REPORT

# MICROWAVE OVENS

## ELECTRICAL HAZARDS ASSOCIATED WITH INTERNAL COMPONENTS

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# 1 Executive Summary

Microwave ovens used in homes and workplaces are a safe and useful tool when used according to their intended application.

Some internal components of microwave ovens carry high voltages that can deliver lethal levels of electric shock to individuals who attempt to repair a microwave oven without the proper training, or who attempt to reuse components from a microwave oven in ways that are not intended by the manufacturer.

This report discusses the hazards associated with the inner components of consumer microwave ovens, and how those hazards might lead to injury through electric shock. For reference, details regarding the functionality of the various components within a microwave oven are also included.

# 2 Introduction

## 2.1 Background

Microwave ovens are a safe and helpful appliance when used according to the manufacturer's instructions, however, internal components of a microwave oven can be hazardous when removed, replaced, or re-used in ways that are not intended by the manufacturer.

Many accidents and injuries to untrained workers have occurred through the misuse of microwave oven components. Electric shock is the primary hazard associated with these devices. This report provides information on the physiological effects on the human body that may result from electric shocks received from microwave oven components.

Additionally, this report provides an overview of the components within a typical microwave oven. Functional descriptions for the various electrical components are provided along with details of the associated hazards that an individual may encounter for each component.

The focus of this report is consumer microwave ovens; it does not consider commercial, industrial, or process microwave ovens or equipment.

## 2.2 References

[1] CSA C22.2 No. 150-16: *Microwave ovens.* Reaffirmed 2021.

[2] IEC 60479-1: *Effects of current on human beings and livestock - Part 1: General aspects.* International Electrotechnical Commission. 2018.

[3] Fish RM, Geddes LA. *Conduction of electrical current to and through the human body: a review.* Eplasty. 2009 Oct 12. PMID: 19907637; PMCID: PMC2763825. (read at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2763825/)

[4] Bernstein T. *Investigations of alleged appliance electrocutions and fires caused by internally generated voltages.* IEEE Ind Appl. 1989;25(4):664–8.

[5] Dalziel, C.F. *Deleterious Effects of Electric Shock.* 1961.

[6] Zemaitis MR, Foris LA, Lopez RA, Huecker MR. *Electrical Injuries.* 2022 Sep 9. PMID: 28846317. (read at https://www.ncbi.nlm.nih.gov/books/NBK448087/)

## 2.3 Acronyms and Definitions

- Ω Ohm symbol: unit of measurement of resistance
- A Amperes (or Amps): unit of measurement of current flow
- AC Alternating Current: the type of electricity from a household receptacle
- AHAM Association of Home Appliance Manufacturers
- Anode A cylindrical outer shell of a magnetron that attracts or gathers electrons
- °C Degrees celsius: unit of measurement of temperature
- C The letter used to represent capacitance in an equation
- Cathode A central electrode within a magnetron that emits electrons
- CSA CSA Group (formerly Canadian Standards Association)
- DC Direct Current: the type of electricity from a battery
- E The letter used to represent energy in an equation
- μF Microfarads: 0.000001 Farads – a unit of measurement of capacitance
- GFCI Ground Fault Current Interrupter
- GHz Gigahertz: 1,000,000,000 Hz
- HV High Voltage: circuits carrying voltages above 750 V.
- Hz Hertz: units of measurement of frequency in cycles per second
- I The letter used to represent current in an equation
- IEC International Electrotechnical Commission
- J Joules: unit of measurement of energy
- kHz Kilohertz: 1,000 Hz
- LV Line Voltage: for this report, voltage available from a household receptacle (120 Vac is the typical household line voltage in North America).
- mA Milliamps: 0.001 A
- mW Milliwatts: 0.001 W
- P The letter used to represent power in an equation
- R The letter used to represent resistance in an equation
- UL UL Solutions (formerly Underwriter Laboratories)
- V Volts: unit of measurement of voltage (independent of supply type) – also the letter used to represent voltage in an equation.
- Vac Volts AC: unit of measurement of AC voltage
- VDC Volts DC: unit of measurement of DC voltage
- W Watts: unit of measurement of power

# 3 Electrical Hazards Associated with Microwave Ovens

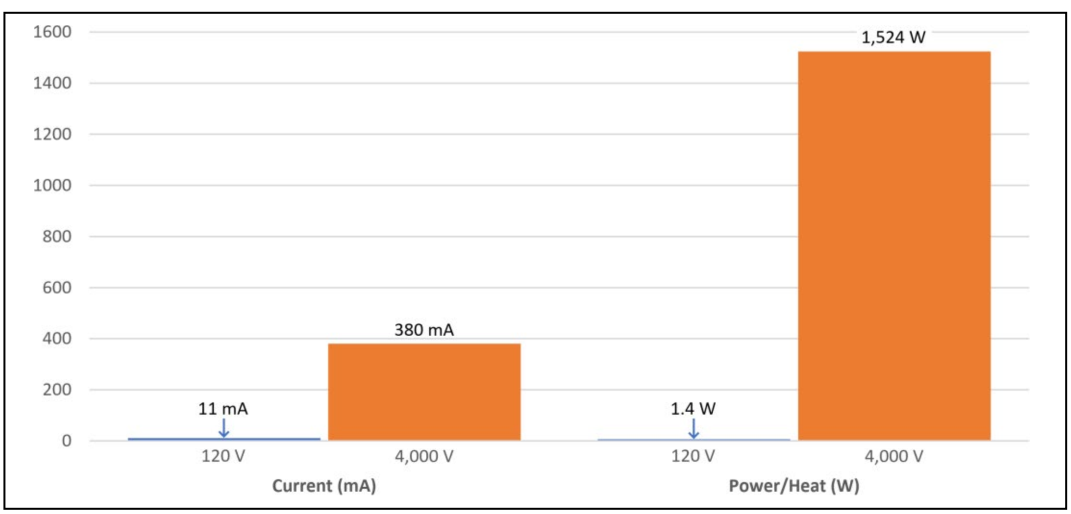
Electricity has the potential to cause serious injury or death. While there are several hazards related to work on microwave ovens – e.g., heat sources, particulates, sharp edges, etc. – the focus of this report is on electrical hazards and possible physiological effects on the human body resulting from electric shocks. Individuals who remove the cover from a microwave oven are exposed to electrical hazards.

Microwave ovens contain high voltage circuits and components operating at 4,000-5,000 volts (depending on the model). The risk associated with high voltages is exponentially greater than household voltages; electrocution by high voltage will almost certainly lead to death or permanent injury. Figure 1 below compares example current and heat dissipation levels that occur at 120 V and at 4,000 V through a resistance of 10,500 Ω. The significance of these levels will be explained further in sections 3.1.1 to 3.1.5.

Attempting to take measurements on energized high voltage components is a common source of arc flash and injuries. Most off-the-shelf measurement tools (i.e., multimeters) are not rated for the voltages produced by the high voltage components of a microwave oven; typical ratings for multimeters are 600 V or 1,000 V. The insulation on measuring devices can be broken down by higher voltages, leading to electrocution.

Hazards also exist with misuse of microwave oven components – i.e., the use of components outside of their intended installation within the appliance. Two common examples are the use of high voltage transformers for fractal wood burning or building a Jacob's Ladder (a travelling arc); in both cases, individuals are exposed to potentially deadly high voltages.

