Microwave Engineering

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About the Tutorial

Of all the waves found in the electromagnetic spectrum, **Microwaves** are a special type of electromagnetic radiation that is used in many ways, from cooking simple popcorn to studying the nearby galaxies!!

This tutorial will help readers get an overall knowledge on how Microwaves work and how we use them in several applications.

Audience

This tutorial will be helpful for all those readers who want to learn the basics of Microwave Engineering. The readers will gain knowledge on how Microwave signals are generated, controlled, transmitted, and measured.

Prerequisites

It is a simple tutorial written in a lucid way. We believe almost any reader having a basic knowledge of analog and digital communication can use this tutorial to good effect.

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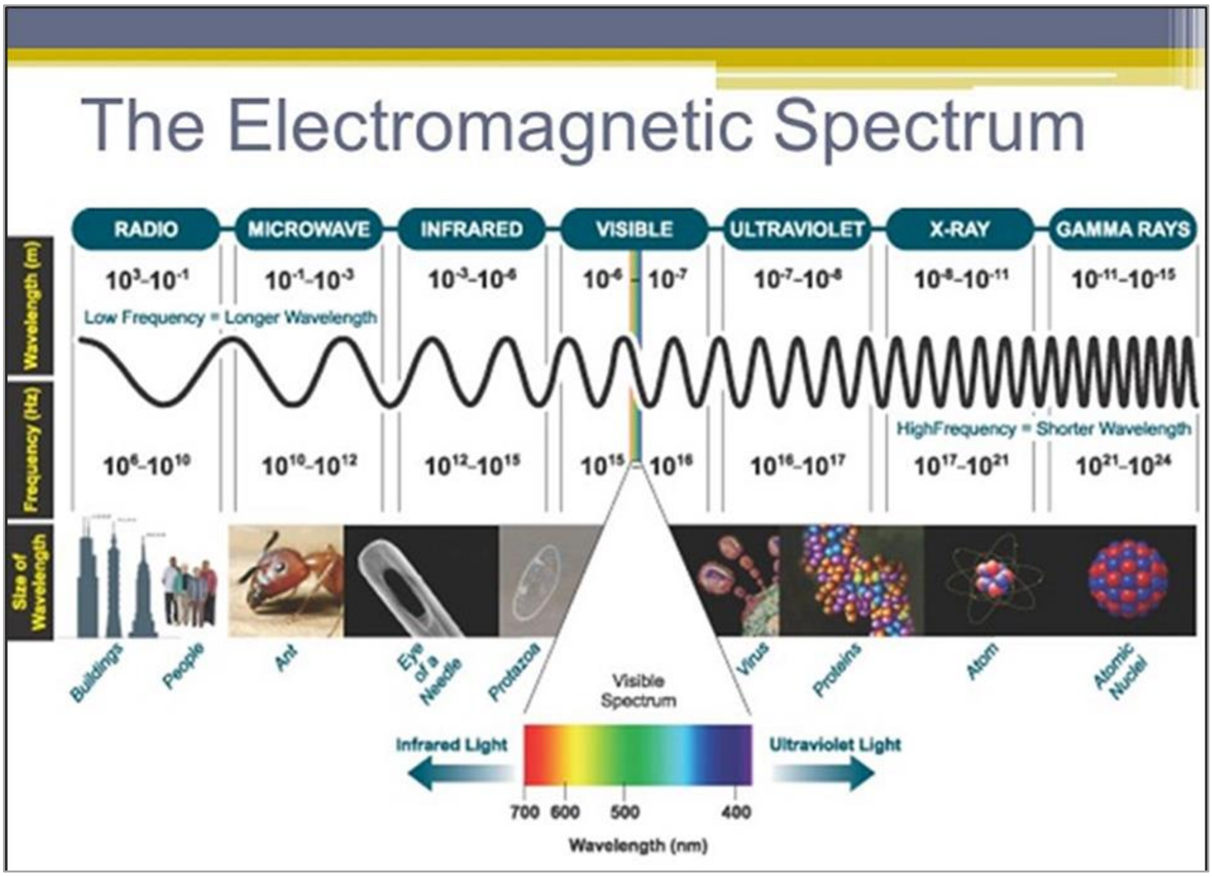
1. Microwaves – Introduction

Electromagnetic Spectrum consists of entire range of electromagnetic radiation. Radiation is the energy that travels and spreads out as it propagates. The types of electromagnetic radiation that makes the electromagnetic spectrum is depicted in the following screenshot.



