PET ENGINEERING COLLEGE

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT – 1

INTRODUCTION TO MICROWAVE SYSTEMS & ANTENNAS

CLASS   : **S7 ECE**

SUBJECT CODE   : **EC8701**

SUBJECT NAME   : **ANTENNA AND MICROWAVE ENGINEERING**

REGULATION   : **2017**

UNIT I INTRODUCTION TO MICROWAVE SYSTEMS AND ANTENNAS

MICROWAVE FREQUENY BAND

| f (GHz)	Letter Band Designation
1–2	L band
2–4	S band
4–8	C band
8–12.4	X band
12.4–18	Ku band
18–26.5	K band
26.5–40	Ka band

NEAR AND FAR FIELD RADIATION

Near Field

The field, which is nearer to the antenna, is called as **near-field**. It has an inductive effect and hence it is also known as **inductive field**, though it has some radiation components.

Far field

The field, which is far from the antenna, is called as **far-field**. It is also called as **radiation field**, as the radiation effect is high in this area. Many of the antenna parameters along with the antenna directivity and the radiation pattern of the antenna are considered in this region only
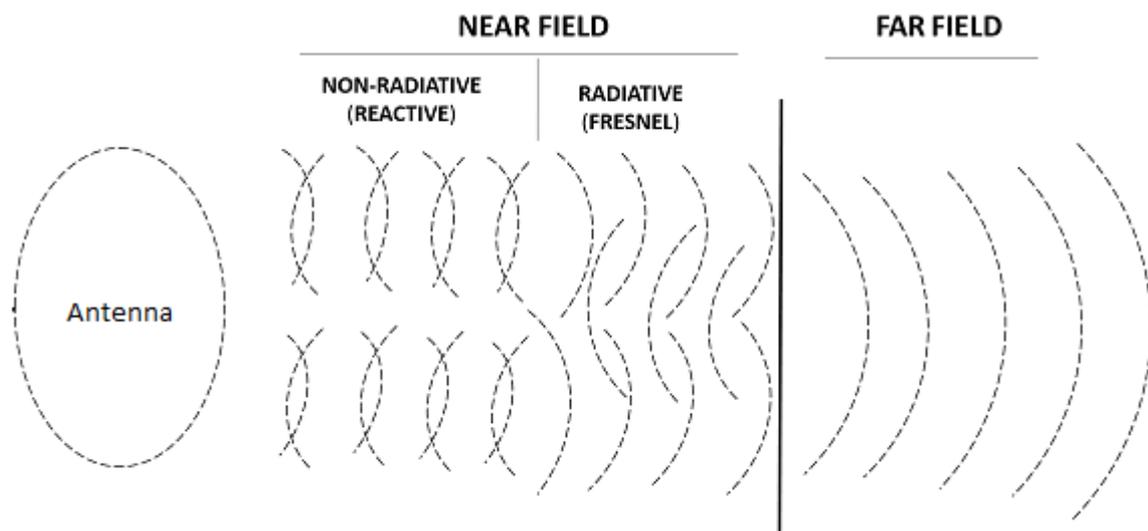
When a signal from a transmitter is applied to an antenna, it sends out electromagnetic waves in to free space. The EM field characteristics vary as a function of distance from the antenna. They are broadly divided into two regions, the near-field region, and the far field region

The **Near Field Region** is the region right next to the antenna. It is defined by the following equation:

$$Near\ Field\ Region < \frac{2D^2}{\lambda}$$

Where D = Maximum linear dimension of the antenna

λ = Wavelength of the EM Waves

In this region, the fields are sort of unpredictable and therefore no measurements are usually made in this region.

This region is further divided into two parts:

Reactive Near Field: This is the region that is adjacent to the antenna. In this region, the E-Field and H-Field are 90 degrees out of phase with each other and are therefore reactive. To radiate or propagate the E/H fields need to be orthogonal (perpendicular) and in phase with each other.

$$Reactive\ Near\ Field\ Region < 0.62\sqrt{\frac{D^3}{\lambda}}$$

Where D = Maximum linear dimension of the antenna

λ = Wavelength of the EM Waves

Radiative Near Field: This region is also known as the Fresnel Region. It is the region between the reactive near field and the far field. This is the region where the EM fields start to transition from reactive to radiating fields. However, since they have not completely transitioned, the shape of the radiation pattern still varies with distance.