**Figure 1 – Comparison of Current and Heating Effects – Household vs High Voltage**



In addition to the presence of high voltages, the transformer is an isolation transformer which has a higher potential for harm as explained further in section 3.2.1.

If work on energized equipment is required, it should only be undertaken by properly trained personnel working with appropriate safety mitigations in place.

## 3.1 Overview of Electric Shocks

The primary factor that determines the extent of injury due to an electric shock is the level of current which passes through the body. Voltage is a key consideration because the current level through a resistance is directly proportional to the voltage level – i.e., higher voltage means higher current. This relationship as it pertains to the human body and electric shock will be described in more detail later.

Electric currents can damage the body in different ways as follows:

- **Contraction of muscles.** The human body's muscles and nervous system operate on electrical impulses. An external electrical signal can disrupt or override the natural bodily functions including control of limbs, breathing, and heartbeat. The intensity of this effect and the nature and severity of injury depend on the current level and the path that electricity takes through the body.
- **Heating or burning of cells and tissue.** The basic premise of an electric heater is that electricity applied across a resistive element causes the element to get hot. When electricity passes through the human body, the same effect occurs internally since the body tissues have primarily resistive properties to electricity.
- **Nervous system damage.** The nervous system is an electrical system. Like wires which overheat and burn when overloaded, nerves can be permanently damaged by the heating effects of electricity, leading to loss of control or function of the associated parts of the body.
- **Other possible effects:**
    - Damage to the kidneys or heart resulting from the release of proteins into the blood from damaged muscle tissues.[6]
    - Damage to cells due to dehydration as a result of heating.[6]
    - Long term psychological effects. [6]

### 3.1.1 Body Resistance

The human body is a very good conductor of electricity – especially the muscles, blood vessels, and nerves – due to the moisture and electrolytes that make up these pathways. As noted above, current is the primary factor in electrical injury; just as current is proportional to voltage level, it is also inversely proportional to resistance. Lower resistance means higher current will flow, leading to more damaging effects. To understand the levels of current that can flow through the body, the resistance of the pathways through the body must first be understood.

The outer layer of skin provides primary protection from electrical currents. The skin of the human body has a resistance anywhere between 1,000 Ω and 100,000 Ω, while the internal resistance of the body is only 300-500 Ω (depending on the path). Generally, skin resistance will be highest for thick or calloused skin; skin that is soft or thin has a lower resistance. In both cases, the resistance of skin is greatly reduced when moisture is present. [3]

While some individuals have demonstrated a tolerance for touching exposed wires carrying household voltage levels, higher voltages (above 500 V) can break down and bypass even tough, high resistance skin. Insulating materials of all types experience breakdown if voltage is raised high enough; an insulator that once blocked the flow of electricity allows it to pass. When skin breaks down, the resistance is greatly reduced, if not eliminated, and the overall pathway resistance drops, leading to a higher current through the body.[1]

### 3.1.2 Effects of Electric Shock

Studies have been carried out to measure the effects of electric currents on the body (see Appendix A for results from one such study). IEC 60479-1 establishes a set of values for AC and DC currents and their expected effects on the human body relative to the duration of exposure. For currents above the threshold of perception, a longer duration leads to more damaging physiological effects. For example, ventricular fibrillation (uncoordinated motion of the heart) is probable at 600 mA when exposed for 200 ms, however, the current level required drops to 60 mA when the exposure is maintained for 2 seconds.

Duration of exposure is a critical factor when combined with so called “let go” limits. Above 23 mA AC (for men) and 15 mA AC (for women), 99.5% of test subjects were unable to let go of a grasped source of electricity [5]. A very short shock (10 ms) as high as 200 mA is

[1] Apart from the high voltage breakdown effect on skin, some studies have shown that the resistance of pathways internal to the body seem to vary depending on the voltage applied. Further, during an electric shock, the resistance seems to change (reduce) over time as the duration of an electric shock continues. These phenomena are addressed in studies and standards which go beyond the scope of this report, but it is worth noting there are some other non-linearities that may apply.

generally considered to have no lasting harm [2], however, if the source of the shock is delivered to a location like the hand where the individual will have a strong muscular contraction, they can grab on to the source and be unable to break free. A prolonged shock of 50 mA passing through the body for more than 5 seconds can lead to burning, breathing arrest, and has a 50% probability of inducing ventricular fibrillation [2]. Although the current from an electric shock may be relatively low, the muscle contraction that causes the individual to cling to the source can lead to more severe injury or fatality due to the duration of the shock.

A comprehensive set of data that incorporates both current levels and duration of exposure is found in the IEC standard [2]. A few important thresholds are:

- 0.5 mA AC: the threshold for perception, but unlikely to have a startled reaction.
- Up to 5 mA AC, any duration: involuntary muscle contractions, potentially painful, no harmful or lasting effects. Note that most GFCI for a household application have trip levels around 6 mA.
- Above “Curve B” (a line from 200 mA for 10 msec to 5 mA for 5 seconds): Strong involuntary muscle contractions, difficulty breathing, reversible disturbance of heart function. These effects increase with increasing levels of current.
- Above “Curve c1” (a curve through 500 mA for 10 msec, 100 mA for 0.5 second, to 40 mA for 5 seconds): Burns and cellular damage, breathing arrest, and possible ventricular fibrillation (5%). Effects increase with increasing current.
- Above 1 A: Currents tend to lead to cardiac standstill rather than fibrillation.

### 3.1.3 Electric Shocks from DC Sources

Some models of microwave ovens use DC voltages in parts of the circuitry. Electric shocks from a DC source generally require higher currents to cause the same physiological effects as AC shocks. At the threshold for perception, DC shocks feel different to the individual; AC shocks cause a tingling or buzzing sensation due to the 60 Hz frequency of the power, DC shocks on the other hand can cause a spark when contact is first made, but after that there is only a sensation of heating.

As DC current increases, many of the effects (muscle contraction, breathing difficulty, and heart arrythmias) are the same, but at 3-5 times higher levels of current. For extremely short impulses of power, AC and DC have similar physiological effects; the thresholds for pain and disruption of heart function are roughly the same current level. As duration increases, the amount of DC current required for similar injury increases. Comparing a threshold discussed earlier, a 50% probability of ventricular fibrillation occurs at 50 mA for 5 seconds of AC current, but 150 mA for 5 seconds of DC current.

### 3.1.4 Example Current Calculations

According to Ohm's Law (V = I * R), current is calculated as voltage divided by resistance. This relationship allows calculation of theoretical shock levels for different voltage and hypothetical body resistances.

The complete path resistance through the body is 2 x skin resistance plus body resistance. For example, moderately soft skin could measure as 5,000 Ω skin resistance at entry + 500 Ω resistance through the body + 5,000 Ω skin resistance at exit = 10,500 Ω total resistance.

Some example scenarios showing currents that flow through the body are as follows:[2]

| Skin Type | Resistance | Line Voltage | LV Current | High Voltage | HV Current |
|---|---|---|---|---|---|
| Soft, Thin | 2,500 Ω | 120 V | 48 mA | 4,000 V | 1.6 A |
| Moderate | 10,500 Ω | 120 V | 11 mA | 4,000 V | 380 mA |
| Thick, Tough | 50,500 Ω | 120 V | 2.4 mA | 4,000 V | 79 mA |

Based on these calculations, comparing to the values charted in IEC 60479-1, high voltage shocks have a high probability of being lethal, even in very short duration. Shocks from household voltage (120 Vac) are less likely to cause permanent damage if the individual being shocked has a high skin resistance but can reach lethal levels if skin resistance is low.