Let us now take a look at the properties of Microwaves.

Properties of Microwaves

Following are the main properties of Microwaves.

- Microwaves are the waves that radiate electromagnetic energy with shorter wavelength.
- Microwaves are not reflected by Ionosphere.
- Microwaves travel in a straight line and are reflected by the conducting surfaces.
- Microwaves are easily attenuated within shorter distances.
- Microwave currents can flow through a thin layer of a cable.

Advantages of Microwaves

There are many advantages of Microwaves such as the following:

- Supports larger bandwidth and hence more information is transmitted. For this reason, microwaves are used for point-to-point communications.
- More antenna gain is possible.
- Higher data rates are transmitted as the bandwidth is more.
- Antenna size gets reduced, as the frequencies are higher.
- Low power consumption as the signals are of higher frequencies.
- Effect of fading gets reduced by using line of sight propagation.
- Provides effective reflection area in the radar systems.
- Satellite and terrestrial communications with high capacities are possible.
- Low-cost miniature microwave components can be developed.
- Effective spectrum usage with wide variety of applications in all available frequency ranges of operation.

Disadvantages of Microwaves

There are a few disadvantages of Microwaves such as the following:

- Cost of equipment or installation cost is high.
- They are hefty and occupy more space.
- Electromagnetic interference may occur.
- Variations in dielectric properties with temperatures may occur.
- Inherent inefficiency of electric power.

Applications of Microwaves

There are a wide variety of applications for Microwaves, which are not possible for other radiations. They are -

Wireless Communications

- For long distance telephone calls
- Bluetooth
- WIMAX operations

- Outdoor broadcasting transmissions
- Broadcast auxiliary services
- Remote pickup unit
- Studio/transmitter link
- Direct Broadcast Satellite (DBS)
- Personal Communication Systems (PCSs)
- Wireless Local Area Networks (WLANs)
- Cellular Video (CV) systems
- Automobile collision avoidance system

Electronics

- Fast jitter-free switches
- Phase shifters
- HF generation
- Tuning elements
- ECM/ECCM (Electronic Counter Measure) systems
- Spread spectrum systems

Commercial Uses

- Burglar alarms
- Garage door openers
- Police speed detectors
- Identification by non-contact methods
- Cell phones, pagers, wireless LANs
- Satellite television, XM radio
- Motion detectors
- Remote sensing

Navigation

- Global navigation satellite systems
- Global Positioning System (GPS)

Military and Radar

- Radars to detect the range and speed of the target.
- SONAR applications
- Air traffic control
- Weather forecasting

- Navigation of ships
- Minesweeping applications
- Speed limit enforcement
- Military uses microwave frequencies for communications and for the above mentioned applications.

Research Applications

- Atomic resonances
- Nuclear resonances

Radio Astronomy

- Mark cosmic microwave background radiation
- Detection of powerful waves in the universe
- Detection of many radiations in the universe and earth's atmosphere

Food Industry

- Microwave ovens used for reheating and cooking
- Food processing applications
- Pre-heating applications
- Pre-cooking
- Roasting food grains/beans
- Drying potato chips
- Moisture levelling
- Absorbing water molecules

Industrial Uses

- Vulcanizing rubber
- Analytical chemistry applications
- Drying and reaction processes
- Processing ceramics
- Polymer matrix
- Surface modification
- Chemical vapor processing
- Powder processing
- Sterilizing pharmaceuticals
- Chemical synthesis
- Waste remediation
- Power transmission

- Tunnel boring
- Breaking rock/concrete
- Breaking up coal seams
- Curing of cement
- RF Lighting
- Fusion reactors
- Active denial systems

Semiconductor Processing Techniques

- Reactive ion etching
- Chemical vapor deposition

Spectroscopy

- Electron Paramagnetic Resonance (EPR or ESR) Spectroscopy
- To know about unpaired electrons in chemicals
- To know the free radicals in materials
- Electron chemistry

Medical Applications

- Monitoring heartbeat
- Lung water detection
- Tumor detection
- Regional hyperthermia
- Therapeutic applications
- Local heating
- Angioplasty
- Microwave tomography
- Microwave Acoustic imaging

For any wave to propagate, there is the need of a medium. The transmission lines, which are of different types, are used for the propagation of Microwaves. Let us learn about them in the next chapter.