$$0.62\sqrt{\frac{D^3}{\lambda}} < Radiative\ Near\ Field\ Region < \frac{2D^2}{\lambda}$$

Where D = Maximum linear dimension of the antenna

λ = Wavelength of the EM Waves

The **Far Field Region** is the region that comes after the near radiative near field. In this region, the EM fields are dominated by radiating fields. The E and H-fields are orthogonal to each other and to the direction of propagation as with plane waves. The far-field region is represented by the following equation:

$$Far\ Field\ Region > \frac{2D^2}{\lambda}$$

Where D = Maximum linear dimension of the antenna

λ = Wavelength of the EM Waves

Antennas are usually used to transfer signals at large distances which are considered to be in the far-field region. One condition that must be met when making measurements in the far field region is that the distance from the antenna must be much greater than the size of the antenna and the wavelength.

Radiation Pattern

The energy radiated by an antenna is represented by the **Radiation pattern** of the antenna. Radiation Patterns are diagrammatical representations of the distribution of radiated energy into space, as a function of direction.

The radiation patterns can be field patterns or power patterns.

- The **field patterns** are plotted as a function of electric and magnetic fields. They are plotted on logarithmic scale.

- The **power patterns** are plotted as a function of square of the magnitude of electric and magnetic fields. They are plotted on logarithmic or commonly on dB scale.

If the radiated power from the antenna, is expressed in terms of electric field, E (v/m). Hence, it is known as **field pattern**. If it is quantified in terms of power (W), then it is known as **power pattern**.

The graphical distribution of radiated field or power will be as a function of

- spatial angles (θ, Ø) for far-field.

- spatial angles (θ, Ø) and radial distance(r) for near-field
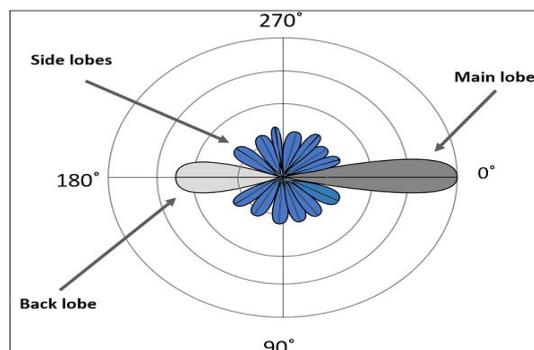
Here, the radiation pattern has main lobe, side lobes and back lobe.

- The major part of the radiated field, which covers a larger area, is the **main lobe** or **major lobe**. This is the portion where maximum radiated energy exists. The direction of this lobe indicates the directivity of the antenna.

- The other parts of the pattern where the radiation is distributed side wards are known as **side lobes** or **minor lobes**. These are the areas where the power is wasted.

- There is other lobe, which is exactly opposite to the direction of main lobe. It is known as **back lobe**, which is also a minor lobe. A considerable amount of energy is wasted even here.

Types of Radiation patterns

The common types of Radiation patterns are −

- Omni-directional pattern (also called non-directional pattern): The pattern usually has a doughnut shape in three-dimensional view. However, in two-dimensional view, it forms a figure-of-eight pattern.

- Pencil-beam pattern − The beam has a sharp directional pencil shaped pattern.

- Fan-beam pattern − The beam has a fan-shaped pattern.

- Shaped beam pattern − The beam, which is non-uniform and patternless is known as shaped beam.

Radiation Intensity

"**Radiation intensity** is defined as the power per unit solid angle"

Radiation emitted from an antenna which is more intense in a particular direction, indicates the maximum intensity of that antenna. The emission of radiation to a maximum possible extent is nothing but the radiation intensity.

Mathematical Expression

Radiation Intensity is obtained by multiplying the power radiated with the square of the radial distance.

$$U = r^2 \times W_{rad}$$

The unit of radiation intensity is Watts/steradian or Watts/radian^2

2.Directivity

The directivity of an antenna is the ratio of the maximum radiation intensity of test antenna to the average radiation intensity

$$D = \frac{Maximum \; radiation \; intensity \; of \; test \; antenna}{Average \; radiation \; intensity \; of \; test \; antenna} = \frac{U(\theta, \phi)_{max}}{U_{av}}$$

$$D = \frac{P(\theta, \phi)_{max}}{P(\theta, \phi)_{av}}$$

It is a dimensionless ratio ≥ 1. The average power density over a sphere is given by

$$P(\theta, \phi)_{av} = \frac{1}{4\pi} \iint_{4\pi} P(\theta, \phi) d\Omega$$

The smaller the beam area Ω_A, the larger the directivity D. Its directivity is :

$$D = \frac{4\pi}{\Omega_A} = \frac{4\pi}{4\pi} = 1$$

This is the lowest possible directivity (D = 1). All actual antennas have directivities greater than 1 (D > 1).

