Electromagnetic Measurements on a Microwave Oven

Electromagnetics
and
Remote Sensing Lab
(ERSLab)

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Outline

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Historical Notes

Percy Spencer was a Raytheon researcher. During the 1930s he won a government contract to produce radar combat equipment.

A strange experiment...

One day at work in 1945 Spencer was standing next to an active microwave source when a candy bar in his pocket melted. Intrigued, he sent out for unpopped popcorn.

When it popped in front of the magnetron, he realized that microwaves could cook food.

Historical Notes

Percy Spencer with its first Microwave Oven (MO).

Historical Notes

In the 1960s, a MO prototype was produced by General Electric.

Historical Notes

The GE's oven depended on an elastomer-cored metal mesh gasket for sealing the door.

Leakage

It took only a few food spills to gunk up that gasket where upon the shielding deteriorated and significant microwave power escaped.

That resulted in quite a recall and hastened the demise of that product.

Outline

Food heating

MOs generate EM waves at 2450 MHz to heat food. The inner cavity is saturated with about 12 cm wavelength EM waves.

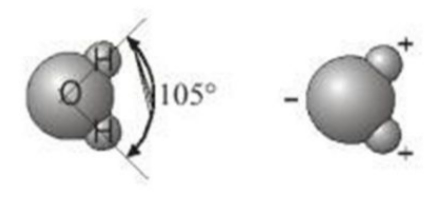
$$\lambda = \frac{c}{f} = \frac{3 * 10^8}{2.45 * 10^9} = \frac{3 * 10^8}{24.5 * 10^8} \cong 12[cm] \qquad (1)$$

Power transfer

This frequency is chosen according to the maximum energy transfer from the magnetron to the food.

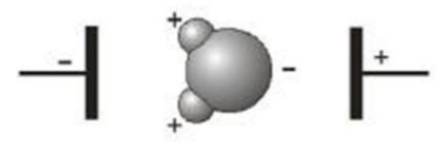
Food heating

Foods are mainly composed of water whose molecules consist of hydrogen and oxygen atoms.
Its chemical formula is H_2O, meaning that each of its molecules contains one oxygen and two hydrogen atoms, connected by polar covalent bonds.



Food heating

When a polar molecule is surrounded by an electric field it orientates its negative terminal towards the positive pole.



Time-varying fields

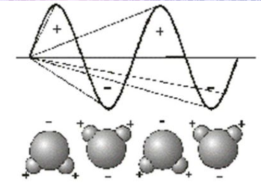
If the electric field is repeatedly reversed, the water molecule repositions itself at every reversal of the field.

Food heating

Resonant frequency of the water

At 2450 MHz the water molecule reverts its position 2450 millions of time every second.

At a higher frequency the rotation would be interrupted before completing the 180° revolution on the contrary at a lower frequency the rotation would be interrupted after completing the 180°.



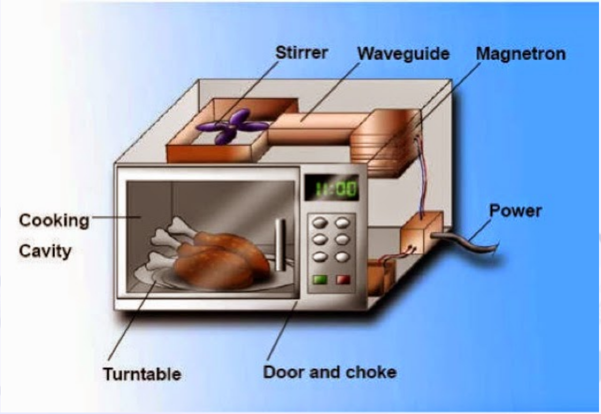
ISM band

Strong interaction with water molecule

Every MO works at 2.45 GHz frequency using quasi-monochromatic waves.
At this frequency EM waves strongly interacts with foods molecules and passes through plastic containers or cutlery without interfering with them.

The 2.45 GHz band is approved for unlicensed use in Industrial Scientific and Medical (ISM) applications.