2. Microwaves – Transmission Lines

A **transmission line** is a connector which transmits energy from one point to another. The study of transmission line theory is helpful in the effective usage of power and equipment.

There are basically four types of transmission lines:

- Two-wire parallel transmission lines
- Coaxial lines
- Strip type substrate transmission lines
- Waveguides

While transmitting or while receiving, the energy transfer has to be done effectively, without the wastage of power. To achieve this, there are certain important parameters which has to be considered.

Main Parameters of a Transmission Line

The important parameters of a transmission line are resistance, inductance, capacitance and conductance.

Resistance and inductance together are called as transmission line **impedance**.

Capacitance and conductance together are called as **admittance**.

Resistance

The resistance offered by the material out of which the transmission lines are made, will be of considerable amount, especially for shorter lines. As the line current increases, the ohmic loss $(I^2R\ loss)$ also increases.

The resistance **R** of a conductor of length "**l**" and cross-section "**a**" is represented as

$$\boldsymbol{R = \rho \frac{l}{a}}$$

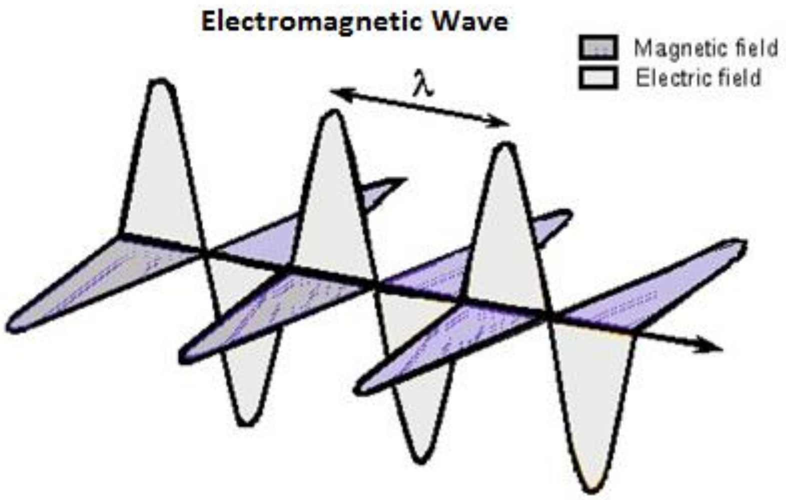
Where
ρ = resistivity of the conductor material, which is constant.

Temperature and the frequency of the current are the main factors that affect the resistance of a line. The resistance of a conductor varies linearly with the change in temperature. Whereas, if the frequency of the current increases, the current density towards the surface of the conductor also increases. Otherwise, the current density towards the center of the conductor increases.

This means, more the current flows towards the surface of the conductor, it flows less towards the center, which is known as the **Skin Effect**.

Inductance

In an AC transmission line, the current flows sinusoidally. This current induces a magnetic field perpendicular to the electric field, which also varies sinusoidally. This is well known as Faraday’s law. The fields are depicted in the following figure.



This varying magnetic field induces some EMF into the conductor. Now this induced voltage or EMF flows in the opposite direction to the current flowing initially. This EMF flowing in the opposite direction is equivalently shown by a parameter known as **Inductance**, which is the property to oppose the shift in the current.

It is denoted by “**L**”. The unit of measurement is “**Henry (H)**”.

Conductance

There will be a leakage current between the transmission line and the ground, and also between the phase conductors. This small amount of leakage current generally flows through the surface of the insulator. Inverse of this leakage current is termed as **Conductance**. It is denoted by “**G”**.

The flow of line current is associated with inductance and the voltage difference between the two points is associated with capacitance. Inductance is associated with the magnetic field, while capacitance is associated with the electric field.