### 3.1.5 Heat Dissipation

The discussion above is focused on the impact of current levels in the body, but another important consideration is power delivery. Heat is usually measured in watts and, for a simple electric circuit is calculated as $P = V^2 / R$. Because the voltage is squared, the increase in heat energy has a parabolic relationship to the increase in voltage.

During an electric shock, voltage level influences the amount of heat energy that is generated, which affects the amount of internal burning or heat damage that can occur. Using data from the table above, the individual with total body resistance of 10,500 Ω would have 1.4 W of heat dissipated at 120 V (almost none), but 1,500 W of heat dissipated at

[2] As was noted earlier, skin resistance is highly variable; these scenarios are illustrative only, to show the levels of current that are possible and to show the difference that high voltages make.

4,000 V (hotter than most household space heaters). This is why burning is so much more drastic at high voltages.

## 3.2 High Voltage Components

Based on the discussion in the previous sections, high voltage components of a microwave oven represent a far more dangerous hazard than the components operating at household voltage. If a microwave oven is operated with the cover removed, live high voltage components and wiring are exposed and accessible. Electrocutions at voltages of 2,000 to 4,000 V – voltages which are available in any off-the-shelf microwave oven such as the example shown in Figure 2 – will most likely lead to permanent injury or death.

Even the highest hypothetical skin resistance of 100,000 Ω results in a current over 25 mA at 4,000 V, which 99.5% of test subjects could not let go of [5], so an electrocution at high voltage where the individual is grasping the source will likely end up as a long duration electrocution with devastating effects. As the duration of an electric shock continues, the resistance will drop due to perspiration and damage to the skin, leading to a higher flow of current through the body and increasing levels of injury.

High voltage can arc through the air; in cases where there is dust or moisture in the air, an arc can connect over longer distances than in a dry and clean environment. Light produced from an arc can temporarily or permanently damage eyesight. Recalling that power is based on voltage squared, high voltage arcs produce an abundance of heat – even if not directly touched, arcing can lead to burning of skin, clothing, or other nearby substances.

Use of high voltage components of a microwave outside of their intended application within the protective housing of the microwave oven is a hazard with potential for severe consequences in the event of an accident. High voltage requires special tools and equipment to safely take measurements or operate. Most standard wiring is rated for 600 V or less; using a transformer from a microwave oven for other purposes can lead to an arc flash, fire, or electrocution in assemblies with wires energized at 2,000 to 4,000 V.

### 3.2.1 High Voltage Isolation Transformer Hazards

The high voltage transformer in a microwave oven is an isolation transformer, which means that some protective devices could be ineffective during an electrical fault on the output side of the transformer. An isolation transformer is one in which the secondary (output) side of the transformer is not electrically connected to the primary (input) side – i.e., the wires are not connected, the coils are coupled together only through the magnetic core of the transformer.

Where installed, GFCI protection will trip power if there is any hazardous fault to ground detected – typically greater than 6 mA. This protection is effective on the input side of an isolation transformer, but due to the isolation between input and output, GFCI protection will not recognize a ground fault on the output side.

If a fault occurs on the output of an isolation transformer, the only protections available are the circuit breaker of the source power and the fuse at the input of the appliance (if one is installed). The smallest typical household breaker is rated at 15 A, which is equivalent to 1,800 W of power (heat) and, on the high voltage secondary side of the transformer, an available current around 1 A. Referring back to section 3.1.2, this current level is far more than would be required to be lethal.

## 3.3 Stored Energy

After power is removed from a microwave oven, one component that may still present a hazard is the high voltage capacitor which is charged up to 2,000 V as described later in the document, and may retain that charge after shutdown, depending on the functionality of a bleed resistor as described below. Touching a fully charged capacitor of this size will deliver a substantial shock that has potential to be fatal in the right conditions.

Assuming a body path resistance of 2,500 Ω, a voltage of 2,000 V results in a current of 800 mA. Capacitors have only a finite charge capacity, so a capacitor discharged through a body in these scenarios would be almost completely discharged in 10 milliseconds. It should be noted that the voltage (and thus current) drops throughout the discharge period, so 800 mA is not continuous for 10 msec. For such an electric shock to be lethal, it would have to be perfectly timed with the vulnerable period of the heartbeat cycle. [2]

Another useful way to consider the hazard of a charged capacitor is from an energy perspective. From $E = 0.5 * C * V^2$ we calculate that a typical microwave oven capacitor holds roughly 2 J of energy. For the sake of comparison, a typical shock from static electricity after walking across carpet is 0.01 J [4], so the shock from a charged capacitor of this size would be very painful. It is generally thought that a momentary pulse shock such as a capacitor discharge will have to achieve 50 J to be lethal, but this is based on limited data and is not an exact number [4, 5].

Most capacitors used in microwave ovens have a built-in resistor that bleeds off the energy relatively quickly. Based on an example microwave with a 10 MΩ bleed resistor, the time constant for capacitor discharge (i.e., the amount of time for 63% of the voltage to be dissipated) is around 10 seconds. That means that 10 seconds after the microwave turns off, the voltage on the capacitor is 735 V; after 20 seconds, the voltage is 270 V; after 30 seconds it is 100 V; after 40 seconds it is 36 V. From an energy perspective, the static shock from walking on carpet (0.01 J) would be the same as a 1 µF capacitor charged to 140 V; on that basis, a period of 30 seconds following removal of power is sufficient to bleed off harmful levels of energy from the capacitor, provided the bleed resistor is functioning correctly.

The physical size of the high voltage capacitor found in a microwave oven is an indication that the capacitor has a high energy capacity. It is possible that a bleed resistor can cease to function, so a capacitor of this size must be treated as an energy source until any energy has been confirmed to be safely dissipated.

## 3.4 Line Voltage Components

Microwave ovens for use in North American household settings are typically powered by single phase, 60 Hz, 120 Vac power. This power is distributed throughout the various components of the microwave oven when it is plugged in, whether it is in operation or not.

Most microwave ovens do not have safety interlocks to prevent operation of the oven with the cover removed. As described in section 4.2 of this report, there are a few interlocks which ensure safe operation of the microwave by users (i.e., doors closed, not overheated, etc.), but monitoring the removal of the exterior cover is typically not done since it requires tools to remove.

When the cover is removed from a microwave oven while it is plugged in, live line voltage components are exposed and there is a risk of electrocution.

# 4 Microwave Functionality

Microwave ovens take advantage of relatively simple laws of physics to heat up food faster than other methods where a heat source is applied.

Temperature is a measurement of the average kinetic energy of the particles (atoms or molecules) that make up a substance. Kinetic energy is based on the motion of particles; to increase the temperature of a substance, the motion of the particles within must be increased. Microwave ovens do this by applying electromagnetic radiation at a specific frequency that is in the “microwave” spectrum (between radio frequencies and visible light).

As microwaves are absorbed by a substance, the molecules within attempt to align themselves with the electromagnetic waves, but because the fields of the wave are continuously changing, the particles cannot keep up; they end up spinning, crashing into each other, and otherwise incurring more motion, which represents an increase in kinetic energy and thus a rise in temperature.