MO components



MO components

MOs are composed mainly of those elements:

- Magnetron
- Power Supply Circuit
- Waveguide
- Fan for cooling
- Metallic Cavity
- Stirrer
- Power Selector Knob

Magnetron

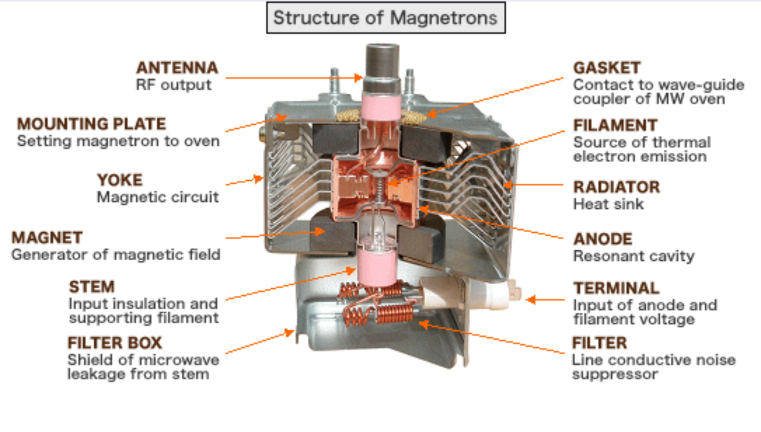
Magnetron

The magnetron is a microwave oscillator that consists of a high power vacuum tube.
Basically, the electrons emitted from a hot cathode and whirl go to an anode, which consists of resonant cavities, at speeds that generate microwave energy.

This microwave energy is coupled out of the magnetron via a probe that, connected to a waveguide, deliver the microwave power (hundreds of Watts) to the oven's cavity.

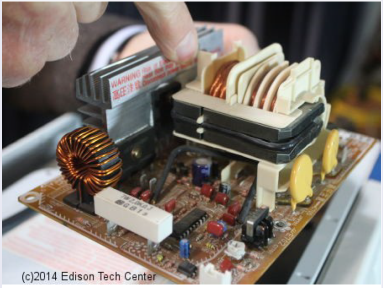
Magnetron

Magnetron



Power Supply Circuit

Power supplies are needed to power magnetrons as they require a high voltage (3 kV) dc supply. The magnetron converts the high voltage DC to the required 2.45 GHz.



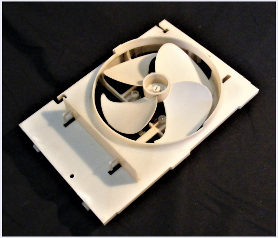
Waveguide

EM Waveguides are metallic structures that are able to guide EM waves to transfer high power with minimal loss of energy by restricting the transmission of energy to one direction. The frequency of the transmitted wave also dictates the size of a waveguide.

Fan cooling

Fan for cooling

Cooling fan for a MO are adapted for directing axially the airflow to be evenly distributed over a magnetron and a high voltage transformer.



Metallic cavity

For a loss-less rectangular metallic cavity the *mnp*−eigenvalue is given by:

$$k_{mnp}^2 = \left(\frac{m * \pi}{w}\right)^2 + \left(\frac{n * \pi}{h}\right)^2 + \left(\frac{p * \pi}{l}\right)^2 \tag{2}$$

where w, h, l stand for the width, the height and the length of the cavity, respectively.

Shielding

Shielding

The metallic cavity is well shielded from the metallic walls and from the MO's door.
To limit the leakage, i.e. the power that goes out of the cavity, the door consists of:

- A metallic pattern that can be assimilated to a grid of circular waveguides in cut-off.
- A choke groove made by a waveguide and absorbing material that limits the leakage through the door opening.

A special mechanism is also present, that switches off the magnetron immediately when the door is opened.

Cut-off frequency

For the fundamental TE_{11} mode of the circular waveguides:

$$\omega_c = c * \frac{1.841}{2 * pi * r} = \frac{0.0879}{r}[GHz] = 87.9[GHz] \qquad (3)$$

where $r = 1[mm]$.

Stirrer

The stirrer inside the MO scatters the EM field more evenly throughout the cooking chamber, to prevent the instances of hot spots that would heat food up only in one area, while leaving the rest cold.

Stirrer

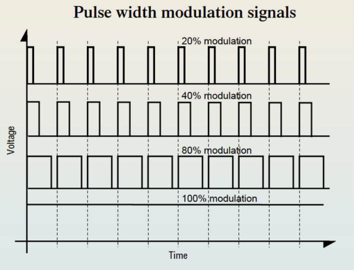
Power Selector Knob

The Power Selector Knob allows the user to choose the power level for cooking.

