cavity will distort the standing wave pattern, but nevertheless the cavity may remain resonant simply because the Q factor will be reduced too, and so the resonant range will be widened.

The heating pattern of a cavity corresponds to the electric field pattern: strong heating in the regions with strong electric field and no heating at all where the electric field falls to zero. Clearly, an oven producing an array of cold and hot spots whould not be very satisfactory for cooking. Fortunately, the heating pattern can be smoothed out by perturbing the electric field with a small metal propeller or "the mode stirrer" as it is usually called. As the name suggests, the mode stirrer moves the electric field standing wave pattern to and fro, so the cold spots at one instant become hot at the next and so on. Of course, in addition to this heat will also spread out by the ordinary conduction process. The mode stirrer is always mounted on the ceiling of the cavity and protected from accidental damage by a plastic sheet of low tan δ. Some manufacturers prefer a turn-table for the food to a mode stirrer, the others fit both.

Power for a microwave oven comes from a magnetron. Typical microwave power rating is 500 W for a small domestic oven, increasing to around 2000 W for a catering model. The nominal guaranteed life of a small megnetron is 1000 hours, but experience shows that with careful use, this can be doubled or even trebled. In any case, bearing in mind that a microwave oven runs only for relatively short periods, 1000 hours can be equivalent to about 3 years of normal use.

Efficiency

The efficiency of cooking magnetrons ranges from 50% for small units to about 75% for bigger ones. Although cooking magnetrons are designed to tolerate large load variations, an oven must not be run empty because microwaves would be reflected back into the magnetron and cause damage by overheating the cathode or the ceramic seals. Some microwave ovens are fitted with a manual power control for reducing the power output when the loading is very light — otherwise the loading should be artificially increased by putting into the oven a small cup of water.

Microwave leakage from an oven occurs mainly through the door seals and the window wire mesh. There may be also some leakage through the poor joints in the box due to poor shielding of the magnetron HT terminals.

The leakage between the door and the cavity flange is prevented by incorporating into the door frame $\lambda/4$ chokes, see figure 4.

When a wave leaking through the small gap between the door and the cavity flange reaches the slot B it is almost completely reflected back because of the discontinuity. By the time it reaches again the input plane A the wave will have travelled a total distance $\lambda/2$ and therefore it will be in the antiphase with just incoming wave and hence cancel it. In terms of impedance, the input plane A behaves as a short circuit. A small fraction of the wave that leaks past the discontinuity at B

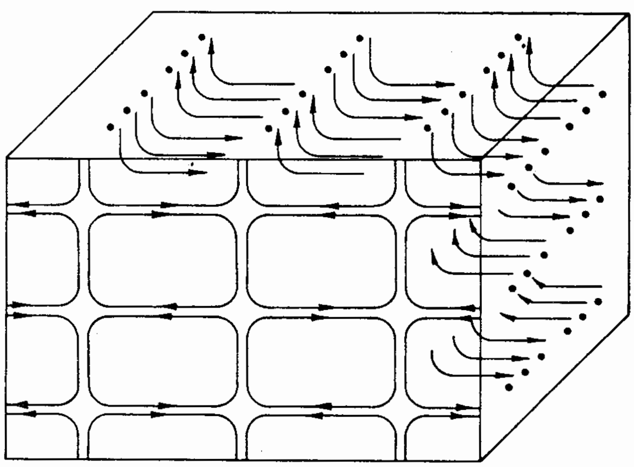


Fig 3. The electric field standing wave patterns in a microwave oven.
The arrows indicate the direction of the electric field at an instant of time – they are reversed once every cycle, 2450 million times per second!

continues to the short circuit C where is reflected back to B. Any leakage from B to the outside is suppressed by the lossy rubber strip, mounted along the edge of the metal box. The $\lambda/4$ choke slot is normally covered with a plastic insert to prevent accumulation of dirt.

The door window is not absolutely necessary but it does help one to follow the progress of cooking in the lit-up oven. A wire mesh is used to prevent radiation through the window. The mesh is protected from accidental damage and from dirt by plastic sheets on both sides of the window.

The interlocks operated by the door latches are another very important safety feature. They ensure that the microwave power cannot be switched on whilst the door is open even if the cooking switch is depressed.