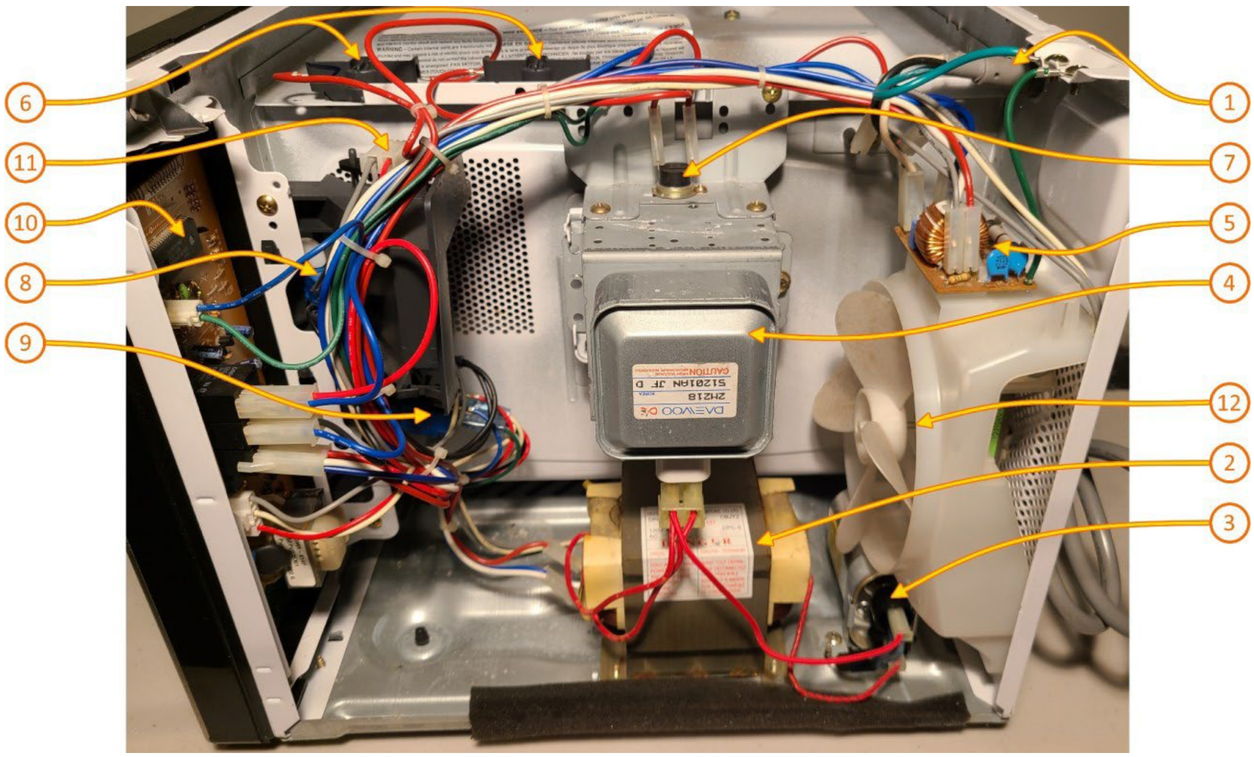
This is a highly shortened explanation of the heating process and is provided only for information. The focus of this report is on the general functionality of the components within a microwave oven to better understand the hazards and the safe work practices that should be observed during use of these appliances and when opening the oven to access the internal components.

## 4.1 Power Delivery Components of a Microwave Oven

This section will focus on the internal components of a microwave oven that are not readily visible. Figure 2 below shows an example microwave oven with the cover removed and the internal working components visible.[3] The components in the figure will be described in more detail in the subsections to follow.

[3] The internal make-up of different models of microwave oven may look different than this example. Key components are generally the same, but control and accessory components vary between models.

**Figure 2 – Electrical Components of a Microwave Oven**




Power Delivery Components

1. AC Incoming Power (4.1.1)
2. High Voltage Transformer (4.1.2)
3. High Voltage Capacitor (4.1.3)
4. Magnetron (4.1.4)

Other Electrical Components

5. Line Filter (4.2.1)
6. Thermal Safety Switches (4.2.2)
7. Magnetron Thermal Switch (4.2.3)
8. Door Interlock Switch 1 of 2 (4.2.4)
9. Interlock Monitor Switch (4.2.5)
10. Control Panel (4.2.6)
11. Light Bulb (4.2.7)
12. Cooling Fan (4.2.8)

### 4.1.1 AC Incoming Power

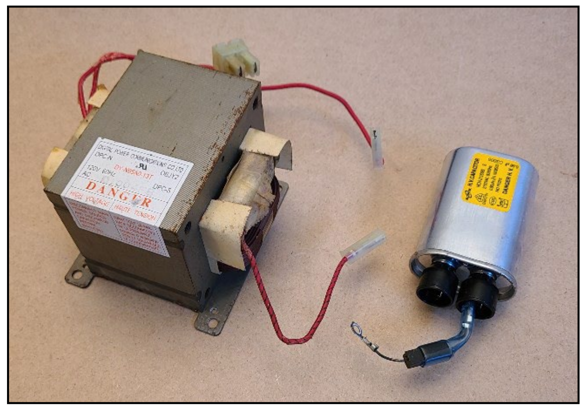
The AC incoming power to a household microwave oven in North America is most commonly a single phase, 120 Vac, 60 Hz circuit. Commercial microwave ovens may operate at voltages up to 600 Vac.

Microwave ovens are supplied with a 3-prong plug, which includes a ground wire. All manufacturers require that microwave ovens be solidly grounded by connecting directly to a properly installed 3-prong receptacle[4]. Connecting a proper ground to the appliance reduces the risk of electric shock if an electrical fault internal to the device were to occur.

Most manufacturers recommend that extension cords not be used with microwave ovens. As a higher power appliance, it is important that all connections be rated to carry the full load; an undersized extension cord can present a risk of overheating and fire if it is overloaded. Additionally, some extension cords allow bypassing the ground circuit. Use of extension cords requires electrical expertise to understand the electrical rating requirements and ensure a safe electrical connection.

### 4.1.2 High Voltage Transformer

**Figure 3 – HV Transformer and Capacitor**



The high voltage transformer works together with the high voltage capacitor to step up power from the AC incoming voltage level (120 Vac) to a level required to activate the magnetron and generate microwaves.

When the control panel activates a cooking cycle, the transformer primary side is connected to 120 Vac power. The secondary side of the transformer has two sets of windings. The main secondary windings output approximately 2,000 Vac (depending on the model) to the high voltage capacitor. A second, smaller set of secondary windings provide 3-5 Vac to activate the magnetron filament.

The high voltage transformer is an "isolation transformer", meaning there is no physical connection between the primary and secondary side of the transformer. The electrical hazard associated with isolation transformers is discussed in section 3.2.1.

The voltage level of the high voltage circuit is discussed further below after consideration of the capacitor's role in the circuit.