Power Selector Knob

Power Selector Knob

This control is based on a Pulse Width Modulator (PWM) that regulates the duty cycle of the EM signal transmitted in the metallic cavity.



Experiments

Goal

The goal of the experiments undertaken in the Electromagnetic Lab is twofold:

- Understanding the main features that characterize the EM waves emitted by the MO.
- Measuring the Average Total Radiated Power (ATRP) that is transmitted out of the MO cavity.

Outline

Reverberating Chamber

A Reverberating Chamber (RC) is a metallic cavity large in terms of wavelength.
It is a controlled environment commonly used in EMC, in particular for Electromagnetic Emission (EMI) measurements and in the emulation of different wireless propagation channels.

Reverberation Chamber of the Università degli Studi di Napoli Parthenope

Outline

Spectrum Analyzer

The Spectrum Analyzer (SA) is able to provide an effective insight into the RF performance of a circuit, module or system. As the name spectrum analyzer indicates, this type of test instrument provides information about the spectrum of a signal in real-time.

Outline

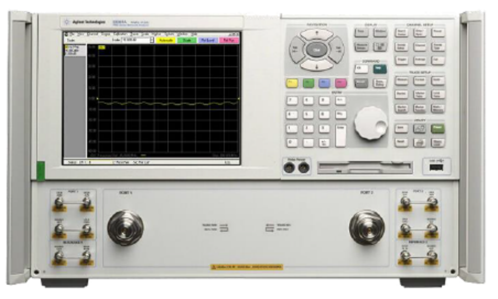
Power Meter

The Power Meter (PM) is a measurement instrument able to measure a power in real-time.

Outline

Vector Network Analyzer

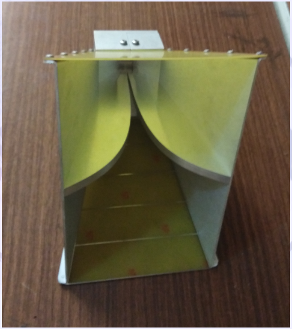
The Vector Network Analyzer (VNA) is an instrument that measures the network parameters of electrical networks such us s-parameters because reflection and transmission of electrical networks are easy to measure at high frequencies.



Outline

Measurements Setup

Measurements are made using a couple of Double Ridge Horn antennas: ETS Lindgren 3115.
Those antennas are able to work in a large frequency range from 1 GHz to 18 GHz.



Measurements Setup

The MO used for the experiments is a Sekom SM720CY6.

Measurements Setup

Two configurations are used for the MO

1. Unloaded: This means that an empty MO is considered.
2. Loaded: The MO is loaded with a standard load, i.e.; a liter of water in a Pyrex box.

Measurements are performed using both the Spectrum analyzer and the power meter using the calibrated measurement set up.

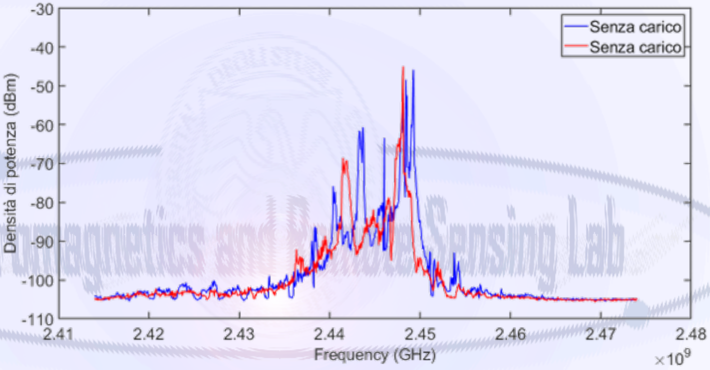
Outline

Spectrum analyzer

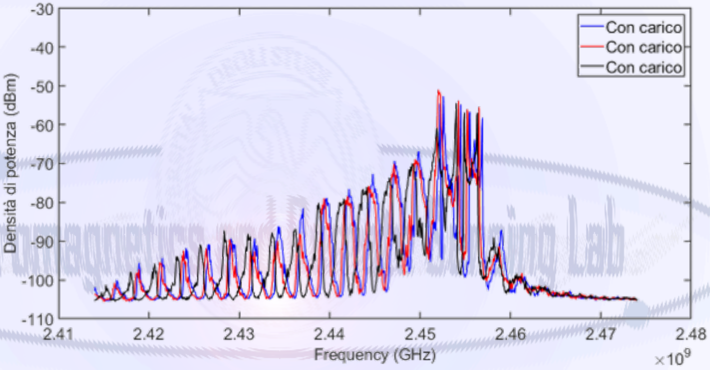
The power spectral density is measured over a frequency range that is centered at the 2.45 GHz MO working frequency.