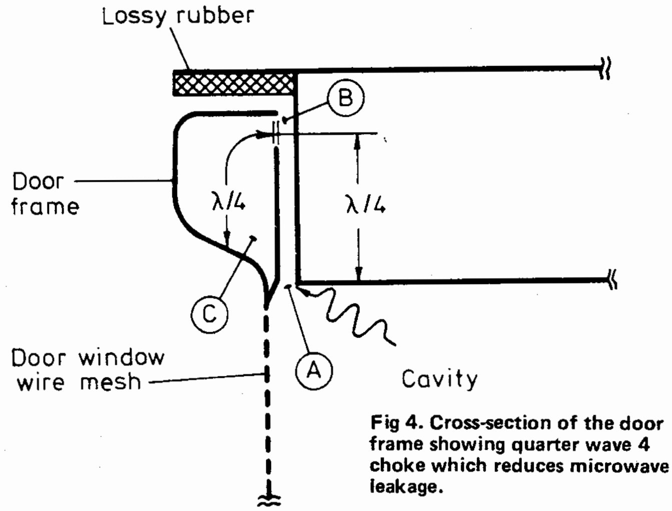


Fig 4. Cross-section of the door frame showing quarter wave 4 choke which reduces microwave leakage.

Microwave hazards arise mainly from internal heating and should not be confused with radio-activity which is far more dangerous. Eyes and genital organs are very sensitive to microwaves and can be damaged by fairly small doses. Prolonged exposure to microwaves can result in eye cataract, a condition in which the lens of the eye becomes clouded.

There is considerable disagreement as to what is the safe power density. The generally accepted figure is about 10mW/cm², although some sources claim that this is still too high. Microwave ovens are normally designed for 1mW/cm² or less and if necessary this could be even further reduced by another factor of 10 — at a marginal increase in the price.

Of course, a damaged door flange can increase the leakage above the permitted level and there is no way of detecting it without a leakage meter. A good practice is never to put one's face into the door window and to operate the oven from an arm's-length distance. Then, even if something does go wrong one will be fairly safe.

Testing Microwave Ovens

Power test — Pour exactly 1 litre of water into a plastic beaker and having measured the water temperature, heat it in the oven for exactly 4 minutes. On removal, stir the water lightly with the thermometer and again measure its temperature. Calculate the temperature rise from the two readings (in °C) and multiply it by 17.5 to obtain the microwave power in watts.

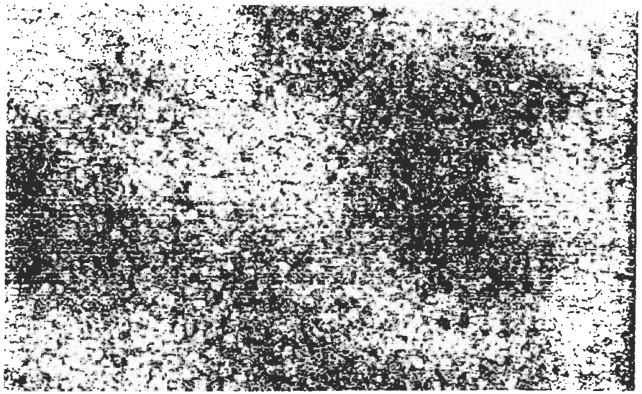
If the measured temperature rise is too large for the thermometer available, use two litres of water or half the heating time — in either case use 35 as the conversion factor.

Checking Uniformity Of The Electric Field

When a small neon lamp is put into a microwave field it glows bright red if the field is strong enough to ionize the gas in it. This fact is used here to sample the electric field in a microwave oven.

Bed the neon lightly into a lump of plasticine, its leads pointing upwards to act as an antenna. Normally the leads are too long and should be reduced to about 2cm or less, so that the lamp is not overheated.

If necessary, sensitivity can be improved by bending the leads apart, to form a Vee. This type of an antenna is



Heating pattern in a microwave oven (recorded in a horizontal plane 4 in. above the cavity bottom). Dark areas indicate strong heating, light areas weak or no heating. (Courtesy Western Dynamics Ltd.)

