SAMPLE STUDY MATERIAL

Electronics Engineering

EC / E & T

Postal Correspondence Course

PSUs

Microwave & RADAR Engineering

ENGINEERS INSTITUTE OF INDIA
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CONTENT

CHAPTER-1

INTRODUCTION TO MICROWAVE ENGINEERING

Microwaves are part of the electromagnetic spectrum of light corresponding to frequencies between 300 MHz and 300 GHz or wavelengths between 1 mm and 1 m.

- Microwave signals propagate in straight lines and are affected very little by the troposphere.
- They are not reflected or reflected by **Ionosphere.**
- Some attenuation occurs when microwave energy passes through trees & frame houses. Radio-frequency (RF) energy at longer wavelengths is affected to a lesser degree by such obstacles.
- Microwave can't be used for ground wave communication as for microwaves frequencies $\frac{\sigma}{\omega\varepsilon} << 1$, so ground behaves as dielectric. So can't reflect em waves at microwave frequencies.

The shortest wavelengths (highest frequencies) of the radio spectrum are in the microwave region but the boundaries are not well defined.

Class (Frequency band)	Frequency Range	Wavelength Range
Very Low Frequency	10-30 KHz	30,000-10,000m
Low Frequency	30-300 KHz	10,000-1000m
Medium Frequency	300-3000 KHZ	1000-100m
High Frequency	3-30 MHz	100-10m
Very High Frequency	30-300 MHz	10-1m
Ultra High Frequency	300-3000 MHz	100-10 cm
Super High Frequency	3-30 GHz	10-1 cm
Extremely High Frequency	30 – 300 GHz	10 – 1 mm

At low frequencies, we consider in terms of lumped circuit elements such as C-Capacitors, L-Inductors & R-Resistors. In fact in microwave circuitry, The resistance, inductance and the capacitance. are assumed to be distributed along the transmission line. So it becomes very difficult to point out a specific circuit element.

In Microwave components the phase of a voltage and current changes significantly over the physical extent of the device, because the device dimensions are on the order of the microwave wavelength.

Relationship between the frequency (*f*) and wavelength (ª) of electromagnetic (EM) waves :

The product of f and λ gives the velocity of electromagnetic energy and it is also called the velocity of light.

It can be expressed as: $c = f$ ª

Where c = velocity of light (approx. 3×10^{10} cm/sec or 1.18×10^{10} inch/sec or 983.98 feet/micro second)

The value of c is the velocity of light or electromagnetic waves in vacuum and same values in air as well.

In a dielectric medium like Polystyrene, Teflon or even in water the electromagnetic waves are slowed down and are inversely proportional to square root of the dielectric constant.

As we know the product of frequency and wavelength must equal the velocity, hence the wavelength in a dielectric (for a given frequency) will also be reduced by the square root of the dielectric constant.

$$\lambda_d = \frac{\lambda_o}{\sqrt{\varepsilon_r}}$$

Where f_d, f_o = Wavelength in dielectric medium / free space.

£$_r$ = Relative dielectric constant of the medium.

The frequency, f_d is considered equal to f_o.

The microwave spectrum starting from 300 MHz is sub-divided into various bands namely L, S, C, X etc.

Band	Frequency Range
UHF	0.3 — 1 GHz
L	1 – 2 GHz
S	2 – 4 GHz
C	4 – 8 GHz
X	8 – 12 GHz
KU	12 – 18 GHz
K	18 – 27 GHz
Ka	27 – 40 GHz

Below characteristics make wide application of microwaves:

(a) **Band-Width:** : At microwave frequencies more bandwidth can be realized as 1% of 100 MHz is 1 MHz and at 100 GHz 1% is 1 GHz.

(b) **High Directivity:** At microwave frequencies, size of dipole is very small hence we may have an aerial array for high directivity. At microwave frequencies, directivity could be increased by using a reflector at focal plane.

(c) **Reliability is high:** As the concentration of F and E layer ionosphere vary widely with time and weather and these layers transfer the energy by reflection to shortwave communication. The energy received by receiver is not of uniform strength this gives rise to *Fading Effect*. In microwave frequencies, fading is less because the propagation of energy from transmitter to receiver takes place by line of sight propagation. The reception becomes clearer as the frequency increases in microwave ranges. It works even in foggy weather.

(d) **Power requirements are low:** At microwave frequencies the power requirement becomes very small for the transmitter & receiver. The transmitter & receiver use the same technique as in shortwaves (medium waves) frequencies but the components used are different. Microwave energy has a heating effect and The heating effect is used for various purpose like microwave ovens for cooking.microwave diathermy therapy, microwave drying machines

What are Radio Waves?

