SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF ELECTRICAL AND ELECTRONICS
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT – I - ANTENNA AND WAVE PROPAGATION – SECA1505

UNIT 1 ANTENNA FUNDAMENTALS AND WIRE ANTENNAS

Antenna Radiation Mechanism - Isotropic radiator- Antenna parameters: Radiation Intensity, Radiation pattern, Gain and Directivity, FBR, Effective Length, Radiation Resistance, Antenna Impedance, Polarization, Beam width, Bandwidth, Antenna temperature- Friis transmission formula. Retarded Potential - Wire Antennas: Short Electric Dipole, Radiation from an alternating current element, Half - wave Dipole, quarter wave monopole - Fields, Power radiated and Radiation Resistance.

I.INTRODUCTION

An antenna is defined by Webster‘s Dictionary as ―a usually metallic device (as a rod or wire) for radiating or receiving radio waves.‖ The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145–1983) defines the antenna or aerial as ―a means for radiating or receiving radio waves.‖ In other words the antenna is the transitional structure between free-space and a guiding device. The guiding device or transmission line may take the form of a coaxial line or a hollow pipe (waveguide), and it is used to transport electromagnetic energy from the transmitting source to the antenna or from the antenna to the receiver. In the former case, we have a transmitting antenna and in the latter a receiving antenna as shown in figure 1.1.

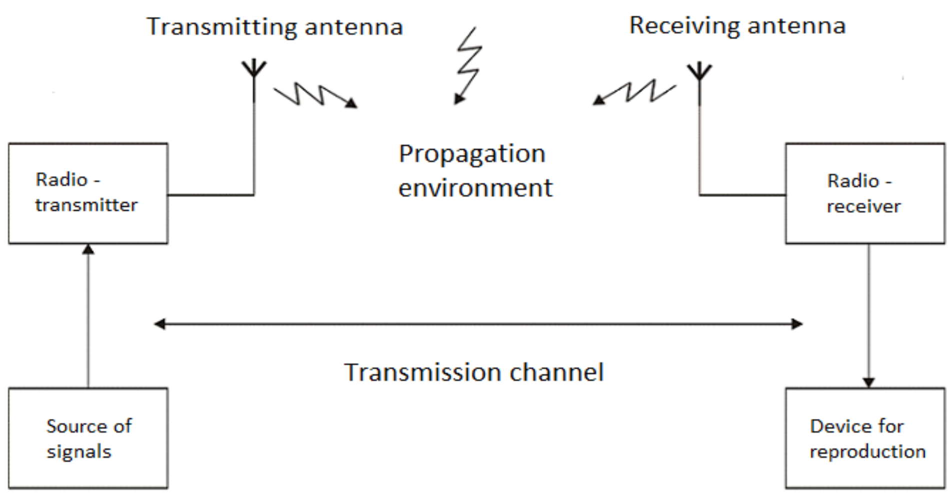

Fig.1.1 .Antenna Fundamentals

An antenna is basically a transducer. It converts radio frequency (RF) signal into an electromagnetic (EM) wave of the same frequency. It forms a part of transmitter as well as the receiver circuits. Its equivalent circuit is characterized by the presence of resistance, inductance, and capacitance. The current produces a magnetic field and a charge produces an electrostatic field. These two in turn create an induction field.

Definition of antenna:

An antenna can be defined in the following different ways:

1. An antenna may be a piece of conducting material in the form of a wire, rod or any other shape with excitation.

2. An antenna is a source or radiator of electromagnetic waves.

3. An antenna is a sensor of electromagnetic waves.

4. An antenna is a transducer.

5. An antenna is an impedance matching device.

6. An antenna is a coupler between a generator and space or vice-versa.

The radiation from the antenna takes place when the Electromagnetic field generated by the source is transmitted to the antenna system through the Transmission line and separated from the Antenna into free space.

1.1ANTENNA PARAMETERS :

1.Field patterns:

- The energy radiated in a particular direction is measured in terms of field strength at a point
- Radiation pattern- graph which shows the variation in actual field strength of electromagnetic field at all points ,equal distance from the antenna
- If the radiation from the antenna is expressed in terms of field strength E (V/m)- Field strength pattern
- If the radiation in a given direction is expressed in terms of power per unit solid-power pattern

Radiation pattern lobes

- Portion of radiation pattern
- Having greater radiation intensity and lesser radiation intensity
- Major lobe-main beam, maximum radiation intensity, exists more than one major lobe
- Minor lobe- any lobe except major lobe
- Side lobe-adjacent to the main lobe ,occupies the hemisphere in direction of the main lobe

- Back lobe-occupies the hemisphere in a direction opposite to that of the major lobe

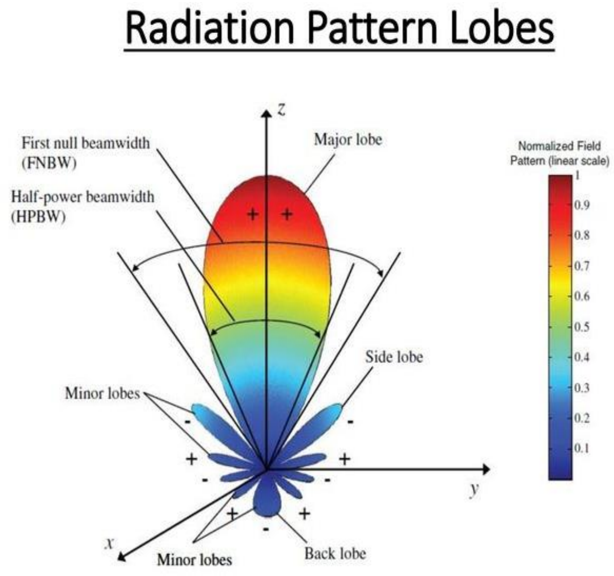

Fig.1.2. Radiation pattern lobes

2. Gain (G)

Antenna gain is the ability of the antenna to radiate more or less in any direction compared to a theoretical antenna. If an antenna could be made as a perfect sphere, it would radiate equally in all directions. Such an antenna is theoretically called an isotropic antenna and does not in fact exist. However, its mathematical model is used as a standard of comparison for the gain of a real antenna.Omni antennas typically radiate with a gain of 2.1 dB over an isotropic antenna. For a vertically oriented omni antenna, this gain in transmission horizontal distance from the antenna is at the expense of transmission above and below it. Its pattern looks similar to a donut.

3.Directivity (D)

Directivity is the measure of the concentration of an antennas's radiation pattern in a particular direction. Directivity is expressed in dB. The higher the directivity, the more concentrated or focussed is the beam radiated by an antenna. A higher directivity also means that the beam will travel further.

4.Effective length (l_e)

In telecommunication, the effective height, or effective length, of an antenna is the height of the antenna's center of radiation above the ground. It is defined as the ratio of the induced voltage to the incident field .

In low-frequency applications involving loaded or non loaded vertical antennas, the effective height is the moment of the current distribution in the vertical section, divided by the input current. For an antenna with a symmetrical current distribution, the center of radiation is the center of the distribution. For an antenna with asymmetrical current distribution, the center of radiation is the center of current moments when viewed from points near the direction of maximum radiation.

5.Effective Aperture (Ae):

- Effective area or capture area
- Tr.antenna-transmits EM waves
- Receiving Antenna-receives fraction of the same
- Cross sectional area over which it extracts EM energy from the travelling EM waves.

6.Radiation Resistance:

It is a equivalent resistance which would dissipate the same amount of power as the antenna radiates when the current in that resistance equals the input current at the antenna terminals.