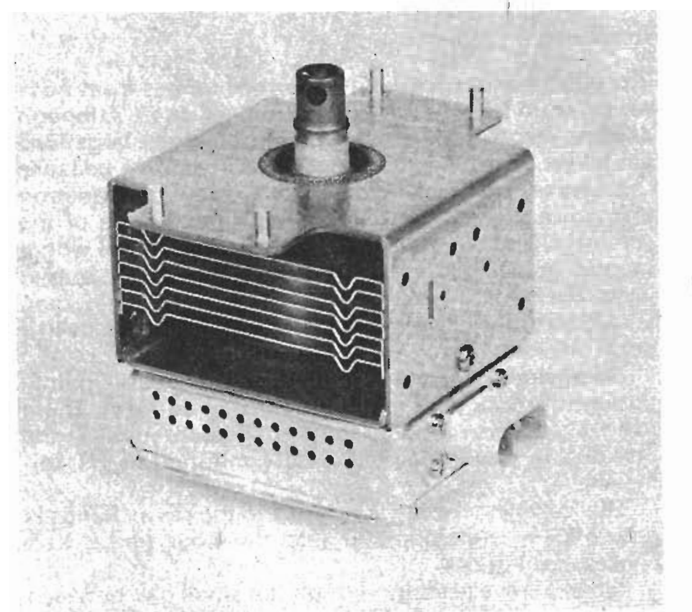
directional, so try various orientations and positions.

If several neons are available stick them on a strip of perspex, about 2cm apart. An oven must never be run empty so do this test with a cup of water in it.

The leakage field outside an oven is far too weak to ionize the gas in a neon lamp and no glow will be observed.

Warning

In operating a microwave oven always follow the maker's instructions. Do not remove the covers because this will not only expose high voltage terminals but also increase the microwave leakage.



Output power 840W. Peak operating voltage 4.5 kV. Average anode current 350 mA. Cooling by blowing air through fins. Focussing by ferrite magnets.

Also do not poke wires or sharp objects into the door seals or cavity perforations for this can significantly increase the microwave leakage.●

Microwave leakage monitor is economical but sensitive

T. Koryu Ishii and Thomas A. Panfil
Marquette University, Milwaukee, Wis.

You can build a simple and inexpensive microwave-leakage monitor that is as sensitive as its costly counterparts and can operate without a power source of any kind. This detector is completely passive, offers an inherent self-test capability, and is ready to operate at all times.

The potential radiation hazard[1] of microwave leakage from household microwave ovens[2], industrial microwave heating and drying equipment, and microwave communications and navigation systems has been widely publicized. Industrial consumers, as well as the general public, are concerned about the safety of their currently installed equipment. Needless to say, monitoring the almost unavoidable low-level microwave power leakage can greatly enhance the safety of operating microwave devices.

A variety of microwave-leakage detectors is available today, but most of them cost too much for household and industrial consumer use. In some models, an electrical discharge tube is used to indicate leakage power level. But since this type of detector does not give any indication at the low leakage levels achieved by well-designed equipment, it does not have any inherent self-test capability, and its failure can go undetected.

The photographs show the front and rear views of an economical yet highly sensitive microwave leakage monitor—it consists of a type 1N263 crystal detector and a milliammeter. The performance of the monitor is determined by the sensitivity of the meter and the crystal mounting configuration.

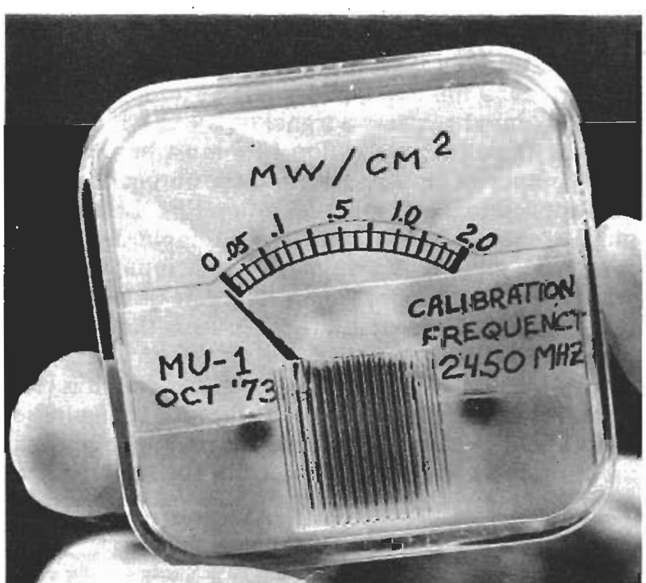
The milliammeter used here has a coil resistance of 730 ohms and a full-scale-deflection current of 1 milliampere. The crystal detector is soldered to the small lugs attached directly to the meter studs, which act as an antenna and an open-circuited transmission line. The inductance of the meter coil behaves as a radio-frequency choke.