Electromagnetic radiation is a wave that combines electric and magnetic fields, moving out from its source as an expanding sphere and having waves as the fields alternate in value. Its formal name is Transverse Electro Magnetic wave, or TEM. This kind of radiation has different utility as its wavelength changes.

Waves of a very long wavelength, such as thousands of meters, tend to travel along the surface of the earth and even penetrate into the water. These are useful for communication with submarines, and for broadcasting time signals. Broadcast radio, short-wave radio, television, cellular telephones, walky-talkies, 2-way police radios, satellite television, and other such communication/broadcast systems all use electromagnetic radiation, or "Radio Frequency Waves". Each communication service uses a part of the spectrum that is suitable for its needs.

Why use microwaves?

Beside the use of microwave in television broadcast services via satellite, radar systems electronic warfare, they also have a large range of consumer, industrial, biomedical, chemical and scientific research applications such as radio astronomy, specters copy and material research which led to the development of semiconductor devices for example. Masers, lasers, Gunn diodes etc.

Among these discoveries were that microwaves are easier to control (than longer wavelengths) because small antennas could direct the waves very well. One advantage of such control is that the energy could be easily confined to a tight beam (expressed as narrow beamwidth). This beam could be focused on another antenna dozens of miles away, making it very difficult for someone to intercept the conversation. Another characteristic is that because of their high frequency, greater amounts of information could be put on them (expressed as increased modulation bandwidth). Both of these advantages (narow beamwidth and modulation bandwidth) make microwaves very useful for RADAR as well as communications.

Application of microwaves communication and navigation are due to line of sight propagation through ionosphere with negligible absorption and reflection from metallic surfaces, larger bandwidth and high antenna directivity gain.

CHAPTER-2

WAVE GUIDES

INTRODUCTION

Generally a hollow metallic tube of a rectangular or circular shape used to guide an electromagnetic wave is known as wave guide. At frequencies higher than 1 GHz, transmission of electro magnetic wave along lines and cables become difficult mainly because of high dielectric and conductor losses in them. Here waveguide comes in use. The size of the waveguide becomes very large at low frequencies, hence waveguides are used principally in microwave range.

As the waves are confined with in hollow tube, there is no loss due to radiation and even dielectric loss is negligible.

However there is some power loss as heat in the walls of the guides, but the loss is very small solutions of Maxwell's equations for a particular waveguide give modes which can propagate through that waveguide.

Difference between wave guides and transmission line :

If the wavelength of the waves is less than some critical value determined by the dimension and the geometry of the guide :

A particular mode propagates down a wave guide with low attenuation.

If the wavelength corresponding to the operating frequency is greater than this critical cut-off value: *The waves in the wave guides die out rapidly in amplitude even if walls of the guide have infinite conductivity.*

Note :

⇒ *Different modes have different cut off wavelengths.*

⇒ *Dominant Mode*: *The particular mode for which the cut off wavelength is the greatest.*

Basics of Waveguides

Waveguides have several advantages over two-wire and coaxial transmission lines. For example, the large surface area of waveguides greatly reduces copper (I^2R) losses. Two-wire transmission lines have large copper losses because they have a relatively small surface area. The surface area of the outer conductor of a coaxial cable is large, but the surface area of the inner conductor is relatively small. At microwave frequencies, the current-carrying area of the inner conductor is restricted to a very small layer at the surface of the conductor by an action called ***skin effect***.

Skin effect tends to increase the effective resistance of the conductor.

Waveguides are the most efficient way to transfer electromagnetic energy. Waveguides are essentially coaxial lines without center conductors. They are constructed from conductive material and may be rectangular, circular, or elliptical in shape.

A waveguide is forming by adding quarter-wave sections shorted at one end on each side of a two-wire line. The lines become part of the walls of the waveguide, as explained in the following figure. *The energy is then conducted within the hollow waveguide instead of along the two-wire transmission line.*

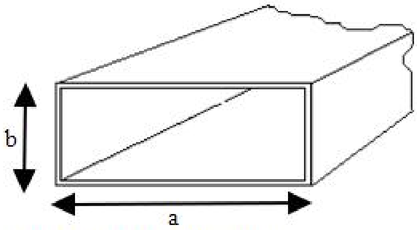


Figure 1: rectangular waveguide

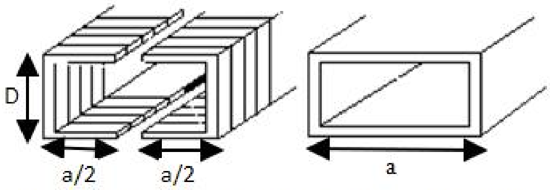


Figure 2: forming a waveguide by adding quarter-wave sections

The widest dimension of a waveguide is called the "a" dimension and determines the range of operating frequencies.