3.Antenna Gain

Gain is related to directivity with antenna efficiency factor as:

$$G = kD$$

k or η: antenna efficiency factor ($0 \leq k \leq 1$), dimensionless. If k or $\eta = 1$, i.e. for a lossless antenna, .In practice, gain is always less than the directivity D.
Gain can be of following types:

- Power Gain (G_p)
- Directive Gain (G_d)

A. Power Gain (G_p): It is the ratio of radiation intensity in a given direction to the average total input power.

$$G_p = \frac{U(\theta, \phi)}{P_T / 4\pi} = \frac{4\pi U(\theta, \phi)}{P_T}$$

Total input power $P_T = P_r + P_l$
P_r: Radiated power;　　　　P_l: Ohmic losses in the antenna

B. **Directive Gain (G_d):** It is the ratio of radiation intensity in a particular direction to the average radiated power.

$$G_d = \frac{U(\theta,\phi)}{P_r \Big/ 4\pi} = \frac{4\pi U(\theta,\phi)}{P_r}$$

G_d does not depend upon the power input to the antenna & its ohmic losses. The maximum value of directive gain is the directivity D of the antenna.
Also,

$$G_p = \eta G_d$$

η: Efficiency factor which lies between 0 to 1

4.Antenna efficiency denoted by ' **η** '. Usually, the antenna efficiency factor lies between 0 and 1.
Antenna Efficiency

$$\eta = \frac{Power\ radiated}{Total\ power\ input} = \frac{P_r}{P_T}$$

With losses efficiency will be $\eta = P_r / (P_r + P_i)$
          [P_r=radiated power; P_i=ohmic losses in the antenna]

5.Aperture efficiency of an antenna, is the ratio of the effective radiating area (or effective area) to the physical area of the aperture."
The mathematical expression for aperture efficiency is as follows −

$$\varepsilon_A = A_{eff}/A_p$$

where

- ε_A is Aperture Efficiency.
- A_{eff} is effective area.
- A_p is physical area.

6. Effective Area of the antenna

$$A_e = \frac{Power\ received}{Power\ density\ of\ incident\ wave\ (W/m^2)} = \frac{P_r}{S}$$

$$A_e = \frac{\lambda^2}{4\pi} G$$

7. Antenna gain-to-noise-temperature (G/T) is a figure of merit in the characterization of antenna performance, where G is the antenna gain in decibels at the receive frequency, and T is the equivalent noise temperature of the receiving system in kelvins

The noise power received from an antenna at temperature T_A can be expressed in terms of the bandwidth (B) the antenna (and its receiver) are operating over:

$$P_{TA} = KT_A B$$

$$T_A = (F-1)T$$

F-Noise Figure of an antenna

System noise temperature = antenna noise temperature + Receiver noise temperature (LNA)

Antenna noise temperature is the noise power seen at the receive output of the antenna.

Receiver G/T (dB/k) Receiver G/T is the Figure of merit at the receiver antenna.

Receiver G/T (dB/K) = Receiver Antenna gain-10 log(system noise temperature) (dB/k)

8. FRIIS TRANSMISSION FORMULA

The Friis Transmission Equation is used to calculate the power received from one antenna (with gain *G1*), when transmitted from another antenna (with gain *G2*), separated by a distance *R*, and operating at frequency *f* or wavelength lambda.

To begin the derivation of the Friis Equation, consider two antennas in free space (no obstructions nearby) separated by a distance R:
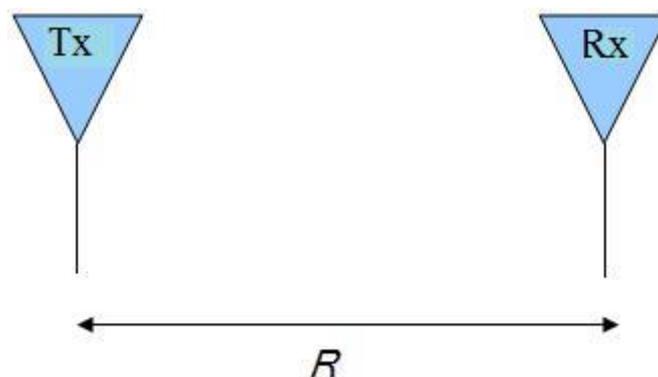
Transmit (Tx) and Receive (Rx) Antennas separated by R.