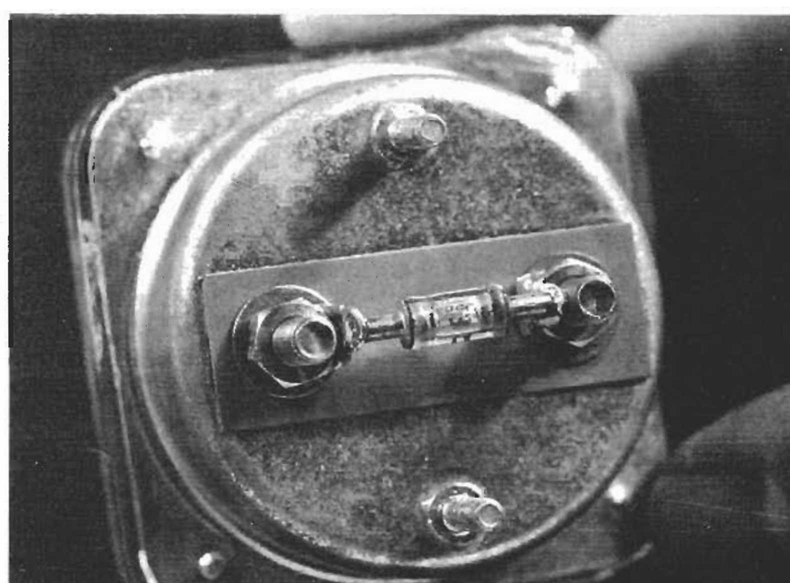
The microwave monitor is calibrated with an approved standard device. The microwave radiation power density is measured at some point, the standard device is then removed, and the monitor is positioned at the same point. Since the monitor is direction-sensitive, its orientation must be adjusted to maximize its deflection. The deflection and power level are then recorded, and the procedure is repeated for other power levels until the meter is fully calibrated.

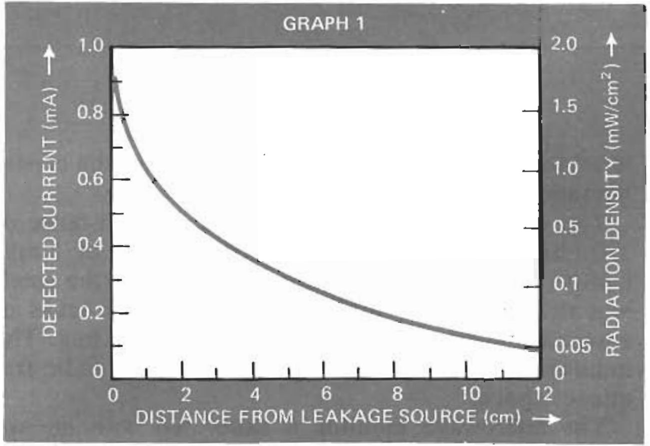
Graph 1 is a plot of the calibrated meter's response with respect to distance from a leakage source. (The meter is always oriented to maximize its deflection.) A full-scale deflection on the calibrated meter represents 2 milliwatts per square centimeter. As the plot indicates, this simple monitor is capable of detecting leakage levels in the neighborhood of 1 mW/cm^2, which is the safety standard set by the U.S. Government Department of Health, Education, and Welfare for new domestic microwave ovens.