- The acquisition time, i.e.; the time during which field samples are collected and processed, is set equal to 360 seconds. This time-span is limited by the water evaporation.
- The main goal is understanding the spectral behavior of the power density in the loaded and unloaded cases.

Unloaded case

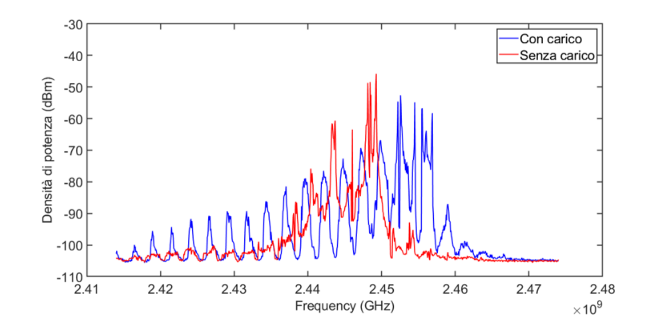


Loaded case



-30
-40
-50
-60
-70
-80
-90
-100
-110
Densità di potenza (dBm)
2.41
2.42
2.43
2.44
2.45
2.46
2.47
2.48
Frequency (GHz)
×10^9
Con carico
Con carico
Con carico

Loaded vs unloaded



Outline

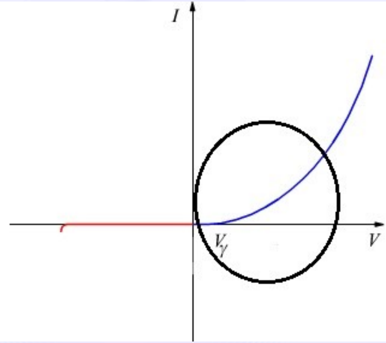
Power meter

It provides power measurements without additional processing

- It needs to be connected to a sensor able to receive the EM field. In our case, a diode sensor is used.
- The diode has to work in the range in which the output voltage is linearly proportional to the power of the EM signal. Hence, an attenuator is needed.

The ATRP is obtained using the power meter and calibrating the measurement set up.

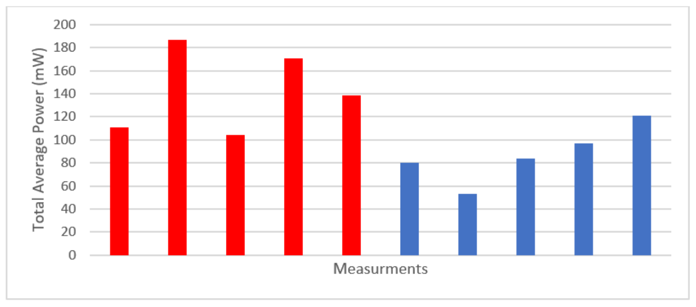
Diode V-I Characteristic



ATRP

ERSLab

S. Gargiulo



Unloaded case

Loaded case

ATRP

The ATRP measured is now compared with the maximum power radiated by some devices of common use.

Mobile Technology	Potenza max (mW)
GSM 900	3162.28
GSM 1800	1584.89
UMTS (bande 1/8)	316.23
LTE (bande 1/3/7/20)	371.54
Wi-Fi Router Bands	
2.4 - 2.4835	100
5.15 - 5.35	200
Microwave Oven	
Sekom SM720CY6	142 (**Average**)

The mobile cellphone specifications reported are referred to a ″Xiaomi Pocophone F1″, while the Wi-Fi device ones are the highest limits for the maximum radiated power.

For further reading

- Stephen J. Boyes and Yi Huang, Reverberation Chambers: Theory and Applications to EMC and Antenna Measurements, 2016 John Wiley & Sons, Ltd.
- Clayton R. Paul, Introduction to Electromagnetic Compatibility, 2005 John Wiley & Sons, Ltd.
- EC 61000 Part 4-21: Testing and measurement techniques-Reverberation chamber test methods, ed. 2, 2011