Capacitance

The voltage difference between the **Phase conductors** gives rise to an electric field between the conductors. The two conductors are just like parallel plates and the air in between them becomes dielectric. This pattern gives rise to the capacitance effect between the conductors.

Characteristic Impedance

If a uniform lossless transmission line is considered, for a wave travelling in one direction, the ratio of the amplitudes of voltage and current along that line, which has no reflections, is called as **Characteristic impedance**.

It is denoted by Z_0

$$Z_0 = \sqrt{\frac{voltage\ wave\ value}{current\ wave\ value}}$$

$$Z_0 = \sqrt{\frac{R + jwL}{G + jwC}}$$

For a lossless line, $R_0 = \sqrt{\frac{L}{C}}$

Where **L** & **C** are the inductance and capacitance per unit lengths.

Impedance Matching

To achieve maximum power transfer to the load, impedance matching has to be done. To achieve this impedance matching, the following conditions are to be met.

The resistance of the load should be equal to that of the source.

$$R_L = R_S$$

The reactance of the load should be equal to that of the source but opposite in sign.

$$X_L = -X_S$$

Which means, if the source is inductive, the load should be capacitive and vice versa.

Reflection Co-efficient

The parameter that expresses the amount of reflected energy due to impedance mismatch in a transmission line is called as **Reflection coefficient**. It is indicated by **ρ (rho)**.

It can be defined as "the ratio of reflected voltage to the incident voltage at the load terminals".

$$\rho = \frac{reflected\ voltage}{incident\ voltage} = \frac{V_r}{V_i}\ at\ load\ terminals$$

If the impedance between the device and the transmission line don't match with each other, then the energy gets reflected. The higher the energy gets reflected, the greater will be the value of **ρ** reflection coefficient.

Voltage Standing Wave Ratio (VSWR)

The standing wave is formed when the incident wave gets reflected. The standing wave which is formed, contains some voltage. The magnitude of standing waves can be measured in terms of standing wave ratios.

The ratio of maximum voltage to the minimum voltage in a standing wave can be defined as Voltage Standing Wave Ratio (VSWR). It is denoted by "**S**".

$$S = \frac{|V_{max}|}{|V_{min}|} \qquad 1 \leq S \leq \infty$$

VSWR describes the voltage standing wave pattern that is present in the transmission line due to phase addition and subtraction of the incident and reflected waves.

Hence, it can also be written as

$$S = \frac{1 + \rho}{1 - \rho}$$

The larger the impedance mismatch, the higher will be the amplitude of the standing wave. Therefore, if the impedance is matched perfectly,

$$V_{max} : V_{min} = 1:1$$

Hence, the value for VSWR is unity, which means the transmission is perfect.

Efficiency of Transmission Lines

The efficiency of transmission lines is defined as the ratio of the output power to the input power.

$$\% \, \boldsymbol{efficiency\ of\ transmission\ line\ \eta} = \frac{\boldsymbol{Power\ delievered\ at\ reception\ end}}{\boldsymbol{Power\ sent\ from\ the\ transmission\ end}} \times \mathbf{100}$$

Voltage Regulation

Voltage regulation is defined as the change in the magnitude of the voltage between the sending and receiving ends of the transmission line.

$$\% \boldsymbol{voltage\ \ regulation} = \frac{\boldsymbol{sending\ end\ voltage - receiving\ end\ voltage}}{\boldsymbol{sending\ end\ voltage}} \times \mathbf{100}$$

Losses due to Impedance Mismatch

The transmission line, if not terminated with a matched load, occurs in losses. These losses are many types such as attenuation loss, reflection loss, transmission loss, return loss, insertion loss, etc.