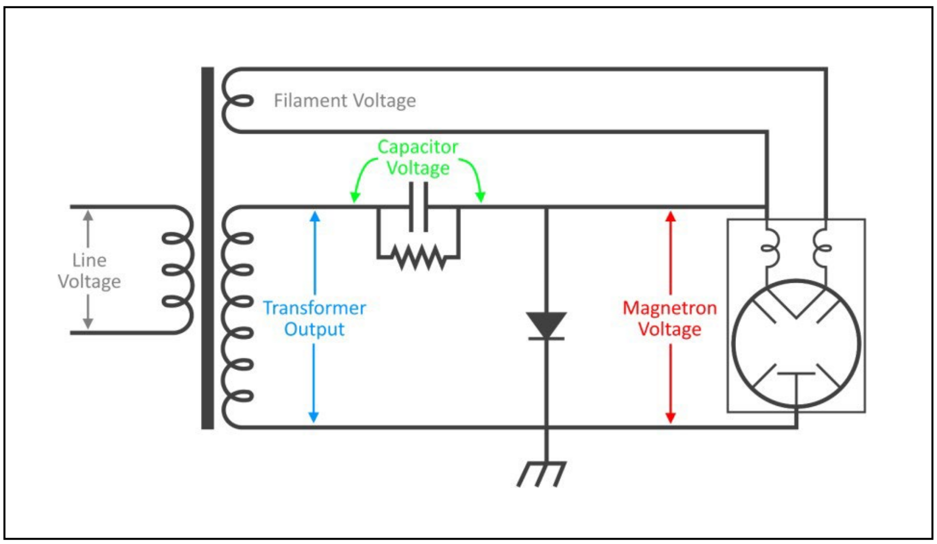
[4] Manufacturer requirement extends from the design requirement and the documentation requirement in CSA C22.2 No. 150-16 [1].

### 4.1.3 High Voltage Capacitor

As is described later in the section regarding the magnetron, a voltage of approximately -3,200 V is required for the magnetron to be active. The high voltage capacitor is connected to the transformer to "double" the voltage that is made available to the magnetron through what is known as a negative unbiased clamp circuit.

AC electricity is a sine wave voltage that oscillates around 0 V and is described according to the RMS (root mean square) value of the voltage as opposed to the peak voltage. Household electricity is typically described as "120 volt power"; in reality, a multimeter measurement would indicate lower voltage of 110-115 Vac. An oscilloscope used to measure voltage out of a household receptable operating at 115 Vac would show a sine wave with positive peaks of roughly +163 V and equal but opposite negative peaks of roughly -163 V. As described earlier, the high voltage transformer in a microwave oven boosts these peaks to +2,000 V and -2,000 V respectively, with the sine wave continuing to be centered around 0 V.

**Figure 4 – High Voltage Circuit Diagram**




The capacitor and diode work together to shift the midpoint of the sine wave so that the voltage peaks are at 0 V and -4,000 V. The peak-to-peak difference in voltage remains the same, but a DC-offset has been introduced by the capacitor that moves the 0 V level. This is accomplished as follows and as illustrated in the diagrams below:

1. Diodes conduct only when a positive voltage is applied and block negative voltages from passing through. Note in the circuit diagram above that the diode voltage is the same as the Magnetron voltage.

2. During the first positive peak of the voltage cycle, the capacitor charges through the diode until it reaches 2,000 V. An analogy would be placing a dead battery in parallel with a source battery – the capacitor (the dead battery in this analogy) is charged up to the voltage of the source.
3. Due to its orientation in the circuit, the capacitor appears as a negative supply on the output to the magnetron – so when the source voltage is at a peak of 2,000 V, the total magnetron voltage is 0 V – ignoring the small forward bias voltage of the diode.
4. As the source voltage turns from its peak and starts going down, the sum of the voltages from the source and the capacitor is a negative voltage at the circuit output. The diode ceases to conduct, and the negative capacitor voltage adds to the source voltage as it changes from positive to negative.
5. When the source voltage reaches a negative peak, the sum of this negative peak and the negative voltage of the capacitor creates a "doubled" negative peak.

It should be noted that through the period of negative voltage, the capacitor is discharging and supplying some power to the circuit. The capacitor voltage drops by some amount which will be recharged on the next positive cycle. The result is a waveform for the capacitor voltage that is usually referred to as a "sawtooth" wave.

**Figure 5 – High Voltage Circuit during Positive Peak**

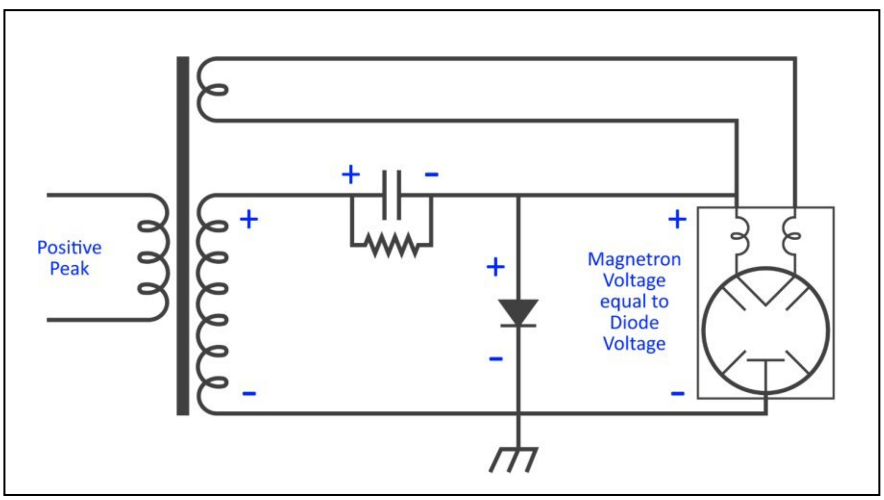


**Figure 6 – High Voltage Circuit during Negative Peak**

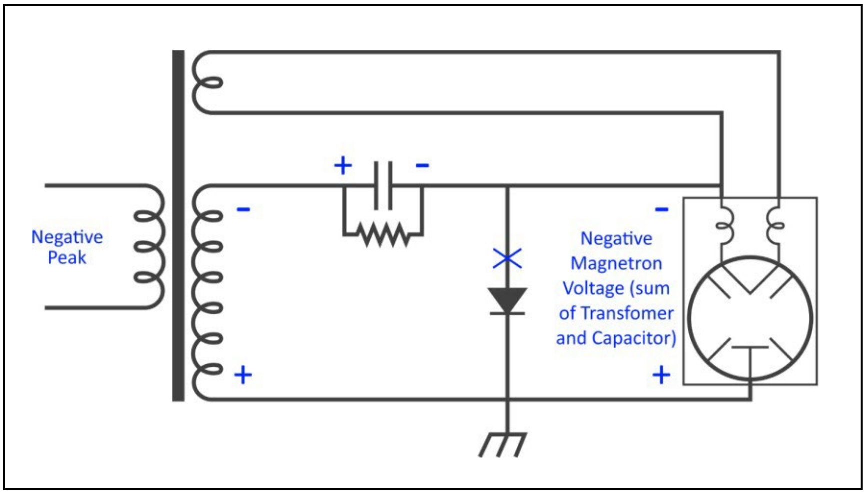
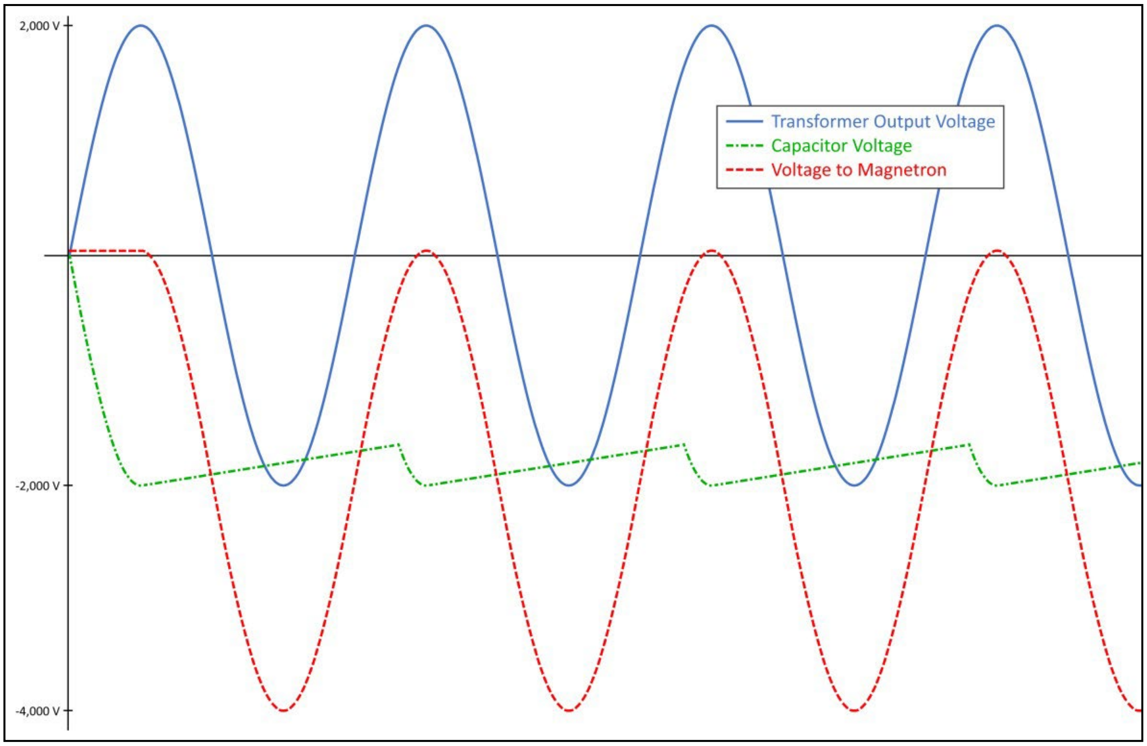



