GATE / PSUs

ELECTRONICS ENGINEERING-ECE

STUDY MATERIAL

MICROWAVE & RADAR ENGINEERING

ENGINEERS INSTITUTE OF INDIA

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CONTENT

CHAPTER-1

INTRODUCTION TO MICROWAVE ENGINEERING

What is Microwave:

Microwaves are part of the EM spectrum having frequencies between 300 MHz and 300 GHz or wavelengths between 1 mm to 1 m. They are lies between radio waves and IR regions in EM spectrum.

They are used in applications like: Transmitting TV programs, Voice data, facsimile signals, cellular phones, weather forecasts, GPS signals, Air to Air communication, ground to ground communication etc.

Electromagnetic (EM) Spectrum:

The EM spectrum is the range of all possible frequencies of electromagnetic radiations. Its starts from radio communication to Gamma radiation.

Figure 1.1 shows the location of the RF and microwave frequency bands in the EM spectrum.

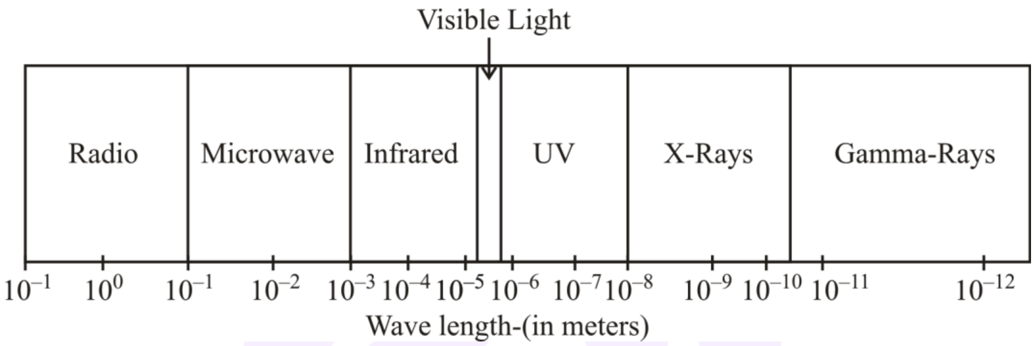

Figure 1.1 EM Spectrum

Approximate Band Designations

Medium frequency	300 kHz – 3 MHz
High frequency (HF)	3 MHz – 30 MHz
Very high frequency (VHF)	30 MHz – 300 MHz
Ultra high frequency (UHF)	300 MHz – 3 GHz
L band	1 – 2 GHz
S band	2 – 4 GHz
C band	4 – 8 GHz
X band	8 – 12 GHz
Ku band	12 – 18 GHz
K band	18 – 26 GHz
Ka band	26 – 40 GHz

Properties of Microwaves

1. Microwaves are propagate in straight lines and very less affected by Troposphere layer.
2. Not reflected or refracted by Ionosphere layer.
3. Some attenuation occurs when microwave energy passes through trees and frame houses.
4. Microwave can't be used for ground wave communication as for microwaves frequencies $\left(\frac{\sigma}{\omega\varepsilon}\right) << 1$, so ground behaves as dielectric. So can't reflect EM waves at microwave frequencies.

Characteristics of Microwaves

1. Large Band-width: The microwave is large bandwidth. More bandwidth means more information carrying capacity. For example, a 1% of 100 MHz is 1 MHz and at 100 GHz 1% is 1 GHz.
2. 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.
3. Microwave travel by line at sight (LOS): Microwave follow the line of sight communication philosophy. It means that the both transmitting and receiving microwaves antennas must face each other without and physical obstruction for effective and reliable communication.
4. Reliability is high: As the concentration of F and E layers Ionosphere vary with time and weather and these layers transfer the energy by reflection to short wave 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 receives tares place by line of sight propagation. The reception becomes clears as the frequency increases in microwave ranges. It works even in foggy weather and nuclear resonance occur at radio and microwave frequencies.
1. Used in Medical application for the treatment of cancer patients
2. Used in Heating applications like microwave oven etc.