7.Antenna Impedance:

- Impedance at the point where the transmission line carrying RF power from the transmitter is connected
- At this point input to the antenna is supplied-Antenna Input Impedance
- Driving point impedance or Terminal impedance
- Represented by a two terminal network

8.Polarization:

- Described in terms of electric vector E
- Defined by the direction in which the electric vector E is aligned during the passage of atleast one cycle
- Refers to the physical orientation of the radiated EM waves in space
- E and H are mutually perpendicular
- Magnetic fields surround the wire and perpendicular to it, it means the electric field is parallel to the wire

Types of polarization:

- a)Linear polarization: E as a function of time remains along a straight line
- b) Circular polarization: E traces a circle
- c) Elliptical polarization: Tip of electric field vector traces an ellipse

9.Bandwidth:

- Defines the width or the working range of frequencies over which the antenna maintain its characteristics and parameters like gain, Radiation pattern , Directivity, impedance and so on without considerable changes

1.2 Basic Antenna Elements:

- **Short Dipole:**

- Hertzian dipole, alternating current element, oscillating current element
- consists of co-linear conductors that are placed end to end, but with a small gap between them for the feeder
- current may be assumed to be constant throughout its length
- length L < $\lambda/10$
- current distribution is triangular

Short Monopole:

- Length L < $\lambda/8$

- current distribution is triangular

Half wave dipole:

- Length L= $\lambda/2$

- current distribution is sinusoidal

Quarter wave monopole:

- Length L=$\lambda/4$

- current distribution is sinusoidal

1.3 Retarded potential

- **Definition:** The retarded potentials are the electromagnetic potential for the electromagnetic field generated by time varying electric current or charge distribution in the past
- **Bio-Savart's Law:** Magnetic field due to a current carrying element is directly proportional to the current and the vector product of length vector. It relates magnetic fields to the currents which are their sources.

1.4 Radiation from an alternating current element

- Oscillating electric dipole, Hertzian dipole
- An infinite small current carrying element
- Useful to calculate the field of a large wire antenna
- Long wire antenna-large number of Hertzian dipoles connected in series
- current is constant along the length whenever it is excited by a RF current
- Concept of retarded vector potential is used to find these fields everywhere around in free space
- elemental length of wire is placed at the origin of the spherical coordinate systems
- current in a dipole is accompanied by magnetic field surrounding the region of short dipole
- Built upon on three mutually perpendicular axes x , y and z and a radial displacement (r)
- and two angular displacements (θ and ϕ) are used to describe the spherical coordinates

1.5 Antenna Field Zones

The energy is stored in the magnetic field in the surrounding zone of the current element and it is alternatively stored in field and returned to the source (Idl) during each half cycle. Electromagnetic radiation is impossible

a) Near field region:electromagnetic field created by an antenna that is only significant at distances of less than $2D/\lambda$ from the antenna, where D is the longest dimension of the antenna.
b) Far field region:electromagnetic field created by the antenna that extends throughout all space. At distances greater than $2D/\lambda$ from the antenna, it is the only field. It is the field used for communications

A distance is reached from the conductor at which both the induction and radiation fields becomes equal and the particular distance depends on the wavelength used

It is given by = 0.15

1.7 Half wave Dipole:

It is one of the simplest antenna and is frequently employed as an element of a more complex directional system. It is made of metal rod or tubing or thin wire which has a physical length of half wavelength in free space at the frequency of operation as shown on figure 1.3

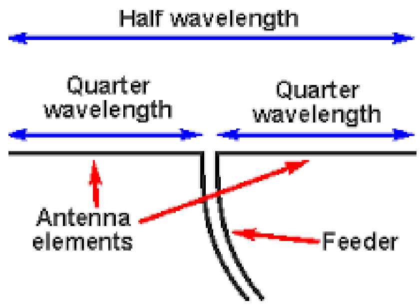

Fig 1.3.Half wave Dipole

A dipole antenna is defined as a symmetrical antenna in which the two ends are at equal potential relative to mid point

Let us consider a centre fed half wave dipole system, the asymptotic current distribution is

$I=I(z)=I_m\sin\beta(h-Z)$;z>+0 (1)

$I=I(z)=I_m\sin\beta(h+Z)$;z<0 (2)

I_m is the maximum current at the current loop

Power radiated by a half wave dipole is given by

$W=73.140\ I^2_{rms}$ Watts

The radiation resistance $R_r=73\ \Omega$

1.8 Quarter wave monopole

- λ/4 antenna
- Marconi Antenna
- Consists of one half of a half wave dipole antenna located on a conducting ground plane
- Perpendicular to the plane which is usually assumed to be infinite and perfectly conducting
- Fed by a coaxial cable connected to its base as shown in figure 1.4

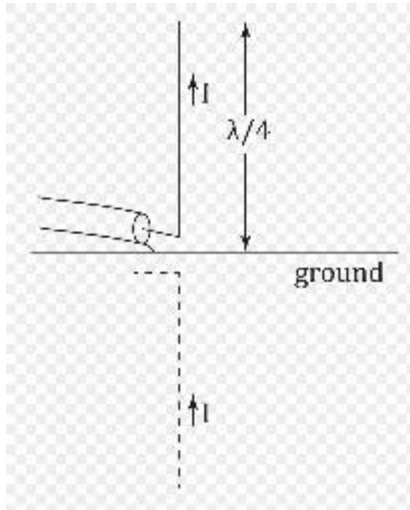

Fig 1.4.Quarter wave Dipole

TEXT / REFERENCE BOOKS

1. K.D.Prasad, “Antennas and Wave Propagation”, 3rd Edition, Satya Prakasan, New Delhi, 2003.
2. R.L. Yadava, “Antennas and Wave Propagation”, 2nd Edition, PHI Learning Private Limited, New Delhi, 2011.
3. Balanis C.A., “Antenna Theory and Design”, 4th Edition, John Wiley & Sons, 2016.
4. Jordan E.C., Balmain, K.G., “Electromagnetic Waves and Radiating Systems”, 2nd Edition, Prentice Hall of India, 2006.
5. Collin R.E., “Antennas and Radio Wave Propagation”, McGraw Hill, 1985.

PART A

1. State Directivity.

2. State Polarization.

3. Interpret Radiation Intensity.

4. Explain retarded potential

5. What is radiation resistance?

6. Find the angle of half wave dipole at 30 MHz.

7. Give the significance of radiation resistance of an antenna.

8. Define Effective length.

9. Illustrate the radiation resistance of a $\lambda/2$ dipole?

10. Define a Hertzian dipole.

PART B

1. Apply the expression for field components of an alternating current element.

2. Develop the expression for power radiated and find the radiation resistance of a half wave dipole.

3. Interpret a) Radiation pattern b) Beam width c) Gain.

4. Explain a) Directivity b) Effective Aperture c) Polarization.

5. a) Summarize retarded potential

   b) Compare the characteristics of half wave dipole and quarter wave monopole

6. Demonstrate the expression for the near and far fields due to short dipole. Find also the distance at near and far fields are equal.

7. Elaborate notes on a) Field patterns b) Effective Aperture c) Self and Mutual Impedance

8. a) Compare Gain and directivity and state the relation between them

   b) Develop equations and explain different types of polarization.

9. A thin dipole is $\lambda/15$ long. If it has loss resistance of 1.5 Ω, calculate directivity, gain, effective aperture, beam solid angle and radiation resistance.

10. Estimate the power radiated and radiation resistance of current element.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF ELECTRICAL AND ELECTRONICS
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT – II – ANTENNA AND WAVE PROPAGATION-SECA1505

UNIT II ANTENNAARRAYS

Types of arrays-Broad side, End fire, Collinear, Parasitic arrays – Arrays of two-point sources – N-element of uniform linear arrays – Arrays of two point sources with equal spacing and currents equal in magnitude and spacing 9broad side array)- Array of N elements with equal spacing and currents equal in magnitude but progressive phase shift (end fire array)- Hasen-woodyard array – Pattern Multiplication- Binomial arrays.