The narrowest dimension determines the power-handling capability of the waveguide and is called the "b" dimension.

The cut-off wavelength of a rectangular waveguide can be calculated by:

$$a_{cut-off} = \frac{2 \cdot a}{m}$$

λ cut-off = cut-off wavelength [m]

a = the widest dimension of the waveguides cross section

Types of RF waveguide

There are a number of different types of RF waveguide that can be used and designed.

• Rectangular waveguide: This is the most commonly used form of waveguide and has a rectangular cross section.

• Circular waveguide: Circular waveguide is less common than rectangular waveguide. They have many similarities in their basic approach, although signals often use a different mode of propagation.

• Circuit board stripline: This form of waveguide is used on printed circuit boards as a transmission line for microwave signals. It typically consists of a line of a given thickness above an earth plane. Its thickness defines the impedance.

• Flexible waveguide is often used to connect to antennas, etc that may not be fixed or may be moveable.

Waveguide theory of propagation

According to waveguide theory there are a number of different types of electromagnetic wave that can propagate within the waveguide. These different types of waves correspond to the different elements within an electromagnetic wave.

- TE waves: Transverse electric waves, also sometimes called H waves, are characterised by the fact that the electric vector (E) is always perpendicular to the direction of propagation.
- TM waves: Transverse magnetic waves, also called E waves are characterised by the fact that the magnetic vector (H vector) is always perpendicular to the direction of propagation.
- TEM waves: The Transverse electromagnetic wave is cannot be propagated within a waveguide, but is included for completeness. It is the mode that is commonly used within coaxial and open

wire feeders. The TEM wave is characterised by the fact that both the electric vector (E vector) and the magnetic vector (H vector) are perpendicular to the direction of propagation.

Text about waveguide theory often refers to the TE and TM waves: $TE_{m,n}$ $TM_{m,n}$. The numerals m and n are alw that can take on separate values from 0 or 1 to infinity. *These indicate the wave modes within the waveguide.*

A limited number of different m, n modes can be propagated along a waveguide dependent upon the waveguide dimensions.

Cut-off frequency: For each mode there is a definite lowest frequency limit known as the cut-off frequency. Below this frequency no signals can propagate along the waveguide. As a result the waveguide can be seen as a high pass filter.

It is possible for many modes to propagate along a waveguide. The number of possible modes for a given size of waveguide increases with the frequency. It is also worth noting that there is only one possible mode, called the dominant mode for the lowest frequency that can be transmitted. It is the dominant mode in the waveguide that is normally used.

Waveguide theory rules of thumb

There are a number of rules of thumb and common points that may be used when dealing with waveguides.

- For rectangular waveguides, the TE10 mode of propagation is the lowest mode that is supported.
- For rectangular waveguides, the waveguide width, i.e. the widest internal dimension of the cross section, determines the lowest cut-off frequency and is equal to 1/2 wavelength of the lowest cut-off frequency.
- For rectangular waveguides, the TE01 mode occurs when the height equals $\frac{1}{2}$ wavelength of the lowest cut-off frequency.
- For rectangular waveguides, the TE20, occurs when the width equals one wavelength of the lowest cut-off frequency.

PHASE VELOCITY AND GROUP VELOCITY IN WAVE GUIDE

Phase velocity is the velocity with which electromagnetic wave changes phase.

In free space this velocity is equal to the velocity of light.

Group velocity is the velocity of the wave in a direction parallel to the conducting surface and is given by

$$\nu_g = \nu_c \sin\theta$$

where ν_c is velocity of light.