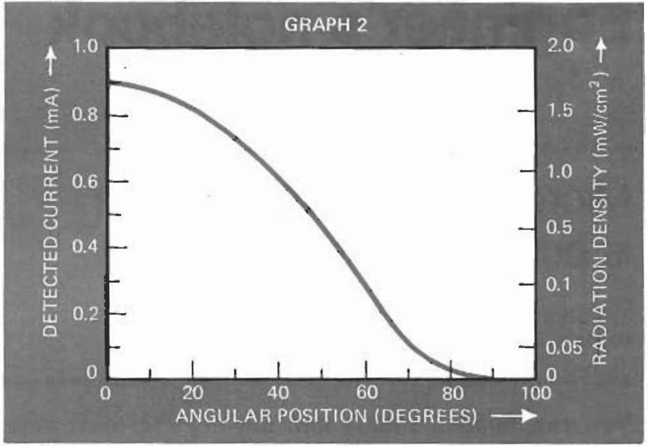
Graph 2 shows the monitor's directional sensitivity. In this case, the orientation angle of 0° means that the direction of the crystal detector is parallel to the microwave electric field. As the figure illustrates, the half-value orientation angle is only 50°, but the meter's sensitivity rapidly degrades to zero thereafter.

A more sensitive microwave-leakage monitor can be made by using a milliammeter that has a greater sensitivity. For example, if a meter with a coil resistance of





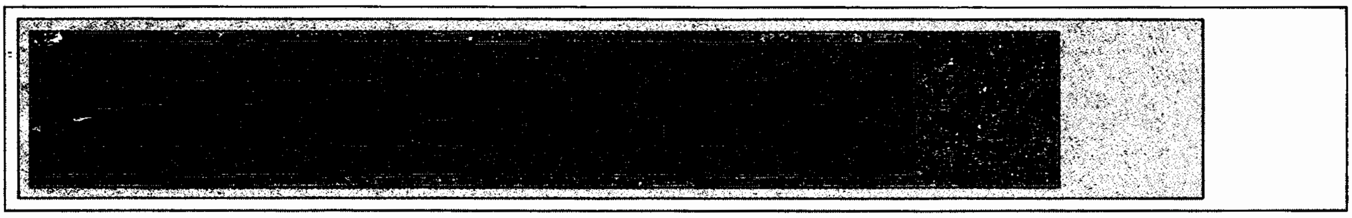




640 ohms and a 200-microampere full-scale deflection is used, the full-scale sensitivity of the leakage monitor increases to 0.05 mw/cm^2, which represents an improvement of a factor of 20. □

REFERENCES

1. W.H. Walter, K.C. Mitchell, P.O. Rustan, J.W. Frazer, and W.D. Hurt, "Cardiac Pulse Generators and Electromagnetic Interference," Journal of the American Medical Association, Vol. 224, Issue N12, pp. 1,628–1,631, 1973.
2. Richard Davis, "Microwave Oven Controversy Sizzles," Microwaves, Vol. 12, No. 5, pp. 9–19, May 1973.



Microprocessors are inching their way into home appliance applications. Here's a look at how the TMS1100 is teamed up with triacs to control a microwave oven.

KARL SAVON, SEMICONDUCTOR EDITOR

THYRISTORS ARE TOUGH COMPONENTS. Silicon-controlled rectifiers and triacs are more damage-resistant than other semiconductors because their regenerative latching mechanism switches them rapidly through the dangerous half-on, high-dissipation region. Thyristors (especially the versatile triac) are unbeatable in AC power switching applications. Their use in industrial control systems is not new, but their recent availability in low-cost plastic packages is responsible for their growing application to home appliances. Thyristors are present in the horizontal-deflection systems and remote power on-off controls of TV receivers. They are also found in microwave ovens, where moderate amounts of power are switched and modulated. They have proved to be more dependable than relay contacts and conventional transistors.