2.1.Antenna Array

To increase the field strength in the desired direction by using group of antennas excited simultaneously such a group of antennas are called as antenna arrays

Purpose of using antenna array:

- Increase field strength
- Increase directivity
- Point to Point communication
- Long distance communication

Array of two point sources

Point source

- Also called as volume less radiator, isotropic radiator, hypothetical antenna

Conditions

Based on amplitude and phase are

Condition 1-Equal amplitude and in phase

Condition 2-Equal amplitude and out of phase

Condition 3-Equal amplitude amp and any phase

Case (i) Equal amplitude and In phase

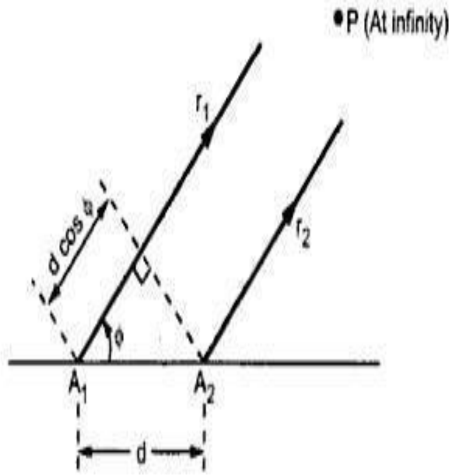

Fig 2.1 .Broad side

Consider two point sources having equal amplitude and same phase

Step :1

Path difference between point source 1&2

Path diff=d/2 Cos θ +d/2 Cos θ

=d Cos θ (2.1)

Path difference in wavelength

=d Cos θ/λ (2.2)

Step :2

Phase angle difference Ψ

Ψ =2∏ [path difference]

Ψ =2∏ [d/λ **Cosθ]**

Ψ = 2∏d/λ **Cos θ**

Ψ= βd **Cos θ** (2.3)

Step :3

Total electric field strength of 2 pt source array is vector sum of individual elements in the array

[-ive sign---pt 1 lags, +ive sign –pt 2 leads]

Both phase angles are same

$E_t = E_0 2 \cos \psi/2$

$E_t = 2E_0 \cos[\beta d \cos\theta/2]$

$2E_0 = 1$

$E_t = \cos[\beta d \cos\theta/2]$

$E_t = \cos \prod/2 \cos\theta$ (2.4)

Step:4 Graphical representation

(i)Direction of maxima:-

Total field strength will be maximum and the direction of maxima is obtained when

$E_t = \pm 1$

$\cos[\prod/2 \cos\theta_{max]} = \pm 1$

$\prod/2 \cos\theta_{max} = \cos^{-1}(\pm 1)$

$\prod/2 \cos\theta_{max} = \pm n\prod$ Where n=0,1,2…

If n=0

$\prod/2 \cos\theta_{max} = 0$

$\theta_{max} = 90°, 270°$ (2.5)

ii)Direction of minima:-

Total field strength will be minimum and the direction of minima is obtained when

$E_t = 0$

$\cos[\prod/2 \cos\theta_{min]} = 0$

$\prod/2 \cos\theta_{min} = \cos^{-1}(0)$

$\cos\theta_{min} = \pm(2n+1)\prod/2$ Where n=0,1,2…

If n=0

$\prod/2 \cos\theta_{min} = \pm\prod/2$

$\theta_{min} = 0°, 180°$ (2.6)

(iii) Half power point Direction

Point at which power is half its value (1/2) (Or) amplitude of voltage or current is VI

$E_t = \pm\frac{1}{\sqrt{2}}$

$\text{Cos}\,[\prod/2\ \text{Cos}\ \theta_{HppD}] = \pm\frac{1}{\sqrt{2}}$

$\prod/2\ \text{Cos}\ \theta_{HppD} = \text{Cos}^{-1}(\frac{1}{\sqrt{2}})$

$\prod/2\ \text{Cos}\ \theta_{HPPD} = \pm(2n+1)\prod/4$ Where n=0,1,2…

If n=0

$\prod/2\ \text{Cos}\ \theta_{HPPD=\pm\prod/4}$

$\text{Cos}\ \theta_{HPPD=\pm\prod/4 * 2/\prod}$

$\theta_{HPPD=\pm 1/2}$

$\theta_{HPPD=60°,120°,240°,300°}$ (2.7)

Figure.2.2 .shows the radiation pattern of broad side array

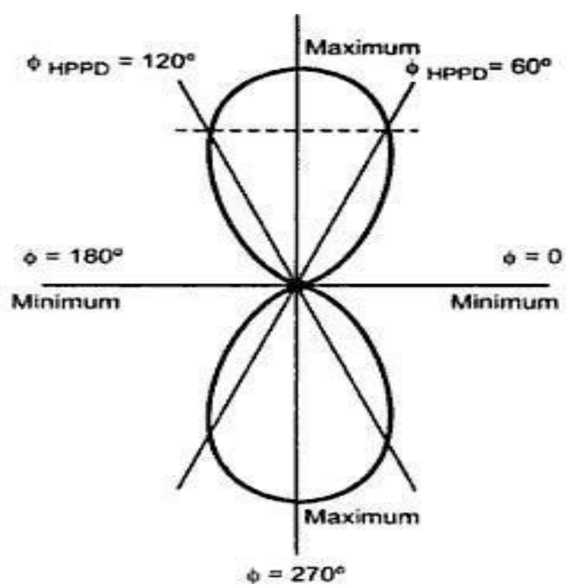

Fig.2.2 .Radiation pattern of broad side

Case (ii) Equal amplitude and out of phase (or) End Fire array

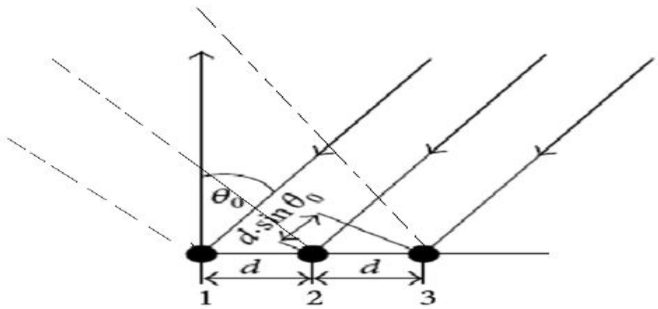

Fig 2.3 .End fire array

Consider two point sources of equal amplitude and out of phase (or) End Fire array as shown in figure 2.3

Step :1

Path difference between point source 1&2

Path diff=d/2 Cos θ +d/2 Cos θ

=d Cos θ

Path difference in wavelength=d Cos θ/ƛ (2.8)

Step :2

Phase angle difference Ψ

Ψ =2∏[path difference]

Ψ =2∏[d/ƛ **Cosθ]**

Ψ = 2∏d/ƛ **Cos θ**

Ψ= βd **Cos θ** (2.9)

Total electric field strength of 2 pt source array is vector sum of individual elements in the array

$E_t = E_0 2j\mathrm{Sin}\psi/2$

$2jE_0 = 1$

$E_t = \mathrm{Sin}\psi/2$

$=\text{Sin}\ \beta d\ \text{Cos}\ \theta$

$E_t = \text{Sin}\ \prod/2\ \text{Cos}\ \theta$ (2.10)

i)Direction of maxima:-

Total field strength will be maximum and the direction of maxima is obtained when

$E_t = \pm 1$

$\text{Sin}\ [\prod/2\ \text{Cos}\ \theta_{max]} = \pm 1$

$\prod/2\ \text{Cos}\ \theta_{max} = \text{Sin}^{-1}(\pm 1)$

$\prod/2\ \text{Cos}\ \theta_{max} = \pm(2n+1)\prod/2$ Where n=0,1,2…

If n=0

$\prod/2\ \text{Cos}\ \theta_{max} = \pm\prod/2$

$\text{Cos}\ \theta_{max} = \pm 1$

$\theta_{max} = 0° \ \&180°$ (2.11)

(ii)Direction of minima:-

Total field strength will be minimum and the direction of minima is obtained when

$E_t = 0$

$\text{Sin}\ [\prod/2\ \text{Cos}\ \theta_{min]} = 0$

$\prod/2\ \text{Cos}\ \theta_{min} = \text{Sin}^{-1}(0)$

$\text{Cos}\ \theta_{min} = \pm n\prod$ Where n=0,1,2…

If n=0

$\prod/2\ \text{Cos}\ \theta_{min} = 0$

$\theta_{min} = 90°, 270°$ (2.12)

(iii) Half power point Direction Point at which power is half its value (1/2)

(Or) amplitude of voltage or current is VI

$E_t = \pm\frac{1}{\sqrt{2}}$

$\mathrm{Sin}[\prod /2 \cos \theta]_{Hp\ pD} = \pm\frac{1}{\sqrt{2}}$

$\prod /2 \cos \theta_{HppD} = \mathrm{Sin}^{-1}(\frac{1}{\sqrt{2}})$

$\prod /2 \cos \theta_{HPPD} = \pm(2n+1)\prod/4$ Where n=0,1,2…

If n=0

$\prod /2 \cos \theta_{HPPD=\pm\prod/4}$

$\cos \theta_{HPPD=\pm\prod/4 *2/\prod}$

$\cos \theta_{HPPD=\pm\prod/4 *2/\prod}$

$\theta_{HPPD=\pm1/2}$

$\theta_{HPPD=60°,120°,240°,300}$ (2.13)

