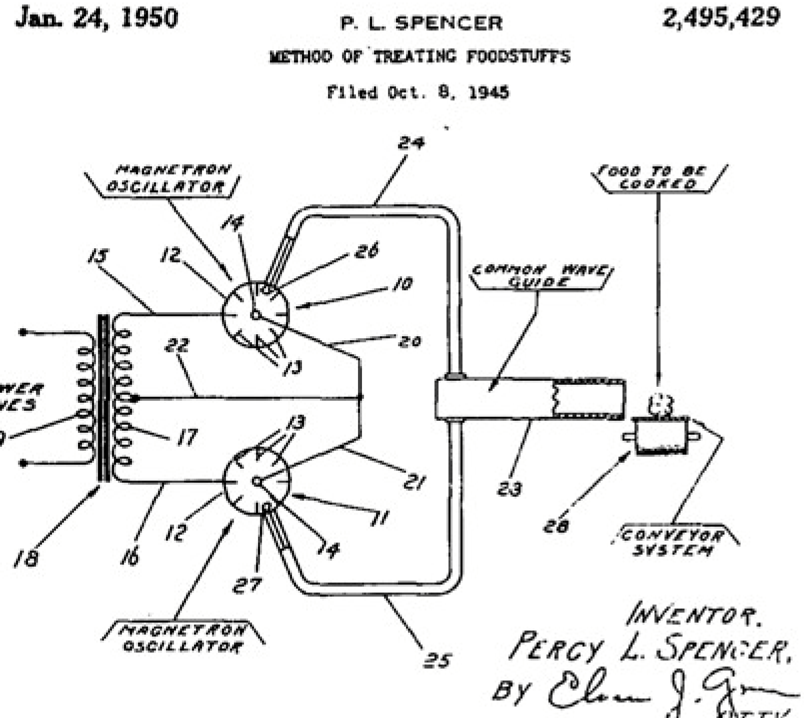
ECE350 – The Microwave Oven

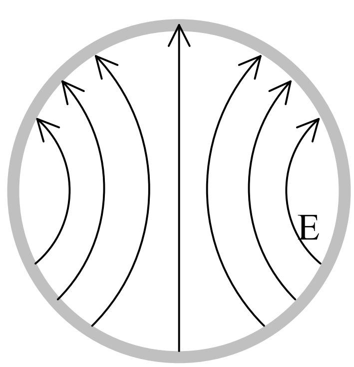
A typical microwave oven is a rectangular wave guide cavity resonator. A microwave tube (usually a magnetron) converts 60 Hz electric power into an electromagnetic wave, with standardized frequency of 2.45 GHz. Below is a figure from the original patent drawn by Dr. Percy Spencer of Raytheon Corporation, in 1950 (the first experiments date from 1946).



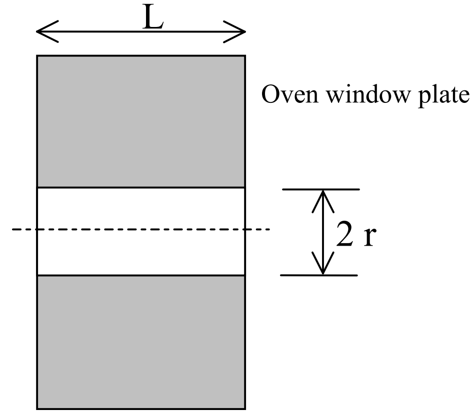
From Spencer Family Archives

The metal enclosure of the home oven, not yet envisioned in the original conception, is necessary for two reasons: a) Concentrating the radiation on the food to cook by creating a cavity resonator; b) Avoiding exposure to potentially harmful electromagnetic energy.

To allow inspection of the cooking process, the microwave oven is fitted with a window. However, if the window consisted of a wide opening, radiation would escape. The solution normally adopted is to make the window by sandwiching between glass panes a metal plate with a large number of circular holes. These holes are circular wave guides. The fundamental mode of a circular wave guide is labeled TE_{11} and it has a field configuration resembling a distorted TE_{10} mode in rectangular wave guide.



TE_{11} mode in circular wave guide



The holes on the oven window plate are circular wave guides operating below cut-off. The cut-off frequency for the fundamental TE_{11} mode, assuming an air-filled wave guide, is given by

$$f_c(\underbrace{TE_{11}}_{\bigcirc \text{ wave guide}}) = \frac{1.841}{2\pi r\sqrt{\mu_0 \varepsilon_0}} = \frac{0.0879}{r} \ [\text{ GHz }]$$

If the holes have a radius of 1.0 mm, the cut-off frequency of the fundamental mode is 87.9 GHz. Note that it is not wise to fill the hole with a dielectric, since the cut-off frequencies would be lowered. To emphasize the attenuation of the evanescent waves, the cut-off frequencies should be as high as possible. The propagation vector component along the axis for the fundamental TE_{11} mode is given by

$$\beta_z = \pm\sqrt{\omega^2 \mu_0 \varepsilon_0 - \left(\frac{1.841}{r}\right)^2}$$

Note that the coefficient 1.841 is obtained from Bessel function theory. Each mode has a different coefficient obtained from the roots of Bessel functions of the first kind (TM modes) or from the roots of the functions derivative (TE modes). At the frequency of 2.45 GHz and for holes with 1.0 mm radius, we have

$$\beta_z = -j1840.285 \ \ [\text{ m}^{-1}]$$

corresponding to an attenuation factor for the electric field

$$\exp(-j\,\beta_z\,L) = \exp(-\alpha\,L) = \exp(-1840.285\,L)$$

$$L = 1.0 \text{ mm} \qquad \exp(-\alpha\,L) = \exp(-1840.285 \times 0.001) = 0.158772$$

$$L = 2.0 \text{ mm} \qquad \exp(-\alpha\,L) = \exp(-1840.285 \times 0.002) = 0.0252086$$

$$L = 5.0 \text{ mm} \qquad \exp(-\alpha\,L) = \exp(-1840.285 \times 0.005) = 0.0001009$$

For power

$$L = 1.0 \text{ mm} \qquad \exp(-2\alpha\,L) = \exp(-2 \times 1840.285 \times 0.001) = 0.0252086 \qquad (-15.98 \text{ dB})$$

$$L = 2.0 \text{ mm} \qquad \exp(-2\alpha\,L) = \exp(-2 \times 1840.285 \times 0.002) = 0.0006355 \qquad (-31.96 \text{ dB})$$

$$L = 5.0 \text{ mm} \qquad \exp(-2\alpha\,L) = \exp(-2 \times 1840.285 \times 0.005) = 1.02 \times 10^{-8} \qquad (-79.91 \text{ dB})$$

Recommended IEEE safety guidelines are that at 2.45 GHz human exposure to electromagnetic radiation should be below approximately 2.0 mW/cm^2 power density. The U.S. and much of Western Europe have a standard of maximum radiation level of 10.0 mW/cm^2 (in the former Soviet Union 1.0 mW/cm^2). A separate U.S. standard for microwave ovens requires that power level at 5.0 cm from any point of the oven should not exceed 1.0 mW/cm^2. From the size and number of the oven window holes and from the knowledge of the power generated by the oven, one can estimate an upper limit for the power that may leak through the oven window. The oven door is also a potential source of radiation leaks. Usually, RF absorbing material is used around the door joint and a special design called "λ/4 choke flange" may be used (similar to a typical arrangement for wave guide contacting joints) to ensures that the closure is a very good "short".