Phase velocity is equal to $\nu_c / \sin\theta$.

$$\nu_g \nu_p = \nu_c \sin\theta . \frac{\nu_c}{\sin\theta} = \nu_c^2$$

- *The product of the group and the phase velocity is the square of the velocity of light .*

- *In free space phase velocity and group velocity are equal.*

If λ_c is the cut off wavelength (the smallest free space wavelength that is just unable to propagate in the wave guide under given conditions) and λ is wavelength corresponding to operating frequency f then

$$\nu_p = f\lambda_g \qquad [\because \lambda_g = \text{guide wave length}]$$

$$= f\frac{\lambda}{\sqrt{\left(1-\frac{\lambda}{\lambda_c}\right)^2}} = \frac{\nu_c}{\sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2}}$$

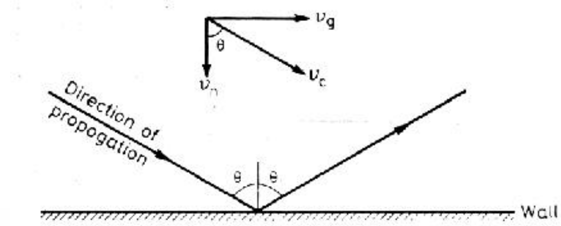


Fig. 4.1 Group velocity in a wave guide (conducting surface)

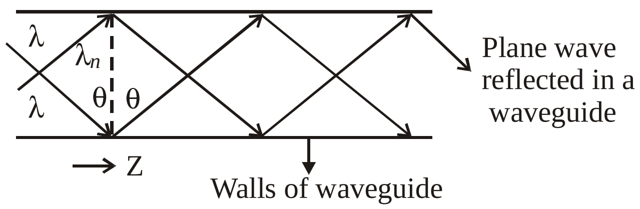
Group velocity is given by

$$\nu_g = \frac{\nu_c^2}{\nu_p} = \nu_c^2\frac{1}{\nu_p} = \frac{\nu_c^2\sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2}}{\nu_c} = \nu_c\sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2}$$

It states that the group velocity in wave guide is less that that in free space.

Rectangular Waveguide

It is one of the earliest type of transmission lines used to transport microwave signals and is still used today for many applications. A rectangular waveguide is a hollow metallic tube with a rectangular cross section. The conducting walls of the guide confine the electromagnetic fields and there by guide electromagnetic wave. A number of distinct field configurations or modes can exist in waveguides. When the waves travel longitudinally down the guide the plane waves are reflected from wall to wall.



So a component of either electric or magnetic field exists in the direction of propagation of resultant wave. Hence no TEM mode exists in this above figure shows that a loss less guide may be resolved into TE and TM waves.

In rectangular wave guide the modes are designated TE_{mn} or TM_{mn}

The integer m, n denotes the number of half waves of electric or magnetic field in x and y direction respectively.

Parameters in Rectangular waveguide

1. Cut off wave number

$$K_C = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} = W_C\sqrt{\mu\varepsilon}$$

(a, b in meters (a) longer side (b) shorter side)

2. Cut off wave length

$$\lambda_C = \frac{1}{\sqrt{\left(\frac{m}{2a}\right)^2 + \left(\frac{n}{2b}\right)^2}}$$

3. Cut off frequency is f_C

$$f_C = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

4. The propagation constant

$$\beta = \pm\,\omega\sqrt{\mu\varepsilon}\sqrt{1-\left(\frac{f_C}{f}\right)^2}$$

5. The phase velocity

$$V_p = \frac{W}{\beta} = \frac{c}{\sqrt{1-\left(\frac{f_C}{f}\right)^2}}$$

where c is free space velocity equals $c = \frac{1}{\sqrt{\mu_o\,\varepsilon}}$

V_p is always greater than c as

$\sqrt{1-\left(\frac{f_C}{f}\right)^2}$ is always less than 1

The wave angle of reflection or tilt angle θ off the walls of the guide is

$$\sin\theta = \sqrt{1-\left(\frac{f_C}{f}\right)^2}$$

6. Wavelength of waveguide λ_g is

$$\frac{1}{\lambda_g^2} = \frac{1}{\lambda_o^2} + \frac{1}{\lambda_C^2}$$

$$\lambda_g = \frac{\lambda_o}{\sqrt{1 - \left(\frac{\lambda}{\lambda_C}\right)^2}}$$

λ_o is free space wavelength
λ_C cut off wavelength

λ_g waveguide wavelength

7. Wave impedance of TE_{mn} modes is

$$Z_{TE} = \frac{\eta}{\sqrt{1 - \left(\frac{f_C}{f}\right)^2}}$$

For TM_{mn} **mode**

$$Z_{TM} = \eta\sqrt{1 - \left(\frac{f_C}{f}\right)^2}$$

η **is intrinsic impedance**

Whenever two or more modes have the same cutoff frequency they are said to be degenerate modes. In rectangular waveguide the corresponding TE_{mn} and TM_{mn} modes are always degenerate.

The mode with the lowest cut off frequency in a particular guide is called dominant mode.

The dominant mode in a rectangular guide with *a* > *b* is the TE_{10} mode. And is TE_{01} when *a* < *b*.