The radiation pattern is shown in figure 2.4

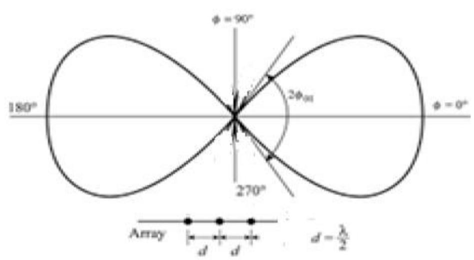

Fig.2.4 .Radiation pattern of broad side array

2.2.Uniform Array:

- An array of identical elements ,with identical magnitude and each with progressive phase is referred to as a uniform array.
- Equally spaced elements in array system is referred as linear antenna arrays

Types of Array:

Based on amplitude, phase excitation and geometrical construction the types of array are

- Broadside array
- End fire array

- Collinear array
- Parasitic array
- Binomial array
- Pattern multiplication

Array of n elements with Equal Spacing and Currents Equal in Magnitude and Phase:

1.Broadside Array:

- ➢ Maximum field strength (or) radiation (or) major lobe is perpendicular to the array axis
- ➢ Apart from major lobe side lobe information can also be found
- ➢ An array to be called as broad side array as it satisfy the following conditions
- ➢ **Condition:1 To get maximum radiation =0**
- ➢ Condition:2 For in phase α =0

=βd Cosθ+α

Condition:3 According to the definition of broad side array

θ max=90°

Condition:4 Minimum field strength is found to be

θ min=0°

The normalized radiation field is given by $E_{t\ norm} = \frac{Sin\ n\varphi/2}{n\varphi/2}$ (2.14)

Figure 2.5 shows the radiation pattern characteristics of broad side array for n=4 sources

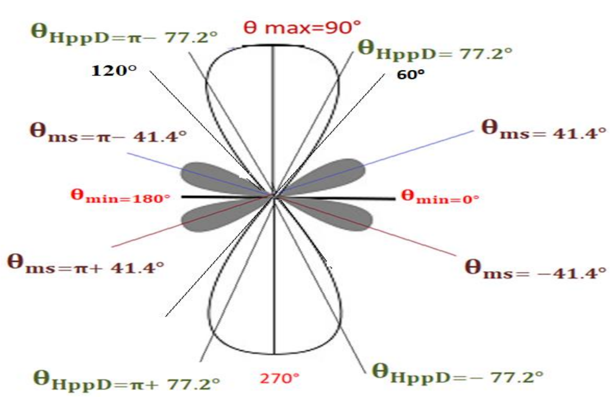

Fig.2.5 .Radiation pattern for n=4

End Fire Array n-4:

- Maximum field strength (or) radiation (or) major lobe is found along the array axis
- Apart from major lobe side lobe information can also be found
- An array to be called as broad side array as it satisfy the following conditions
- **Condition:1** To get maximum radiation $\psi = 0$
- **Condition:2** $\psi = \beta d \cos\theta + \alpha$

Figure 2.6 shows the radiation pattern characteristics of End fire array for n=4 sources

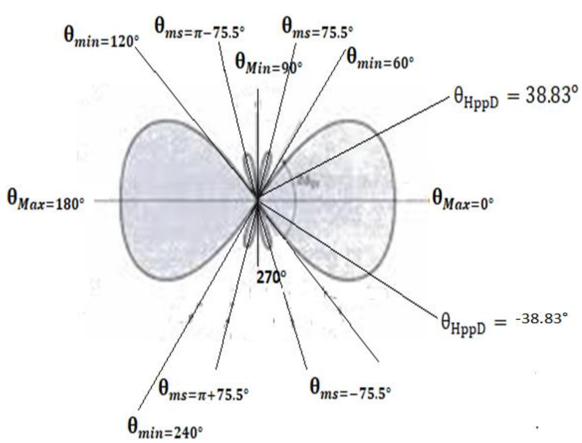

Fig.2.6 .Radiation pattern for n=4

Collinear Array:

- Power gain of this array does not increase in direct proportion of number of collinear elements used

Gp of 2 elements=1.9dB

Gp of 3 elements=3.2dB

Gp of 4 elements =4.3 dB…hence not more than 4 in an array is not used, for multiband operation 2 element system is considered.

Gain is maximum when spacing between elements are in the order of 0.3λ-0.5λ,spacing introduces constructional and feeding problems. To overcome this problem, ends of the radiators are joined by insulator.

(i) To consider collinear array as broadside array $\alpha=0, \psi=0$, Which defines $\theta=90°$ [direction of maximum radiation is perpendicular to the line of antenna].Direction of maximum axis, minimum axis and half power point direction[same procedure as similar to broad side array]. Hence collinear array is also referred as broad side array or Omni directional array.

Parasitic Array:

In order to ease the problem of fed line, it is desirable to feed certain elements of an array parasitically [i.e., arrays in which not all of the elements are driven are called parasitic arrays].The non driven or parasitic elements are excited by mutual impedance (or through EM coupling)

- Coupling with the driven elements as well as with the other parasitic elements
- The design of parasitic elements mainly dependent with

Mutual impedances, elemental length, applied wavelength and optimum spacing

Binomial Array:

- Binomial array is an array of non uniform amplitudes and the amplitude of the radiating sources are arranged according to the coefficient of successive term of the following binomial series and hence the name.

Pattern Multiplication:

The principle of pattern multiplication

- The principle of pattern multiplication states that "the radiation pattern of an array is the product of the pattern of the individual antenna with the array pattern of isotropic point sources each located at the phase centre of the individual source."
- The array pattern is a function of the location of the antennas in the array and their relative complex excitation amplitudes.
- The phase center of the array is the reference point for total phase pattern

Advantage:

It helps to sketch the radiation pattern of array antennas rapidly from the simple product of element pattern and array pattern

Disadvantage

- This principle is only applicable for arrays containing identical elements.
- The principle of pattern multiplication is true for any number of similar sources.
- Total phase pattern is the addition of the phase pattern of the individual sources and that of the array of isotropic point sources.

TEXT / REFERENCE BOOKS

1. K.D.Prasad, "Antennas and Wave Propagation", 3rd Edition, Satya Prakasan, New Delhi, 2003.
2. R.L. Yadava, "Antennas and Wave Propagation", 2nd Edition, PHI Learning Private Limited, New Delhi, 2011.
3. Balanis C.A., "Antenna Theory and Design", 4th Edition, John Wiley & Sons, 2016.
4. Jordan E.C., Balmain, K.G., "Electromagnetic Waves and Radiating Systems", 2nd Edition, Prentice Hall of India, 2006.
5. Collin R.E., "Antennas and Radio Wave Propagation", McGraw Hill, 1985.

PART A

1. Interpret beam width of major lobe?
2. State broadside array.
3. State end fire array?
4. Give the directivity expression for broadside array.
5. Give the directivity expression for end fire array.
6. Identify pattern multiplication?
7. Classify binomial array with necessary diagram.
8. State the calculation of beam width in two point array of equal amplitude and spacing.
9. List the purpose of antenna array?
10. How to convert broad side array radiation pattern into unidirectional?