Attenuation Loss

The loss that occurs due to the absorption of the signal in the transmission line is termed as Attenuation loss, which is represented as

$$Attenuation\ loss\ (dB) = 10\ log_{10}\left[\frac{E_i - E_r}{E_t}\right]$$

Where

- E_i = the input energy
- E_r = the reflected energy from the load to the input
- E_t = the transmitted energy to the load

Reflection Loss

The loss that occurs due to the reflection of the signal due to impedance mismatch of the transmission line is termed as Reflection loss, which is represented as

$$Reflection\ loss\ (dB) = 10\log_{10}\left[\frac{E_i}{E_i - E_r}\right]$$

Where

- E_i = the input energy
- E_r = the reflected energy from the load

Transmission Loss

The loss that occurs while transmission through the transmission line is termed as Transmission loss, which is represented as

$$Transmission\ loss\ (dB) = 10\log_{10}\frac{E_i}{E_t}$$

Where

- E_i = the input energy
- E_t = the transmitted energy

Return Loss

The measure of the power reflected by the transmission line is termed as Return loss, which is represented as

$$Return\ loss\ (dB) = 10\log_{10}\frac{E_i}{E_r}$$

Where

- E_i = the input energy
- E_r = the reflected energy

Insertion Loss

The loss that occurs due to the energy transfer using a transmission line compared to energy transfer without a transmission line is termed as Insertion loss, which is represented as

$$Insertion\ loss\ (dB) = 10\log_{10}\frac{E_1}{E_2}$$

Where

- E_1 = the energy received by the load when directly connected to the source, without a transmission line.

- E_2 = the energy received by the load when the transmission line is connected between the load and the source.

Stub Matching

If the load impedance mismatches the source impedance, a method called "Stub Matching" is sometimes used to achieve matching.

The process of connecting the sections of open or short circuit lines called **stubs** in the shunt with the main line at some point or points, can be termed as **Stub Matching**.

At higher microwave frequencies, basically two stub matching techniques are employed.

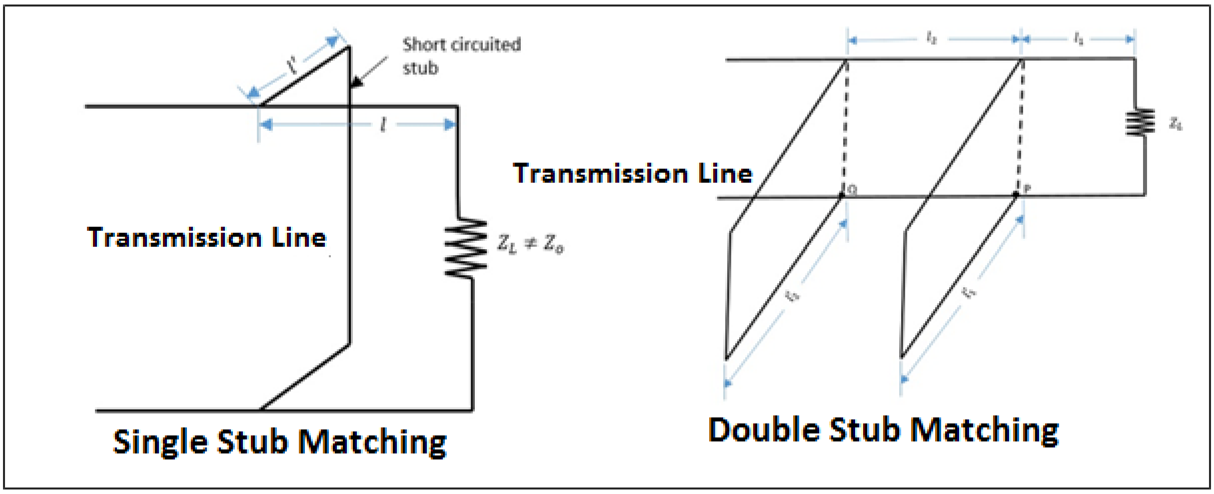
Single Stub Matching

In Single stub matching, a stub of certain fixed length is placed at some distance from the load. It is used only for a fixed frequency, because for any change in frequency, the location of the stub has to be changed, which is not done. This method is not suitable for coaxial lines.

Double Stub Matching

In double stud matching, two stubs of variable length are fixed at certain positions. As the load changes, only the lengths of the stubs are adjusted to achieve matching. This is widely used in laboratory practice as a single frequency matching device.

The following figures show how the stub matchings look.



The single stub matching and double stub matching, as shown in the above figures, are done in the transmission lines to achieve impedance matching.