Microwave Propagation:

Microwave propagation obeys the straight line in free space. In free space it does not suffer from any attenuation or losses due to the fact that the free space has ideal values of permittivity and permeability. The microwave signals are affected by phenomena like ducting, Reflection, Refraction, Diffraction, Polarization, Absorption and Attenuation.
1. Atmospheric Effects: In atmosphere, Microwaves experience reflection, refraction and diffraction like light.
2. Effect of Permittivity: In microwave permittivity decreases as altitude increase and there is a drop in air pressure and humidity with increase in altitude.
3. Effect of Temperature and Ducting: Microwave can travel long distance parallel to the Earth's surface via the duct created by the layer of air along the temperature inversion.
4. Effect of Attenuation:
The attenuation is mainly caused by absorption. Absorption is the process by which some part of microwave energy is retained by the atmosphere. Maximum absorption occurs when the frequency of microwave energy coincides with molecular resonance of water vapour of oxygen.
5. Power Requirements are low: At microwave frequencies the power requirement becomes very small for the transmitter and receiver.

Advantages of Microwaves:
1. Microwave provide proper wireless communication. There is no need for laying any cables to establish communication links.
2. It has wider bandwidth
3. Low cost miniaturized microwave components
4. It provides very reliable and high quality signals.

Disadvantages of Microwaves
1. Easily reflected from flat and metal surfaces.
2. Microwave signals suffer from attenuation due to atmospheric disturbances like rain, fog, snow etc.

Application of Microwaves
1. Used in Military applications of radar live missile tracking and fire control.
2. Used for civilian applications like deployed for air traffic control and aircraft landing systems.
3. Used in applied research to study the behaviour of matter as various molecular.

Microwave Systems

A microwave system normally consist of a transmitter subsystems, including a microwave oscillator, waveguides, and a transmitting antenna, and a receiver sub system that includes a receiving antenna, transmission line or waveguide, a microwave amplifier and a receiver. Figure 1.2 shows a typical microwave systems.

In order to design a microwave system and conduct a proper test of it, an adequate knowledge of the components involved is essential.

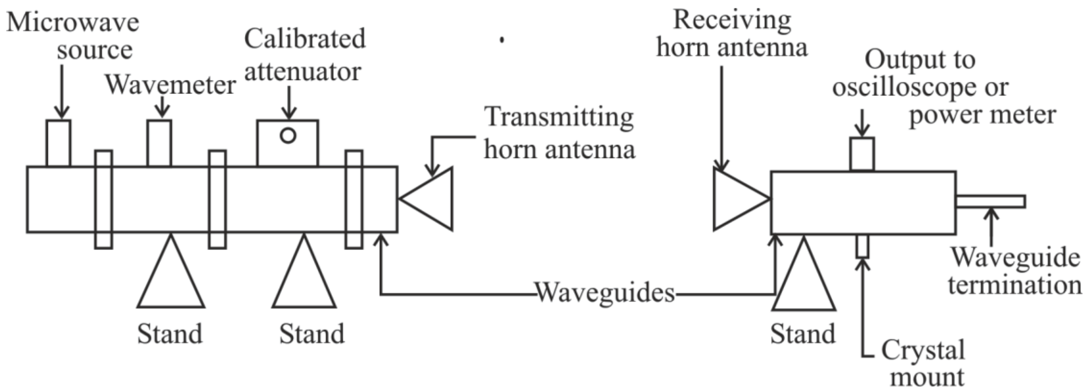

Figure 1.2 Microwave System

Relationship between the frequency (*f*) and wavelength (λ) of 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:

$$C = f\lambda \qquad \text{or} \qquad f = \frac{C}{\lambda} \qquad \ldots(1.1)$$

$$C = \frac{1}{\sqrt{\mu_o \varepsilon_o}} = 3\times10^8 \text{ m/s} \qquad \ldots(1.2)$$

Where, μ_o = Permeability of free space = $4\pi\times10^{-7}$ H/m

ε_o = Permittivity of free space = 8.85×10^{-12} F/m

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

Solved Examples based on Relationship between *f*, λ and C

1. What is the speed of light in vaccum?

(*a*) 3×10^{10} m/s (*b*) 3×10^{20} m/s
(*c*) 3×10^{8} m/s (*d*) None of these

Sol. (c)

2. Calculate the wavelength of a half wave dipole antenna receive a 10 MHz radio signal. Assume that the velocity of EM waves on antenna is 3×10^8 m/s.

(*a*) 20 meters (*b*) 10 meters
(*c*) 30 meters (*d*) 40 meters

Sol. (c) $f = \frac{C}{\lambda}$

$\therefore$ $\lambda = \frac{C}{f} = \frac{3\times10^8}{10\times10^6} = 30$ meters

3. Determine the intended frequency of operation of a dipole antenna cut to a length of 3.5 m. Assume a velocity of 3×10^8 m/s for EM waves on the antenna.