PART B

1. Develop the expression for broadside array and draw the radiation pattern for the same.
2. Analyze the expression for end fire array and draw the radiation pattern for the same.
3. Demonstrate the expressions for electric field of a broad side array of two point sources and also find the maxima directions, minima directions and half-power point direction.
4. Develop the beam width and draw the radiation pattern for two point sources with equal amplitude and opposite phase.
5. Illustrate the following with neat sketch (a) binomial array (b) pattern multiplication.
6. a) Compare broad side and end fire arrays.

   b) Categorize the various types of antenna arrays.
7. Develop the expression for directions of maxima of broad side array. Comment on the expressions and draw the radiation pattern.
8. Illustrate an expression for field strength of an n-element linear isotropic array.
9. Analyze the field pattern of end fire array of 4-isotropic point source of same amplitude and $\lambda/2$ spacing apart.
10. Summarize the following a) Collinear arrays b) Parasitic arrays

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF ELECTRICAL AND ELECTRONICS
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT – III – ANTENNA AND WAVE PROPAGATION-SECA1505

UNIT III TRAVELLING WAVE AND BROADBAND ANTENNAS

Travelling wave radiators: basic concepts, Long wire antennas - field strength calculations and patterns - V-antennas, Rhombic Antennas, Small Loop antennas, Concept of short magnetic dipole, Helical Antennas, Folded Dipole Yagi-Uda Arrays, Log periodic antennas. Reflector Antennas: Huygens' principle - Flat Sheet and Corner Reflectors, Paraboloid Reflectors, Cassegrain Feeds. Slot antennas - Babinet's principle, Horn antennas, Lens antennas, Microstrip antennas

3.1Loop Antennas

All antennas used radiating elements that were linear conductors. It is also possible to make antennas from conductors formed into closed loops as shown in figure.3.1. There are two broad categories of loop antennas:

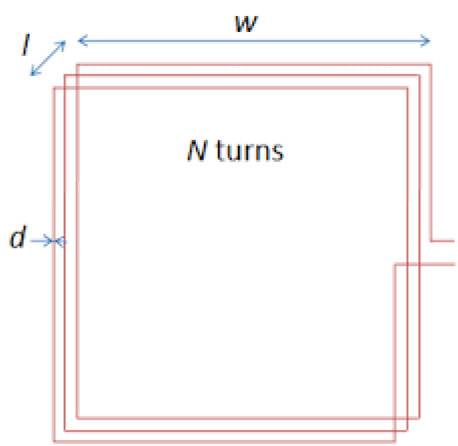

Fig.3.1.Loop Antenna

1. Small loops which contain no more than 0.086λ wavelength, s of wire

2. Large loops, which contain approximately 1 wavelength of wire.

Loop antennas have the same desirable characteristics as dipoles and monopoles in that they are inexpensive and simple to construct. Loop antennas come in a variety of shapes (circular, rectangular, elliptical, etc.) but the fundamental characteristics of the loop antenna radiation pattern (far field) are largely independent of the loop shape. Just as the electrical length of the dipoles and monopoles effect the efficiency of these antennas, the electrical size of the loop (circumference) determines the efficiency of the loop antenna. Loop antennas are usually classified as either electrically small or electrically large based on the circumference of the loop.

electrically small loop = circumference $\lambda/10$

electrically large loop - circumference λ

The electrically small loop antenna is the dual antenna to the electrically short dipole antenna. That is, the far-field electric field of a small loop antenna is identical to the far-field magnetic field of the short dipole antenna and the far-field magnetic field of a small loop antenna is identical to the far-field electric field of the short dipole antenna.

Advantages

1. A small loop is generally used as magnetic dipole.

2. A loop antenna has directional properties whereas a simple vertical antenna not has the same.

3. The induced e.m.f around the loop must be equal to the difference between the two vertical sides only.

4. No e.m.f is produced in case of horizontal arms of a loop antenna.

5. The radiation pattern of the loop antenna does not depend upon the shape of the loop (for small loops).

6. The currents are at same magnitude and phase, throughout the loop.

Disadvantages

1. Transmission efficiency of the loop is very poor.

2. It is suitable for low and medium frequencies and not for high frequencies.

3. In loop antenna, the two nulls of the pattern result in 180° ambiguity.

4. Loop antennas used as direction finders are unable to distinguish between bearing of a

Distant transmitter and its reciprocal bearing

3.2 Yagi-Uda Array

A Yagi-Uda array is an example of a parasitic array. Any element in an array which is not connected to the source (in the case of a transmitting antenna) or the receiver (in the case of a receiving antenna) is defined as a parasitic element. A parasitic array is any array which employs parasitic elements. The general form of the N-element Yagi-Uda array is shown in figure 3.2.

Driven element - usually a resonant dipole or folded dipole , folded dipoles are employed as driven elements to increase the array input impedance

Reflector - slightly longer than the driven element so that it is inductive (its current lags that of the driven element).Approximately 5 to 10 % longer than the driven element.

Director - slightly shorter than the driven element so that it is capacitive (its current leads that of the driven element).Approximately 10 to 20 % shorter than the driven element), not necessarily uniform.

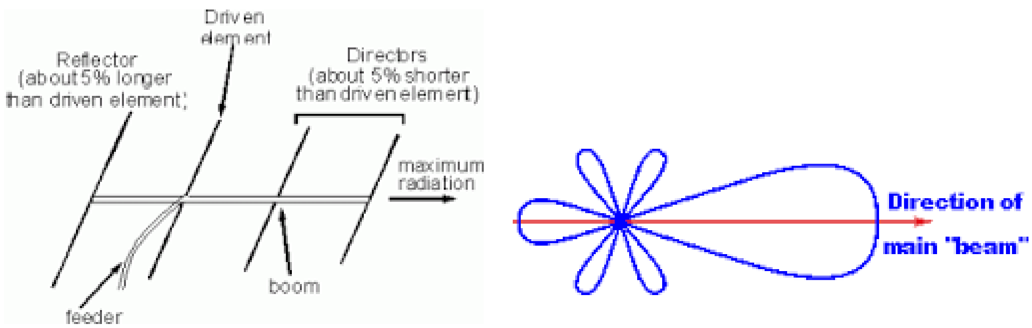

Fig.3.2.Loop Antenna

Advantages

1. Light weight, Low cost

2.Simple construction

3.Unidirectional beam (front-to-back ratio)

4.Increased directivity over other simple wire antennas

5.Practical for use at HF (3-30 MHz), VHF (30-300 MHz), andUHF (300 MHz - 3 GHz)

Reflector spacing 0.1 to 0.258

3.3 V- Traveling Wave Antenna

The main beam of single electrically long wire guiding waves in one direction (traveling wave segment) was found to be inclined at an angle relative to the axis of the wire as shown in figure 3.3. Traveling wave antennas are typically formed by multiple traveling wave segments. These traveling wave segments can be oriented such that the main beams of the component wires combine to enhance the directivity of the overall antenna. A V- traveling wave antenna is formed by connecting two matched traveling wave segments to the end of a transmission line feed at an angle of 22 degrees .

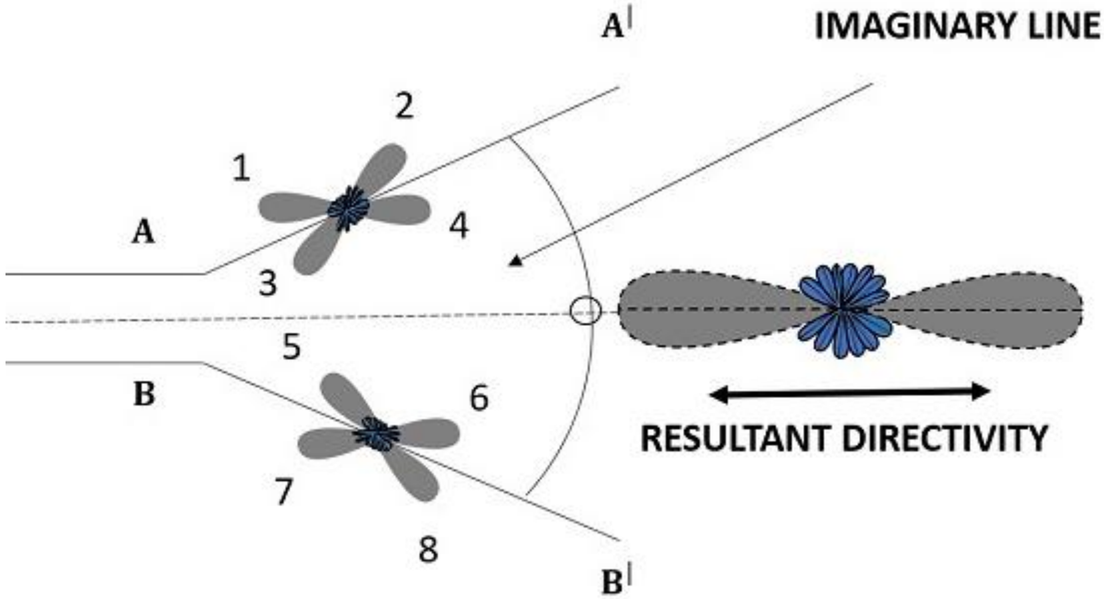

Fig.3.3. V- Antenna

3.4 Rhombic Antenna

The highest development of the long-wire antenna is the RHOMBIC ANTENNA . It consists of four conductors joined to form a rhombus, or diamond shape as shown in figure 3.4 . The antenna is placed end to end and terminated by a non inductive resistor to produce a uni-directional pattern. A rhombic antenna can be made of two obtuse-angle V antennas that are placed side by side, erected in a horizontal plane, and terminated so the antenna is non resonant and unidirectional.