Assume that P_T Watts of total power are delivered to the transmit antenna. For the moment, assume that the transmit antenna is omnidirectional, lossless, and that the receive antenna is in the far field of the transmit antenna. Then the power density p (in Watts per square meter) of the plane wave incident on the receive antenna a distance R from the transmit antenna is given by:

$$p = \frac{P_T}{4\pi R^2}$$

If the transmit antenna has an antenna gain in the direction of the receive antenna given by G_T, then the power density equation above becomes:

$$p = \frac{P_T}{4\pi R^2} G_T$$

The gain term factors in the directionality and losses of a real antenna. Assume now that the receive antenna has an effective aperture given by A_{ER}. Then the power received by this antenna (P_R) is given by:

$$P_R = \frac{P_T}{4\pi R^2} G_T A_{ER}$$

Since the effective aperture for any antenna can also be expressed as:

$$A_e = \frac{\lambda^2}{4\pi} G$$

The resulting received power can be written as:

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2}$$

This is known as the Friis Transmission Formula. It relates the free space path loss, antenna gains and wavelength to the received and transmit powers.

Link budget and Link margin calculation

A **link budget** is an accounting of all of the gains and losses from a transmitter, through a medium (free space, cable, waveguide, fiber, etc.) to the receiver in a telecommunication system. It accounts for the attenuation of the transmitted signal due to propagation, as well as the antenna gains and feedline and other losses.

In a wireless communication system, the **link margin** (LKM), measured in dB, is the difference between the receiver's sensitivity (i.e., the received power at which the receiver will stop working) and the expected minimum received power.

A system with a negative link margin would mean the system is insufficient to transfer data, usually this means a better receiver is needed, with improved sensitivity

From Friis Transmission formula

Received power at Receiver antenna:

$$P_r = \frac{P_t G_t G_r}{\left(\frac{4\pi d}{\lambda}\right)^2}$$

$$\left(\frac{4\pi d}{\lambda}\right)^2 \rightarrow \text{Path loss}$$

$$P_r(dB) = 10\log(P_t G_t) + 10\log G_r - 20\log\left(\frac{4\pi d}{\lambda}\right)$$

$$P_r(dB) = (EIRP)_{dB} + 10\log G_r - \text{Path loss in dB}$$

Where **path loss in dB=32.45 + 20log d(in Km) + 20 log f(in Hz)**

*
Carrier Power= Pr   Noise Power= KTB

Carrier to Noise Ratio at Satellite Receiver input

$$\frac{C}{N} = \frac{P_t G_t G_r}{\left(\frac{4\pi d}{\lambda}\right)^2 \times kTB}$$

or

$$\frac{C}{N} = (EIRP)_{dB} + 10\log G_r - (\text{Path loss})_{dB} + 228.6$$

$$(C/N)_{dB} = (EIRP)_{dB} + (G/T)_{dB} - (Path\ Losses)_{dB} - K$$

There are two types of link budget calculations since there are two links namely, **uplink** and **downlink**.

Earth Station Uplink

It is the process in which earth is transmitting the signal to the satellite and satellite is receiving it. Its **mathematical equation** can be written as

$$(C/N_0)_U = [EIRP]_U + (G/T)_U - [LOSSES]_U - K$$

Where,

- $[C/N_0]$ is the carrier to noise density ratio
- $[G/T]$ is the satellite receiver G/T ratio and units are dB/K

Here, Losses represent the satellite receiver feeder losses. The losses which depend upon the frequency are all taken into the consideration.

The EIRP value should be as low as possible for effective UPLINK. And this is possible when we get a clear sky condition.

Here we have used the (subscript) notation "U", which represents the uplink phenomena.

Satellite Downlink

In this process, satellite sends the signal and the earth station receives it. The equation is same as the satellite uplink with a difference that we use the abbreviation "D" everywhere instead of "U" to denote the downlink phenomena.