(*a*) 85.00 MHz (*b*) 105 MHz (*c*) 42.857 MHz (*d*) 40.857 MHz

Sol. (c)

We have given, Length of half wave dipole $\left(\frac{\lambda}{2}\right) = 3.5$ meters

$\therefore$ $f = \frac{C}{\lambda}$ Hz but $\frac{\lambda}{2} = 3.5$ meters or $\lambda = 2\times3.5 = 7$ m

Hence, $f = \frac{C}{\lambda} = \frac{3\times10^8}{7}\text{ Hz} = 42.857\times10^6\text{ Hz}$

$$\boxed{f = 42.857\text{ MHz}}$$

Table 1.1 Tabulates all the radio bands with frequency range and their major applications.

Designation as per (IRCC) Band	Frequency Range	Wavelength Range	Applications
VLF: Very low frequency	0 – 30 kHz	Infinity to 10^4 m	Radio navigation services SONAR so NAR Geophysics.
LF : Low frequency	30 – 300 kHz	10^4 to 10^3 m	Radio be cons, AM, Long wave Broadcasting.
MF: Medium Frequency	300 kHz – 300 MHz	10^3 to 10^2 m	AM Broad casting, coast guard communication.
HF: High Frequency	3 – 30 MHz	100 to 10 m	Telephone, Telegraph, Facsimile, Radio Frequency Identification (RFID)
VHF: Very High Frequency	30 – 300 MHz	10 to 1 m	Ground to Air communication, Air to Air communication, TV, FM broad cast.
UHF: Ultra High Frequency	300 MHz – 3 GHz	1 to 0.1 m	TV broad cost, Microwave oven, Microwave device, LAN, blue tooth, GPS, Zigbee.
SHF: Super High Frequency	3 – 30 GHz	10 to 1 cm	Satellite communication, All modern air borne radars.
EHF: Extremely High Frequency	30 – 300 GHz	10 to 1 mm	Millimeter radars, Remote sensing
Sub millimeter	300 – 300 GHz	1 to 0.1 mm	Terahertz imaging, Night vision

Table 1.1 ITU Band

Solved Example based on EM Spectrum

1. Match the following EM spectrum according to their applications

	A	B
A.	VLF	**1.** AM Broadcasting
B.	UHF	**2.** SONAR
C.	VHF	**3.** FM Broadcasting
D.	MF	**4.** Microwave oven

Codes:

	A	B	C	D
(*a*)	1	2	3	4
(*b*)	2	4	1	3
(*c*)	3	4	1	2
(*d*)	4	1	2	3

Sol. **(b)**
See table 1.1

2. Microwaves are lies between

(*a*) Radio and UV rays (*b*) Radio and IR rays
(*c*) Radio and Gamma rays (*d*) Radio and X-rays

Sol. **(b)**
See Figure 1.1

3. What is the frequency range of Ku band?

(*a*) 1 – 2 GHz (*b*) 2 – 4 GHz
(*c*) 12 – 18 GHz (*d*) 18 – 26 GHz

Sol. **(c)**

Band	L	→	S	→	C	→	X	→	Ku	→	K	→	Ka
Frequency Range	(1-2GHz)		(2-4GHz)		(4-8GHz)		(8-12GHz)		(12-18GHz)		(18-26GHz)		(26-40GHz)

4. (2 – 4 GHz) is the frequency range of which Band?

(*a*) L band (*b*) X band (*c*) Ka band (*d*) S band

Sol. **(d)**

5. What is the wavelength range of microwave?

(*a*) 1 mm to 1 cm (*b*) 1 mm to 1 m

(*c*) 1 m to 1 cm (*d*) None of these

Sol. **(b)**

Summary:

Microwaves are Radio waves having frequency range of 300 MHz to 300 GHz

- Microwaves are used for Military, Civil, Industrial, Commercial and applied Research purposes etc.
- Microwaves are also used for many commercial application like cooking, treating cancer patients
- The EM spectrum is the largest envelop which comprises of radio and optical spectrum. Radio spectrum covers radio waves, micro waves and terahertz radiations where optical spectrum covers infrared, visible, X-rays, gamma and cosmic rays.
- The Microwave energy is severely affected by phenomena like ducting, Reflection, Refraction, Diffraction, Polarization, absorption etc.
- Temperature inversion is a phenomenon where the temperature increases with variation in altitude. It is produced by variation in local weather condition.
- Plasma state is also known as fourth state.
- Microwave propagation through a plasma region is only possible when

  $\omega > \omega_p$, where $\omega = 2\pi f$, f is frequency of propagation
- Microwave systems consists of Microwave source, wavemeter, calibrated attenuator, Transmitting horn antenna, Receiving Antenna, waveguides.