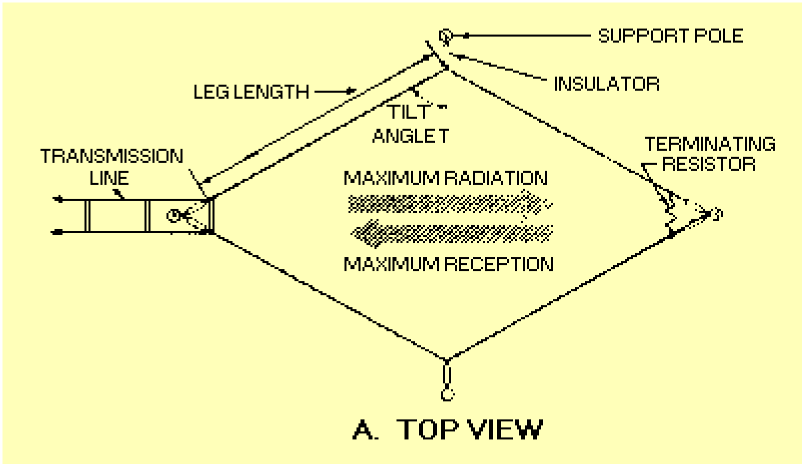

Fig.3.4. Rhombic Antenna

The rhombic antenna is widely used for long-distance, high-frequency transmission and reception. It is one of the most popular fixed-station antennas because it is very useful in point-to-point communication.

Radiation Patterns

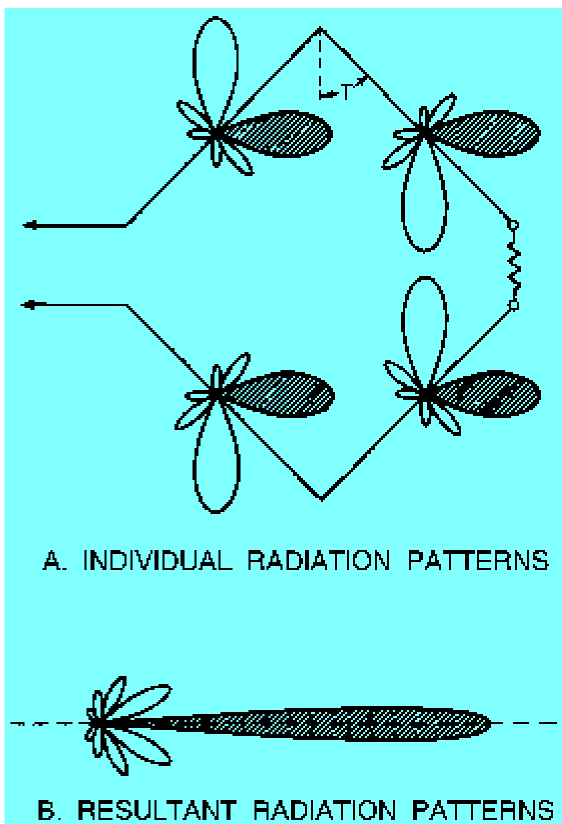

Fig.3.5. Rhombic Antenna

Figure 3.5. shows the individual radiation patterns produced by the four legs of the rhombic antenna and the resultant radiation pattern. The principle of operation is the same as for the V and the half-rhombic antennas.

Advantages

- The input impedance and radiation pattern of rhombic antenna do not change rapidly over a considerable frequency range.
- It is highly directional broad band antenna with greatest radiated or received power along the main axis.
- Simple and cheap to erect
- Low weight

Disadvantages

- It needs a larger space for installation
- Due to minor lobes, transmission efficiency is low

3.5 Folded Dipole:

A folded dipole is a dipole antenna with the ends folded back around and connected to each other, forming a loop as shown in Figure. It turns out the impedance of the folded dipole antenna will be a function of the impedance of a transmission line of length L/2. Also, because the folded dipole is "folded" back on itself, the currents can reinforce each other instead of cancelling each other out, so the input impedance will also depend on the impedance of a dipole antenna of length L.

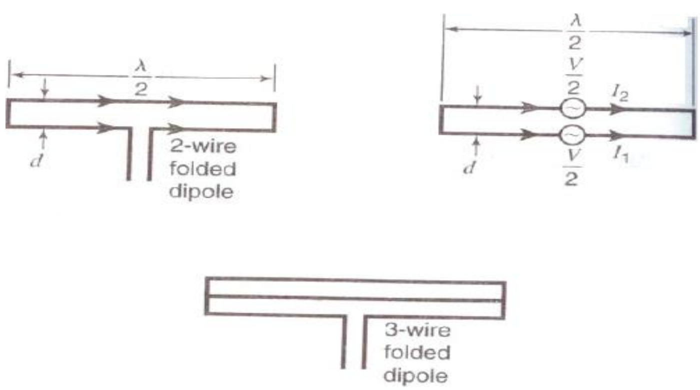

Fig.3.6. Rhombic Antenna

The input impedance for a dipole is 73 Ω. Hence for a folded dipole with 2 arms the radiation resitance is 2* 73Ω= 292Ω. If 3 arms are used the resistance will be $3^2 * 73\Omega = 657\Omega$

Advantages

- High input impedance
- Wide band in frequency
- Acts as built in reactance compensation network

Uses:

Folded dipole is used in conjunction with parasitic elements in wide band operation such as television. In this application, in the yagi antenna, the driven element is folded dipole and remaining are reflector and director

3.6 Horn Antennas

Horn antennas are popular in the microwave band (above 1 GHz). Horns provide high gain, low VSWR (with waveguide feeds), relatively wide bandwidth, and they are not difficult to make. The horns can be also flared exponentially. This provides better matching in a broad frequency band, but is technologically more difficult and expensive. The rectangular horns are ideally suited for rectangular waveguide feeders. The horn acts as a gradual transition from a waveguide mode to a free-space mode of the EM wave. When the feeder is a cylindrical waveguide, the antenna is usually a conical horn as shown in figure.3.7.

Types of the horn antennas as - Plane Sectoral Horn - Plane Sectoral Horn - Pyramidal and Conical Horn These horns are fed by a rectangular waveguide oriented its broad wall horizontal. If flaring is done only in one direction, then it is called sectoral horn. Flaring in the direction of E and H, the sectoral E-plane and sectoral H plane are obtained respectively. If flaring is done along both the walls (E&H),then pyramidal horn is obtained.

Horn antenna emphasizes traveling waves leads to wide bandwidth and low VSWR. Because of longer path length from connecting waveguide to horn edge, phase delay across aperture causes phase error. Dielectric or metallic plate lens in the aperture are used to correct phase error. Those with metallic ridges increase the bandwidth. Horns are also used for a feed of reflector antennas.

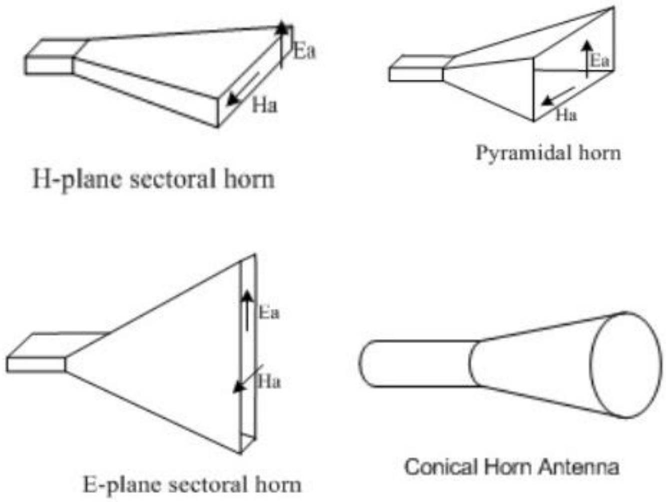

Fig.3.7. Rhombic Antenna

3.7 LENS ANTENNA:

Another antenna that can change spherical waves into flat plane waves is the lens antenna. This antenna uses a microwave lens, which is similar to an optical lens to straighten the spherical wave fronts. Since this type of antenna uses a lens to straighten the wave fronts, its design is based on the laws of refraction, rather than reflection.