Figure 7 below is a simplified view of what the voltages in the high voltage circuit are expected to do on start up. The purpose of the diagram below is to show that the capacitor voltage is negative, which when added to the transformer output voltage leads to a power supply to the magnetron that maintains a sine wave shape, but is now effectively a pulsed-DC power supply with peaks of 0 and -4,000 V.

**Figure 7 – Voltages in the High Voltage Circuit[5]**



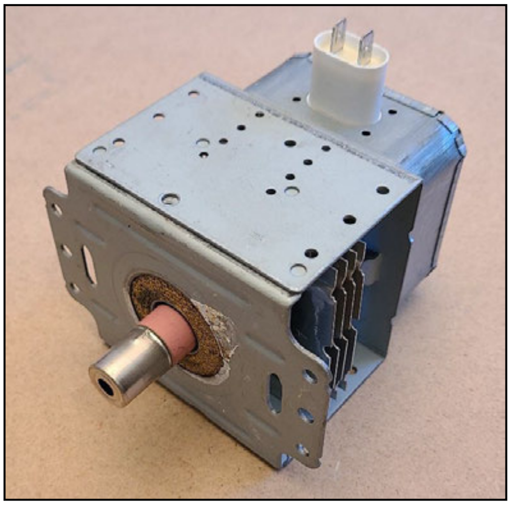

It is important to note that this is just one example of a microwave oven and others do exist which may operate slightly differently. A specific example is the inverter microwave which is discussed later in this report. Some microwave oven models, particularly older vintages, are understood to have used more elaborate capacitor/diode circuits to convert AC to a more stable DC power supply to energize the magnetron. These are not discussed in detail in this report, but the guidance related to safety is generally applicable.

[5] Figure 7 is illustrative only, and a few inaccuracies are acknowledged. Specifically, this diagram does not accurately reflect the timing of the capacitor charge/discharge as the time constant values may vary. The forward bias voltage of the diode is acknowledged by the output wave briefly going positive on the capacitor charge cycle, however, since the timing and duration of this positive excursion depends on the timing of the capacitor charging, it too is not precisely represented.

### 4.1.4 Magnetron

The magnetron within a microwave oven is the device that produces the microwaves which heat the food in the chamber. The physics of microwave production from a magnetron are complex, so for the purposes of this report, only a summary is provided.

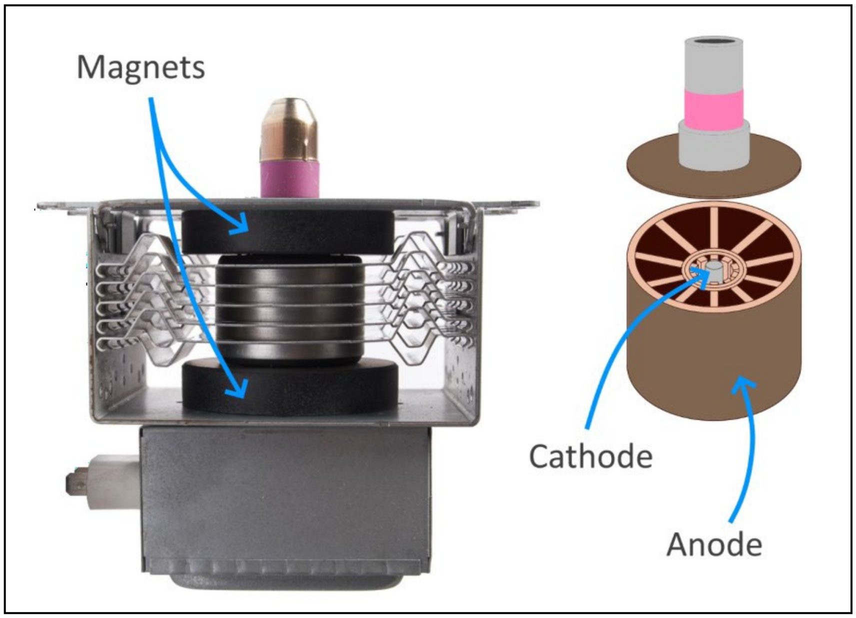
**Figure 8 – Magnetron**



The power output that is discussed in the prior section is what charges the anode and cathode of the magnetron. The cathode is the central filament, and the anode is the outer shell.

A magnetron works to accelerate electrons in a way to produce electromagnetic radiation close to the desired frequency of 2.45 GHz. The filament within the magnetron is heated to a high temperature which causes the release of electrons. These electrons normally would travel directly to the anode (outer shell) of the magnetron, which is positive relative to the cathode, except that there are two large magnets on each end of the chamber as shown in Figure 9. The magnetic field from these magnets causes the electrons to take a curved path through the chamber. The outer shell of the magnetron has several cavities – as the electrons spiral past the openings of these cavities, electromagnetic radiation is produced at the desired frequency. This radiation is gathered by an antenna and radiated into the cavity of the microwave oven through a metal channel.

**Figure 9 – Magnetron Details**



Production of microwaves depends on the voltage reaching a threshold of around -3,200 V. In a simple microwave oven as described here, microwaves are only generated for the part of each of the negative voltage peaks when the voltage has passed the threshold voltage.

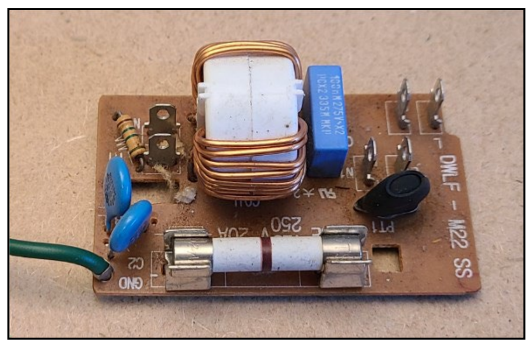
## 4.2 Other Electrical Components of a Microwave Oven

The components detailed in section 4.1 above are the high voltage components which represent the greatest electrical hazards to an individual who may be accessing the internal parts of a microwave oven. In this section, other electrical components will be described. While the hazard is lower for these components, they do still carry electricity at levels that can lead to injury or death.