1. Match the following EM spectrum of light according to decreasing wavelength

List-I	**List-II**
A. Long wave radio	**1.** 10^3 meters
B. Microwaves	**2.** $1-10^{-3}$ meters
C. FM broadcast radio	**3.** 1 mm to 1 meter
D. Visible light	**4.** 10^{-6} meters

Codes:

	A	**B**	**C**	**D**
(*a*)	1	2	3	4
(*b*)	1	3	4	3
(*c*)	4	3	2	1
(*d*)	1	3	2	4

Sol. **See EM spectrum in Figure 1.1**

2. Match the following approximate band designations

List-I	**List-II**
A. Ka band	**1.** 26 – 40 GHz
B. K band	**2.** 2 – 4 GHz
C. S band	**3.** 8 – 12 GHz
D. X band	**4.** 18 – 26 GHz

Codes:

	A	**B**	**C**	**D**
(*a*)	1	2	3	4
(*b*)	1	4	2	3
(*c*)	1	4	3	2
(*d*)	1	4	4	2

Sol.

Band → L → S → C → X → Ku → K → Ka

Frequency Range → (1–2 GHz) → (2–4 GHz) → (4–8 GHz) → (8–12 GHz) → (12–18 GHz) → (18–20 GHz) → (20–40 GHz)

3. Which one of the following is operating frequency of Microwave Oven
(*a*) 30 MHz (*b*) 3.1 – 10.6 GHz
(*c*) 3 – 30 MHz (*d*) 2.54 GHz

Sol. **See Table 1.1**

4. Microwaves lies in which of the following IEEE bands
(*a*) L band (*b*) S band (*c*) X band (*d*) C band

Sol. **See Solution of Question 2**

5. Microwaves are not reflected or reflective by
(*a*) Ionosphere (*b*) Attenuation in space
(*c*) Fading (*d*) Velocity distortion

6. C-band frequencies are in which one of the following ranges?
(*a*) 5.5 to 8.0 GHz (*b*) 12.4 to 16.4 GHz
(*c*) 2 to 4 GHz (*d*) 4 to 8 GHz

Sol. **See Question 2 Solution**

7. Which one of the following is not an application of Microwave
(*a*) Space communication (*b*) Radar
(*c*) TV (*d*) Agriculture Industry

8. The advantage of Microwave is that
(*a*) Small S/N ratio (*b*) They are free from impulse noise
(*c*) Moves at the speed of light (*d*) Highly Directive

9. Which of the following will have least frequency
(*a*) UHF (*b*) HF (*c*) VHF (*d*) EHF

10. Broad casting of TV signal in India is done in
(*a*) Microwave bands (*b*) UHF bands
(*c*) HF bands (*d*) VHF bands

11. Wavelength of 14 mm could be expected in
(*a*) HF (*b*) UHF (*c*) VHF (*d*) SHF

12. Microwave cannot be used for
(*a*) Ground wave communication (*b*) Space communication
(*c*) Mobile communication (*d*) Telecommunication

13. Which of the following are true for microwaves
(*a*) Directivity could be increased by using a reflector at focal length
(*b*) These are high directive in nature
(*c*) Their bandwidth does not between 30 MHz to 300 GHz
(*d*) Used for Mobile communication

14. In, Microwave frequencies, fading effect is less due to
(*a*) Foggy weather (*b*) Sky propagation
(*c*) Propagation of energy from transmitter to receiver takes place by line of sight propagation
(*d*) None of the above

15. Which of the following are true for Microwave frequencies
(*a*) Power requirements are low (*b*) Reliability is high
(*c*) High Directivity (*d*) All of the above

16. Which of the frequencies have heating effect
(*a*) Visible rays (*b*) Microwave
(*c*) Both (*a*) and (*b*) (*d*) None of the above