Two types of lenses have been developed to provide a plane-wave front narrow beam for tracking radars, while avoiding the problems associated with the feed horn shadow. These are the conducting (acceleration) type and the dielectric (delay) type.

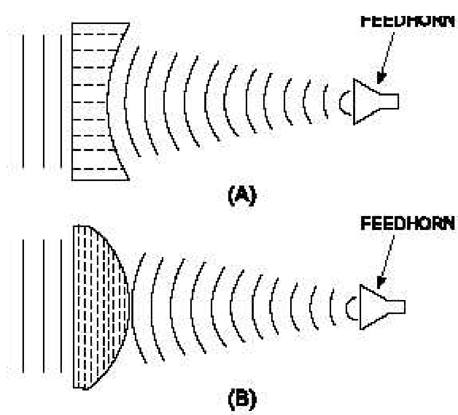

Fig.3.8. Rhombic Antenna

The lens of an antenna is substantially transparent to microwave energy that passes through it. It will, however, cause the waves of energy to be either converged or diverged as they exit the lens. This type of lens consists of flat metal strips placed parallel to the electric field of the wave and spaced slightly in excess of one-half of a wavelength. To the wave these strips look like parallel waveguides. The velocity of phase propagation of a wave is greater in a waveguide than in air. Thus, since the lens is concave, the outer portions of the transmitted spherical waves are accelerated for a longer interval of time than the inner.

Advantages :

1. The lens antenna, feed and feed support do not block the aperture as the rays are transmitted away from the feed

2. It has greater design tolerance

3.It can be used to feed the optical axis and hence useful in applications where a beam is required to be moved angularly with respect to the axis.

3.8. Parobolic Reflector Antenna

A parabolic antenna is an antenna that uses a parabolic reflector, a curved surface with the cross-sectional shape of a parabola, to direct the radio waves. The most common form is shaped like a dish and is popularly called a dish antennaor parabolic dish. The main advantage of a parabolic antenna is that it has high directivity. It functions similarly to a search light or flashlight reflector to direct the radio waves in a narrow beam, or receive radio waves from one particular direction only. Parabolic antennas have some of the highest gains, that is, they can produce the narrowest beamwidths, of any antenna type. In order to achieve narrow beam widths, the parabolic reflector must be much larger than the wavelength of the radio waves used, so parabolic antennas are used in the high frequency part of the radio spectrum, at UHF and microwave (SHF) frequencies, at which the wavelengths are small enough that conveniently-sized reflectors can be used.

Parabolic reflector basics

The RF antenna consists of a radiating system that is used to illuminate a reflector that is curved in the form of a paraboloid. A parabolic shape has the property that paths taken from the feed point at the focus to the reflector and then outwards are in parallel, but more importantly the paths taken are all the same length and therefore the outgoing waveform will form a plane wave and the energy taken by all paths will all be in phase. This shape enables a very accurate beam to be obtained. In this way, the feed system forms the actual radiating section of the antenna, and the reflecting parabolic surface is purely passive.

When looking at parabolic reflector antenna systems there are a number of parameters and terms that are of importance:

•**Focus:** The focus or focal point of the parabolic reflector is the point at which any incoming signals are concentrated. When radiating from this point the signals will be reflected by the reflecting surface and travel in a parallel beam and to provide the required gain and beam width.

•**Vertex:** This is the innermost point at the centre of the parabolic reflector.

•**Focal length**: The focal length of a parabolic antenna is the distance from its focus to its vertex. Read more about the focal length

Design

The operating principle of a parabolic antenna is that a point source of radio waves at the focal point in front of a paraboloidal reflector of conductive material will be reflected into a collimated plane wave beam along the axis of the reflector. Conversely, an incoming plane wave parallel to the axis will be focused to a point at the focal point.

A typical parabolic antenna consists of a metal parabolic reflector with a small feed antenna suspended in front of the reflector at its focus, pointed back toward the reflector. The reflector is a metallic surface formed into a paraboloid of revolution and usually truncated in a circular rim that forms the diameter of the antenna. In a transmitting antenna, radio frequency current from a transmitter is supplied through a transmission line cable to the feed antenna, which converts it into radio waves. The radio waves are emitted back toward the dish by the feed antenna and reflect off the dish into a parallel beam. In a receiving antenna the incoming radio waves bounce off the dish and are focused to a point at the feed antenna, which converts them to electric currents which travel through a transmission line to the radio receiver.

Advantages:

- **High gain:** Parabolic reflector antennas are able to provide very high levels of gain. The larger the 'dish' in terms of wavelengths, the higher the gain.
- **High directivity:** As with the gain, so too the parabolic reflector or dish antenna is able to provide high levels of directivity. The higher the gain, the narrower the beam width. This can be a significant advantage in applications where the power is only required to be directed over a small area. This can prevent it, for example causing interference to other users, and this is important when communicating with satellites because it enables satellites using the same frequency bands to be separated by distance or more particularly by angle at the antenna.

Disadvantages:

Like all forms of antenna, the parabolic reflector has its, limitations and drawbacks:

- **Requires reflector and drive element:** the parabolic reflector itself is only part of the antenna. It requires a feed system to be placed at the focus of the parabolic reflector.
- **Cost :** The antenna needs to be manufactured with care. A paraboloid is needed to reflect the radio signals which must be made carefully. In addition to this a feed system is also required. This can add cost to the system
- **Size:** The antenna is not as small as some types of antenna, although many used for satellite television reception are quite compact.

Parabolic reflector antenna applications

There are many areas in which the parabolic / dish antenna may be used. Its performance enables it to be used almost exclusively in some areas.

- **Direct broadcast television:** Direct broadcast or satellite television has become a major form of distribution for television material. The wide and controllable coverage areas available combined with the much larger bandwidths for more channels available mean that satellite television is very attractive.

- **Satellite communications:** Many satellite uplinks, or those for communication satellites require high levels of gain to ensure the optimum signal conditions and that transmitted power from the ground does not affect other satellites in close angular proximity. Again the ideal antenna for most applications is the parabolic reflector antenna.

- **Aperture** : The aperture of a parabolic reflector is what may be termed its "opening" or the area which it covers. For a circular reflector, this is described by its diameter. It can be likened to the aperture of an optical lens.
- **Gain:** The gain of the parabolic reflector is one of the key parameters and it depends on a number of factors including the diameter of the dish, wavelength and other factors.
- **Feed systems**: The parabolic reflector or dish antenna can be fed in a variety of ways. Axial or front feed, off axis, Cassegrain, and Gregorian are the four main methods. Read more about Parabolic reflector feed types.

Parabolic reflector feed types

There are several different types of parabolic reflector feed systems that can be used. Each has its own characteristics that can be matched to the requirements of the application.

- Focal feed - often also known as axial or front feed system
- Cassegrain feed system
- Gregorian feed system
- Off Axis or offset feed

Focal feed system

The parabolic reflector or dish antenna consists of a radiating element which may be a simple dipole or a waveguide horn antenna as shown in figure .3.9. This is placed at the focal point of the parabolic reflecting surface. The energy from the radiating element is arranged so that it illuminates the reflecting surface. Once the energy is reflected it leaves the antenna system in a narrow beam. As a result considerable levels of gain can be achieved.

Achieving this is not always easy because it is dependent upon the radiator that is used. For lower frequencies a dipole element is often employed whereas at higher frequencies a circular waveguide may be used. In fact the circular waveguide provides one of the optimum sources of illumination.