Microcomputers, too, have moved from their industrial beginnings into the appliance market. The control microcomputer is an inexpensive IC, the result of thousands of hours of human endeavor and accomplishment. Single-IC microcomputers such as the Texas Instruments

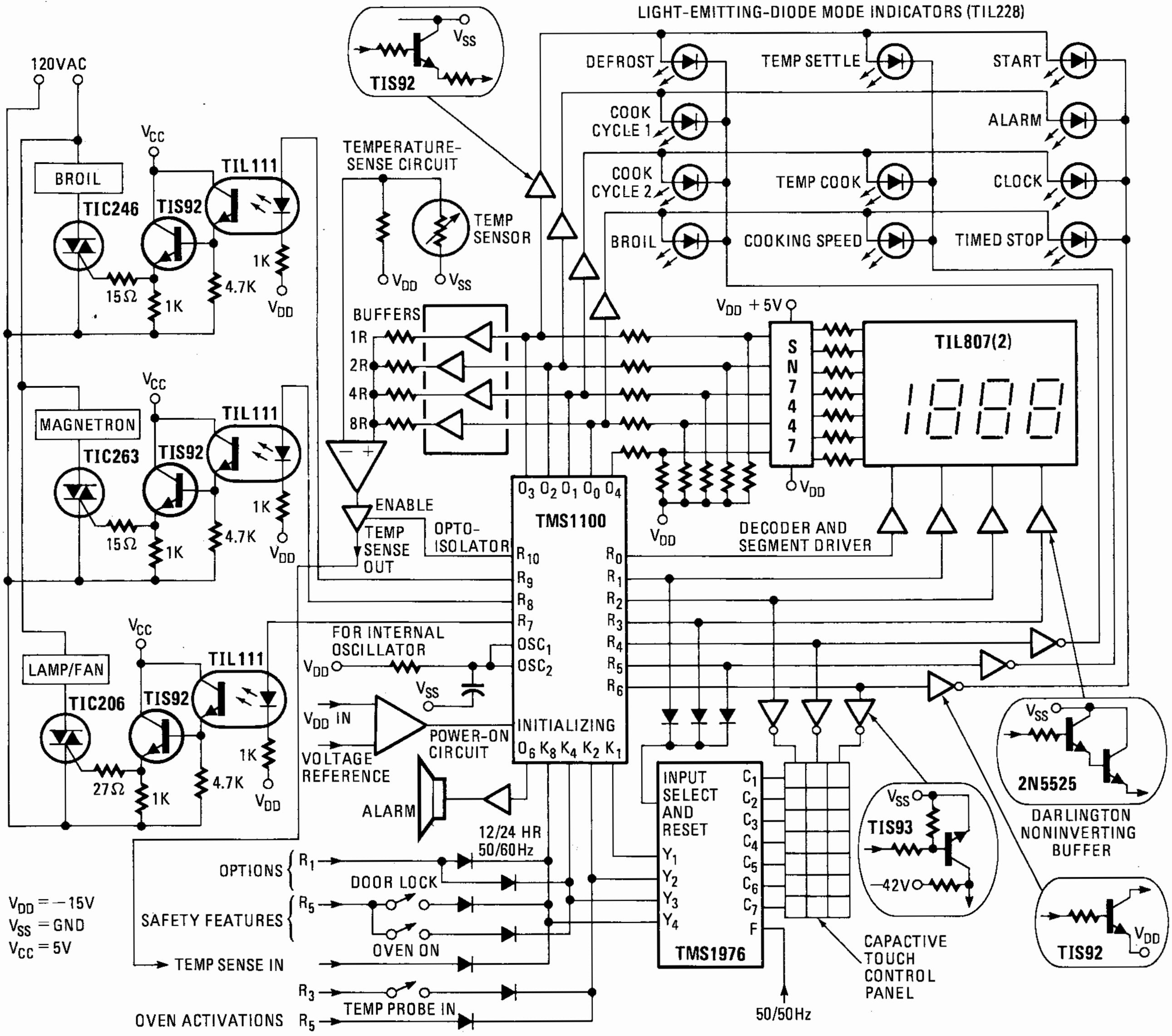


FIG. 1—MICROWAVE OVEN CONTROL system based on Texas Instruments TMS1100 8-bit microprocessor.

TMS1000 contain the central processing unit (CPU), a small amount of RAM (*R*andom-*A*ccess *M*emory) and a substantial block of ROM (*R*ead-*O*nly *M*emory).

Microwave cooking is generally a time-sequential procedure. Each time interval has a different heat setting. Combining a microcomputer with triacs in an oven-controller system eliminates many objections to such an ecologically attractive appliance. The factory presetting of popular cooking procedures and easy user programming of special sequential operations are just two possibilities of such a combination.