Its **mathematical** equation can be written as;

$$[C/N_0]_D = [EIRP]_D + [G/T]_D - [LOSSES]_D - K$$

Where,

- $[C/N_0]$ is the carrier to noise density ratio
- $[G/T]$ is the earth station receiver G/T ratio and units are dB/K

Here, all the losses that are present around earth

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NOISE CHARACTERIZATION OF A MICROWAVE RECEIVER.

Internal Noise:
i) Shot Noise
ii) Flicker Noise

(ii) Transit Time Noise
(iv) Thermal Agitation Noise

Shot Noise: Caused by random variation in arrival of electrons at the output of amplifying device.

Current due to shot noise $I_n = \sqrt{2eI_{dc}B}$

$\rightarrow$ RMS Shot Noise Current

$\rightarrow$ Average Current

$e \rightarrow$ Charge of e^-

$B \rightarrow$ Bandwidth

RMS value of Shot Noise Voltage $\boxed{V_n = \sqrt{2eI_{DC}BR_d^2}}$

Transit Time Noise: It is due to transit time effect (Time taken by e^- to reach the collector) and observed at the upper end of VHF.

Flicker Noise: It is observed at low audio frequencies below 500 Hz.

Thermal Agitation Noise: Also called Johnson Noise. It is caused by the random flow of electrons due to thermal agitation in resistive device.

Thermal Noise $P_n = KTB$

$\rightarrow$ Temperature in Kelvin

$B \rightarrow$ Bandwidth of device

Johnson Voltage or Thermal Noise Voltage: $\boxed{V_n = \sqrt{4kTB\ R_{eq}}}$

$\rightarrow$ Equivalent Resistance

Amplifier Signal to Noise Ratio: $\boxed{\dfrac{S}{N} = \dfrac{V_s^2}{4kTB\ R_{eq}}}$

Noise Figure: Ratio of input SNR to output SNR.

$$F = \frac{SNR_i}{SNR_o} = \frac{(S/N)_i}{(S/N)_o}$$

$$\because SNR_i > SNR_o$$

$$\therefore F > 1$$

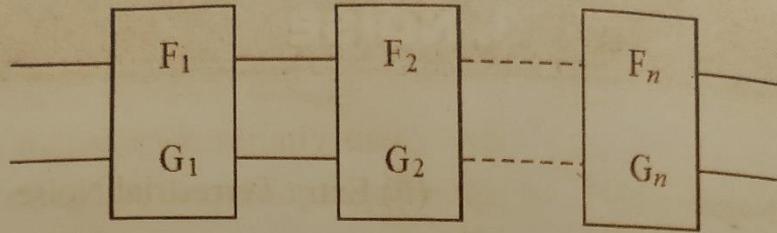**Equivalent Noise Temperature of Amplifier:** $\boxed{T_{eq} = (F-1)T}$

$T \rightarrow$ Temperature in Kelvin

$F \rightarrow$ Noise Figure of Antenna

Power Added by Antenna: $P_n = KT_{eq}B = K(F-1)TB$

Equivalent Noise Figure, Resistance and Temperature of Multistage Amplifier:

[172]

$F_1, F_2 .... F_n \to$ noise figures in dB $\qquad G_1, G_2 .... G_n \to$ gains in dB

Equivalent Noise Figure: $\qquad F_{eq} = F_1 + \dfrac{F_2 - 1}{G_1} + \dfrac{F_3 - 1}{G_1 G_2} + \dfrac{F_4 - 1}{G_1 G_2 G_3} + \cdots$

Equivalent Noise Temperature: $\qquad T_{eq} = T_{eq_1} + \dfrac{T_{eq_2}}{G_1} + \dfrac{T_{eq_3}}{G_1 G_2} + ...$

$\qquad T_{eq_1} \to$ Equivalent Noise Temperature of Stage-1

Equivalent Noise Resistance: $\quad R_{eq} = R_1 + \dfrac{R_2}{A_1^2} + \dfrac{R_3}{A_1^2 A_2} + ...$ $A_i \to$ voltage gain

Figure of merit: $\qquad \boxed{\dfrac{\gamma_{FM}}{\gamma_{AM}} = \dfrac{\dfrac{3}{2} m_f^2}{\dfrac{m_a^2}{m_a^2 + 2}}}$

when, $\qquad m_a = 1 \qquad \boxed{\dfrac{\gamma_{FM}}{\gamma_{AM}} = \dfrac{9}{2} m_f^2}$