### 4.2.1 Line Filter

In the example microwave shown in Figure 2, power from the incoming power cable is connected to a small circuit board which includes a fuse and power filtering components. In simpler models, there is no circuit board, and the fuse holder may be mounted directly to an interior surface.

**Figure 10 – Line Filter PCB**



Filter components protect the microwave from conducted electrical noise (i.e., disruptive currents or voltage fluctuations, also known as transients) that may be present on the incoming power source. The filter also prevents any electrical noise generated within from being conducted back onto the supply power where it might affect other devices connected to the household supply.

The circuit board in Figure 10 contains overcurrent protection in the form of a 20 A fuse which cuts power to the microwave during certain electrical faults[6] that draw enough power to overload the circuit (assuming an upstream circuit breaker does not trip first). This fuse can also be blown (by design) by the Interlock Monitor Switch as described further below.

The overcurrent protection fuse and the line filter components operate at 120 Vac.

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[6] Refer to section 3.2.1 for a discussion about the isolation transformer and GFCI protection

### 4.2.2 Thermal Safety Switches

Thermal switches are a simple construction that is based on either a bimetallic strip or dome in contact with a single pole switch. Two different metals that expand or contract at different rates when temperature changes result in the strip or dome flexing so that the circuit through the switch is broken once a certain temperature limit is reached. These switches will generally reset automatically once the temperature has been reduced to a specified level so that the metal returns to its original shape.

In Figure 2, the microwave oven has two thermal safety switches that are provided to protect the appliance from overheating in case a user has run the microwave exceedingly long, or in case of a malfunction:

- The switch on the left monitors the temperature of the cavity and opens if the temperature exceeds 100 °C. When the switch opens, the main incoming power is cut off from all internal circuits, preventing all operation from occurring.
- The switch on the right monitors the temperature above the heating element (the microwave shown includes an optional browning feature and this switch will only exist in models with that option). The grill temperature safety switch opens if the temperature exceeds 70 °C to turn off power to the heater element, and resets when the temperature is below 60 °C. The grill temperature safety switch does not affect any other components of the microwave oven.

The thermal safety switches and their connected circuits operate at 120 Vac.

### 4.2.3 Magnetron Thermal Switch

The thermal switch monitors the temperature of the magnetron. If a microwave oven runs with nothing in the cooking chamber (or something that does not absorb microwaves well), the microwaves can ultimately reflect back to the magnetron. This leads to heating and potential damage to the magnetron.

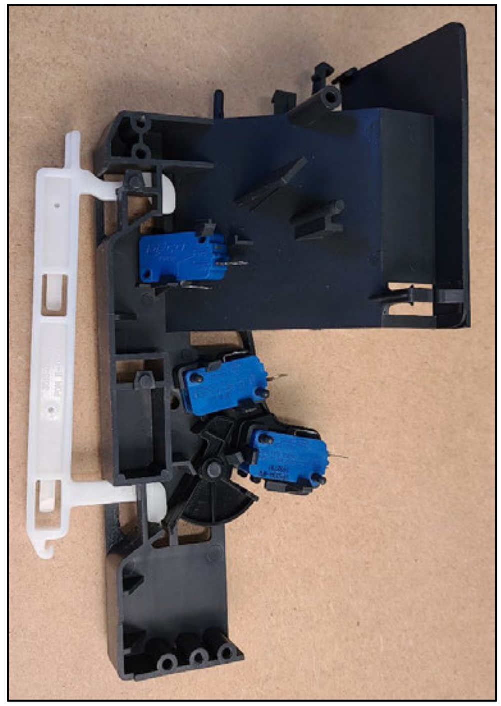
The magnetron thermal switch works similarly to the other thermal safety switches described above. When the setpoint temperature is reached (120 °C in this example), the switch opens and removes power from the high voltage transformer so that microwave production is stopped.

The magnetron thermal switch operates at 120 Vac.

### 4.2.4 Door Interlock Switches

Microwave oven doors must be fully closed to prevent leakage of microwaves from the cavity during use. Hazards associated with microwave radiation are not discussed in this report.

**Figure 11 – Interlock Switches**



In Figure 11, the interlock switches for a typical microwave are shown. The door interlocks are the two blue devices at the top and bottom (the blue device in the middle is the Interlock Monitor Switch which will be discussed next). These two switches provide redundancy and operate independently to ensure the door is closed while cooking. The white actuator is built into the door in a spring-loaded channel.

For this microwave oven, the upper interlock switch prevents power flowing to the cooking elements if the door is open. The control panel will operate, but if a cooking function is selected, no power will be passed through to either the magnetron or the heating element. This interlock is a concealed interlock, meaning it cannot be defeated by insertion of a straight rod [1].

The lower interlock switch is connected to the control panel to provide status of the door open or closed to the controller. If the door is open, the control panel will not command any cooking functions to start.

### 4.2.5 Interlock Monitor Switch

The interlock monitor switch provides a backup safety function to the top door interlock in case it fails or is attempted to be overridden.

While the door interlock switches are normally open switches that close when the door is closed, allowing power to flow, the interlock monitor switch is a normally closed switch that opens when the door is closed. The switch is connected directly between the hot and neutral wires of the incoming power, in series with the top interlock switch. If the top door interlock switch has failed and is stuck closed, or is somehow overridden, the input power will be short-circuited, blowing the fuse, and ensuring the microwave cannot operate. The physical design of the mounting mechanism for the switches ensures the interlock monitor switch opens slightly before the top interlock closes to prevent nuisance trips of the fuse.

The circuits through the door interlock and monitor switches all operate at 120 Vac.

#### 4.2.6 Control Panel

The control panel is made up of components – often on one or more circuit boards, but in more simple cases designed using only switches – which control all functionality of the microwave oven. On the front of the appliance, buttons or dials allow the user to select various functions. Depending on what function is chosen, relays or switches on the back side of the control panel will operate to direct power accordingly.

The relays and control switches operate at 120 Vac. In the case of a control panel that makes use of a circuit board and a wider set of control options, lower voltages may be present on the circuit board to operate the various chips and display components.

#### 4.2.7 Light Bulb

A light bulb is provided to allow the user to monitor the food as it is being cooked. The light bulb is not directly inside the cooking cavity but is typically behind a metal screen between the cavity and the electrical compartment – it turns on whenever the microwave oven is active.

The light bulb circuit operates at 120 Vac.

#### 4.2.8 Cooling Fan

A cooling fan is provided at the back of all microwave ovens to provide forced air cooling primarily of the transformer and magnetron. The fan is wired in parallel with the light bulb and turns on whenever the microwave oven is active.

The fan circuit operates at 120 Vac.

### 4.3 Inverter Powered Microwave Ovens

An evolution in the design of household microwave ovens is the change from transformers to the use of inverter technology to generate the high voltage used by the magnetron to generate microwaves.

Inverters have two main benefits:

- They are much lighter than the heavy weight transformers.
- They allow better control and higher power delivery to foods being heated.