17. What is the full form of RADAR
(*a*) Radio Deflection and Ranging (*b*) Radio Detection and Ranging
(*c*) Radio Detection and Reflection (*d*) None of the above

18. Which of the following is/are not a part of Microwave systems
(*a*) Waveguides (*b*) Transmitting and Receiving antenna
(*c*) Strain gauge (*d*) Microwave amplifier

19. CMBR is stands for?
(*a*) Cathode Microwave Back ground Radiation
(*b*) Crystal Microwave Back ground Radio
(*c*) Cosmic Microwave Back ground Radiation

(*d*) Both (*a*) and (*c*)

20. Among which of the following EM waves have highest-frequency

(*a*) Microwaves (*b*) Cosmic waves
(*c*) X-rays (*d*) Gamma rays

21. Microwaves are a part of EM spectrum lies between

(*a*) Radio Frequencies and Visible region
(*b*) Radio Frequencies and Infrared light (IR)
(*c*) X-rays and Gamma rays
(*d*) Radio Frequencies and Cosmic rays

22. 1 GH means 10^9 Hz

True ☐ False ☐

23. Relative permeability of air is

(*a*) Bismuth (*b*) Air (*c*) Vaccum (*d*) Cobalt

24. The wavelength of X-rays is 30 pm. The frequency is

(*a*) 10^{22} Hz (*b*) 10^{16} Hz (*c*) 10^{19} Hz (*d*) 10^{16} Hz

25. As electromagnetic waves travel in free space then only one of the following can happen

(*a*) Absorption (*b*) Attenuation (*c*) Refraction (*d*) Reflection

26. What of the following has longest wavelength?

(*a*) HF (*b*) VHF (*c*) UHF (*d*) SHF

ANSWER KEY

1	2	3	4	5	6	7	8	9	10
d	b	d	b	d	d	d	d	b	a
11	12	13	14	15	16	17	18	19	20
c	c	d	b	d	b	b	c	c	b
21	22	23	24	25	26				
b	true	b	c	d	d				

CHAPTER-2

WAVE GUIDES

INTRODUCTION

- A waveguide is a hollow conducting tube to guide an electromagnetic waves.

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.

- Any configuration of electric and Magnetic fields that exists inside waveguide must be a solution of Maxwell's field equations.
- Along these fields must also satisfy the boundary conditions imposed by the walls of the guides. There can be no tagential components of electric field at walls of the wave guide if the walls are perfect conductor.

Difference between waveguides and Transmission Lines

- Waveguides provide an alternative to transmission lines for transmission of electrical energy at microwave frequencies.
- Transmission lines are used at Low frequencies where as waveguides are used at highest frequencies *i.e.* microwave etc. because they are relatively much less lossy in comparison to transmission lines. For example, the large surface area of waveguides greatly reduces copper (I^2R) losses.

Two-wire transmission lines have large cooper losses because they have a relatively small surface area.

General Characteristics of Waveguides

- Waveguides 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.
- If the wavelength of the waves is less than some critical value determined by the dimension and the geometry of the guide then a particular mode propagates down a waveguide with low attenuation.
- If the wavelength corresponding to the operating frequency is greater than this critical cut off value then the waves in the waveguides die out rapidly in amplitude even if walls of the guide has infinite conductivity.

Modes of Operation in Waveguides

- Different field configurations that meet the requirements of boundary conditions accordingly each such configurations is called Mode of waveguide.
- There are basically three modes used in waveguides TE mode, TM mode and TEM mode
- **TEM Mode:** If the electric field is every where transverse to the axis of the guide and has no component in the direction of the guide axis except the associated magnetic field. This is also called H mode or Transverse Electric.

TM Mode: If the magnetic field is every where transverse to the guide axis and at some places the electric field has components in the direction of the axis. This type of mode is called Transverse-Magnetic or TM modes or E-modes.

- **TEM Mode:** This mode, having neither E_z nor H_z field components. It is the dominant mode of transmission line having at least two conduction.
- The propagation constant of TEM mode of all frequencies are pure imaginary.
- TEM mode of waves of all frequencies are always guided without attenuation along the axis (of the parallel plate guide)
- Different modes are designated by double subscript *e.g.* TE_{20}, TM_{11} etc.
- Different modes have different cut off wavelengths.
- The particular mode for which the cut off wavelength is the greatest is called dominant mode.