Figure 1 shows the partial schematic of a microwave oven-control system built around the TMS1100, a single-IC microcomputer with 2048 eight-bit words of ROM. The ROM is factory-programmed to carry out the control-function algorithms designated by the oven manufacturer. The design approach is competitive with discrete control-logic circuitry, and is more reliable because of the product's reduced component count.

The control system's primary function is to properly activate the oven's power-consuming heat and air-circulation portions: The magnetron, the broiler heating coil and the lamp and fan, shown on the left-hand side of Fig.1. Each element is connected in series with the AC power line and a controlling thyristor. The triacs are chosen to handle the individual circuits' current requirements: the TIC263 controlling the magnetron is rated at 25 amp, the TIC246 is rated at 16 amp and supplies from 5 to 10 amp to the heater element, and the TIC206, rated at 3 amp, supplies about 1 amp to the lamp and the fan.

A triac is the equivalent of two SCR's connected back to back. It can be triggered by either positive or negative gate voltage with respect to main terminal No. 1 (the axial lead merging with the gate lead), although the sensitivity is different depending on the power source and trigger polarities. The triac triggering pulse must only be long enough to insure regenerative latching. This minimum pulse-width requirement varies from about 2 to 20 μs depending on the level of gate overdrive for those triacs shown in Fig. 1. If the gate drive is discontinued by the time the AC signal waveform reverses its polarity, so that the triac current is reduced below its holding current, the triac turns off. Radio frequency interference is minimized if turn-on is restricted to zero crossings of the power-line cycle. In Fig. 1, the three TIS92 emitter-follower transistors supply the turn-on gate current. The series resistors between the emitter of the transistors and the triac gates determine the gate current. These resistors generally supply twice the nominal current to take care of tolerance and temperature variations.

The signals on the triac gate and the driver-follower transistors are referenced to one side of the AC power line. For safety and to prevent power-line or SCR-induced transients from damaging or causing incorrect computer operation, it is necessary to isolate the power circuitry from the processor circuitry and operator controls. Optical couplers are a natural choice for this isolation because only light and high-resistance leakage paths exist between the input and output sides of the circuit. An internal LED provides photon coupling to a phototransistor; a higher LED current provides more light and more current drive to the phototransistor base. Standard couplers provide a voltage isolation of 2.5 kV. Note that the three TIL111 optical coupler inputs are driven by microcomputer outputs R7, R8 and R9. These outputs are controlled by the ROM program permanently stored in the TMS1100 to trigger the triacs in response to predetermined sequences or by direct front-panel control. The SETR and RSTR instruction mnemonics correspond to the machine language codes controlling the status of these outputs.

The controls and displays are directly interfaced to the microcomputer through outputs R_0—R_6, outputs O_1—O_3 and inputs K_1, K_2, K_4 and K_8. The TMS1976 capacitive touch-control IC converts touch into logic levels.

The column being scanned is selected by outputs R_2, R_4 and R_6 under program control, and the six parallel panel outputs feed the TMS1100 through inputs K_1, K_2, K_4 and K_8. Since these inputs are the only microcomputer inputs, they must be shared by other oven functions, including the safety features and temperature-sensing input. These other inputs are strobed by the R outputs not used to scan the touch panel. The LED oven display is multiplexed by driving the segments from microcomputer outputs O_0, O_1, O_2, O_3 and O_4. In this case, the binary computer outputs are decoded by the SN7447 BCD-to-7-segment decoder/driver. The TMS1100 includes a PLA (*P*rogrammable *L*ogic *A*rray), which in some applications is programmed for 7-segment display decoding.

The other LED oven-function indicators are scanned by outputs, R_4, R_5 and R_6 and driven by outputs O_0–O_3. Keyboard scanning is done with the same R outputs used by the display. The input sense instruction (mnemonic KNEZ) can be used to detect an input switch condition, then jump to a routine that determines which input (or inputs) has been activated and respond to it. Then, a few milliseconds or so after the interruption, the program can continue with the display-scan routine.

For additional information on thyristor gating for microprocessor applications, write for *Bulletin CA-191* from Texas Instruments Incorporated, Inquiry Answering Service, Box 5012, M/S 308 (Attn: CA-191), Dallas, TX 75222. **R-E**