In microwave ovens that use inverters, the 120 Vac, 60 Hz incoming power is first converted to DC voltage, then transistors are used to chop that DC voltage into a higher frequency, high voltage output that is sent to the magnetron. The frequency of the magnetron voltage wave form can be in the range of 10-20 kHz as compared to 60 Hz for a conventional microwave oven.

As was described above at the end of section 4.1.4, the magnetron in transformer-powered microwave ovens is only producing microwaves for part of the voltage cycle. Inverters, on the other hand, operate more efficiently by modulating the output pulses so that the threshold voltage is exceeded for a longer part of each cycle.

An additional advantage of inverter-powered microwaves is in lower power cooking modes. In conventional microwave ovens, when a user selects a lower cooking power level, the controller turns the magnetron fully on or off in 5-10 second cycles. Inverter-powered microwaves control the power level selected by the user by modifying the width of each pulse so that a more even cooking of food is achieved.

# 5 Safe Work Practices

As with any task, personal protective equipment appropriate to the task should be worn. In the case of work on a microwave oven, this includes hand and eye protection as a minimum.

Microwave oven repair or testing should not be attempted by anyone other than qualified personnel, and then repair or testing should only be undertaken according to documentation provided by the manufacturer. Service personnel must be aware of the various hazards associated with microwave ovens and how to mitigate them.

Electric shock is generally the most dangerous hazard associated with a microwave oven. Moisture is a contributing factor to electric shock. A hot or damp workspace that increases moisture (including through perspiration) can increase the probability of an electric shock. Conductive tools and work surfaces are often a contributing factor to electric shock incidents; one way to reduce the risk of electric shock is through the use of insulating work surfaces to prevent transmission of electricity to other areas or contact surfaces.

Workers need to be aware that there is little or no sound created when components internal to a microwave oven are energized. When the appliance is plugged in, many of the circuits within are energized to line voltage. It is possible that control components may fault in a way that the high voltage circuits could be energized as well.

# 6 Codes and Standards

This section provides information on a number of standards for household microwave ovens. Although the focus of this report is on electrical safety, a few additional standards related to performance or other safety factors are included for completeness.

This list does not consider commercial applications, which have some additional or different standards. This list also excludes "peripheral" standards – those which cover topics like grounding, cables, switches, etc. – many of those related standards are referenced within the text of the standards below.

There are additional regulations which govern the use of electromagnetic radiation. Microwave ovens operate in the "Industrial, Scientific, and Medical (ISM) Band". Regulations related to the specific frequency of operation are not discussed here.

**CSA C22.2 No. 150 – Microwave Ovens**

This is the general standard for design, construction, and testing of microwave ovens that applies in Canada and covers safety requirements including:

- General requirements
- Construction and mechanical assembly
- Door components – gaskets, viewing screen, barriers
- Interlocks
- Supply cord, grounding, internal wiring
- Electrical components – motors, transformers, heaters, lamps, switches, controls
- Insulation
- Protection
- Markings
- Testing requirements – function, leakage, interlocks, temperature, abuse, abnormal operation, fires

Similar standards to CSA C22.2 No. 150 from other jurisdictions include:

- UL 923 – Microwave Cooking Appliances
- IEC 60335-2-25 – Household and similar electrical appliances - Safety - Part 2-25: Particular requirements for microwave ovens, including combination microwave ovens

### Health Canada Regulations

Health Canada has established regulations on allowable energy leakage from microwave ovens under the Radiation Emitting Devices Act. As of the date of writing this report, those regulations are:

As measured 5 cm from the surface of the microwave oven:

- 1.0 $mW/cm^2$ with test load
- 5.0 $mW/cm^2$ without test load

The US FDA lists similar limits for microwave oven leakage under the United States Code of Federal Regulations Title 21, section 1030.10.

### Natural Resources Canada Regulations

Natural Resources Canada has established regulations on allowable standby power consumption for microwave ovens under the Energy Efficiency Act. As of the date of writing this report, those regulations are:

- Less than 1.0 watts of standby power for microwave ovens and countertop convection microwave ovens
- Less than 2.2 watts of standby power for built-in or over-the-range convection microwave ovens

This regulation is coordinated with US Department of Energy standards as found in United States Code of Federal Regulations Title 10, part 430, subpart C, section 430.32(j)(3).

These measurements must be based on the CSA C388 testing standard or the US Department of Energy Federal Regulation on cooking product test methods. See below for more.

### CSA C388 – Energy performance and capacity measurement of household microwave ovens

This standard provides guidance on standard test methods for establishing the energy consumption of a microwave oven. The intent is to allow for comparison of energy consumption between brands from a common perspective.

CSA C388 is coordinated with US Department of Energy standards as found in United States Code of Federal Regulations Title 10, part 430, subpart B, Appendix I: Uniform Test Method for Measuring the Energy Consumption of Cooking Products.

An international standard on the same topic exists under IEC 60705 – Household microwave ovens – Methods for measuring performance

#### CSA SPE-7007 – Sustainability standard for household microwave oven appliances

A relatively recent standard that looks not just at the energy consumption of a microwave oven, but at the complete lifecycle environmental impact of the appliance. This standard is jointly published with AHAM and UL standards of the same number (7007).

# Appendix A Study: Effects of Current on Humans

Professor Charles Dalziel carried out research on human volunteers and published the results in a 1961 paper titled “Deleterious Effects of Electric Shock” [5]. The data from the study has been refined and used as a foundation for development of electrical codes and standards. Note that the data does not include time (i.e., the duration of the electric shock) as a factor, but since the test subjects are intentionally being shocked, it is assumed the duration of exposure is at least 1 second. The data pertaining to fibrillation and death is based on very limited data or comes from animal testing instead of human testing, so these are not considered to be precise.

The International Electrotechnical Commission has produced a Basic Safety Publication – IEC 60479-1 – Effects of current on human beings and livestock – that includes current vs. time graphs which identify zones of varying physiologic effects for both AC and DC power. These charts are protected by IEC copyright and cannot be reproduced here without permission, but they are recommended as a better resource with more conservative limits than those listed below.

| Effects | DC Power | | AC Power | |
|---|---|---|---|---|
| | Men | Women | Men | Women |
| Slight sensation on hand, not surprising | 1 mA | 0.6 mA | 0.4 mA | 0.3 mA |
| Perception Threshold | 5.2 mA | 3.5 mA | 1.1 mA | 0.7 mA |
| Electric shock – surprising but not painful, no loss of muscle control | 9.0 mA | 6.0 mA | 1.8 mA | 1.2 mA |
| Painful shock – muscle control lost by 0.5% of subjects | 62 mA | 41 mA | 9.0 mA | 6.0 mA |
| Painful shock – median let-go threshold | 76 mA | 51 mA | 16 mA | 10 mA |
| Severe shock – difficulty breathing, muscle control lost by 99.5% of subjects | 90 mA | 60 mA | 23 mA | 15 mA |
| Possible ventricular fibrillation | | | | |
| Very short shock (0.03 seconds) * | | | 1 A | 1 A |
| Longer shock (3 seconds) | 500 mA | 500 mA | 100 mA | 100 mA |
| High Voltage Surge Energy | 50 J | 50 J | 13.6 J | 13.6 J |
| Ventricular fibrillation, Certain Death | | | | |
| Very short shock (0.03 seconds) * | | | 2.75 A | 2.75 A |
| Longer shock (3 seconds) | | | 275 mA | 275 mA |

* - Note: for very short shocks to be lethal, they must occur during the susceptible phase of the heartbeat.