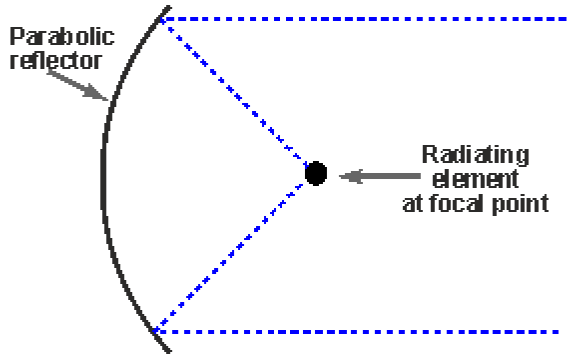

Fig.3.9.Diagram of a focal feed parabolic reflector antenna

The focal feed system is one of the most widely used feed system for larger parabolic reflector antennas as it is straightforward. The major disadvantage is that the feed and its supports block some of the beam, and this typically limits the aperture efficiency to only about 55 to 60%.

Cassegrain feed system

The Cassegrain feed system, although requiring a second reflecting surface has the advantage that the overall length of the dish antenna between the two reflectors is shorter than the length between the radiating element and the parabolic reflector as shown in figure.3.10 .This is because there is a reflection in the focusing of the signal which shortens the physical length. This can be an advantage in some systems.

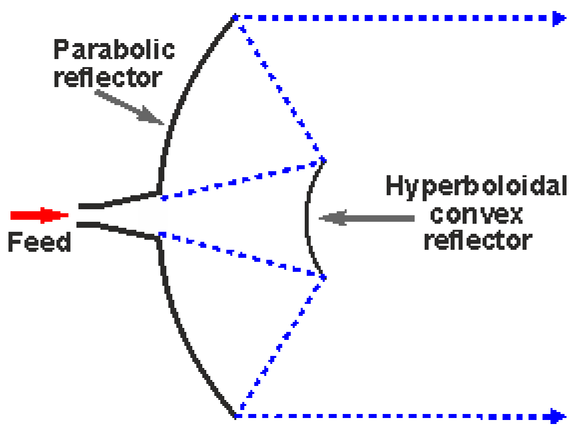

Fig.3.10.Diagram of a Cassegrain feed parabolic reflector or dish antenna

Typical efficiency levels of 65 to 70% can be achieved using this form of parabolic reflector feed system.The Cassegrain parabolic reflector antenna design and feed system gains its name because the basic concept was adapted from the Cassegrain telescope. This was reflecting telescope which was developed around 1672 and attributed to French priest Laurent Cassegrain.

Gregorian parabolic reflector feed

The Gregorian parabolic reflector feed technique is very similar to the Cassegrain design. The major difference is that except that the secondary reflector is concave or more correctly ellipsoidal in shape as shown in figure.3.11 .

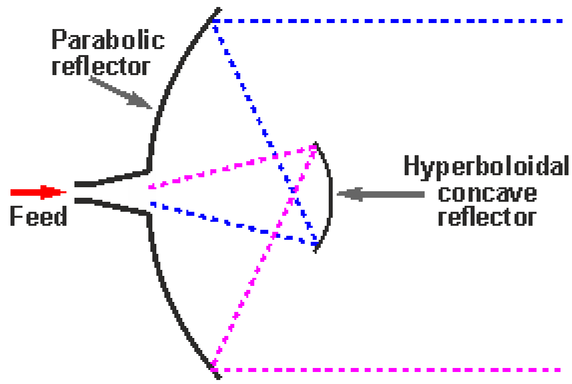

Fig.3.11.Diagram of a Gregorian feed parabolic reflector or dish antenna

Typical aperture efficiency levels of over 70% can be achieved because the system is able to provide a better illumination of the entire reflector surface.

Off axis or offset parabolic reflector antenna feed

As the name indicates this form of parabolic reflector antenna feed is offset from the centre of the actual antenna dish used.

The reflector used in this type of feed system is an asymmetrical segment of the parabolic shape normally used as shown in figure.3.12. In this way the focus and the feed antenna are located to one side of the reflector surface.

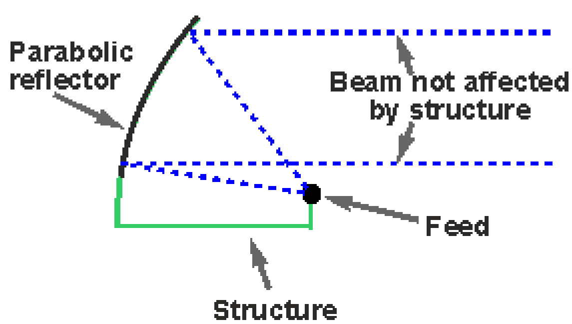

Fig.3.12.Diagram of an Offset feed parabolic reflector or dish antenna

The advantage of using this approach to the parabolic reflector feed system is to move the feed structure out of the beam path. In this way it does not block the beam.

3.9 LOG PERIODIC DIPOLE ARRAY

The log periodic dipole array (LPDA) is one antenna that almost everyone over 40 years old has seen as shown in figure.3.13. They were used for years as TV antennas. The chief advantage of an LPDA is that it is frequency-independent. Its input impedance and gain remain more or less constant over its operating bandwidth, which can be very large. Practical designs can have a bandwidth of an octave or more.

Although an LPDA contains a large number of dipole elements, only 2 or 3 are active at any given frequency in the operating range. The electromagnetic fields produced by these active elements add up to produce a unidirectional radiation pattern, in which maximum radiation is off the small end of the array. The radiation in the opposite direction is typically 15 - 20 dB below the maximum. The ratio of maximum forward to minimum rearward radiation is called the Front-to-Back (FB) ratio and is normally measured in dB.

Operation of the Log Periodic Dipole Antenna

The log periodic dipole antenna basically behaves like a Yagi-Uda array over a wide frequency range. As the frequency varies, the active set of elements for the log periodic antenna (those elements which carry the significant current) moves from the long-element end at low frequency to the short-element end at high frequency. The director element current in the Yagi array lags that of the driven element while the reflector element current leads that of the driven element. This current distribution in the Yagi array points the main beam in the direction of the director.

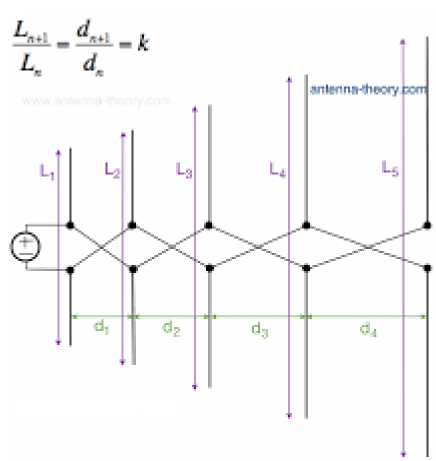

Fig.3.13.Log Periodic Dipole antenna

In order to obtain the same phasing in the log periodic antenna with all of the elements in parallel, the source would have to be located on the long-element end of the array.The log periodic dipole array must be driven from the short element end. But this arrangement gives the exact opposite phasing required to point the beam in the direction of the shorter elements. It can be shown that by alternating the connections from element to element, the phasing of the log periodic dipole elements points the beam in the proper direction.

3.10 Microstrip Antennas

- Also called "patch antennas"
- One of the most useful antennas at microwave frequencies (f > 1 GHz).
- It consists of a metal "patch" on top of a grounded dielectric substrate.
- The patch may be in a variety of shapes, but rectangular and circular are the most common as shown in figure.3.14.

Basic Principles of Operation

The patch acts approximately as a resonant cavity (short circuit walls on top and bottom, open-circuit walls on the sides). In a cavity, only certain modes are allowed to exist, at different resonant frequencies. If the antenna is excited at a resonant frequency, a strong field is set up inside the cavity, and a strong current on the (bottom) surface of the patch. This produces significant radiation (a good antenna).

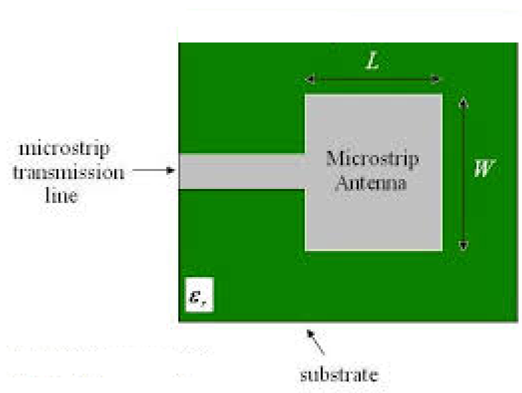

Fig.3.14.Log Periodic Dipole antenna

Advantages :

• Low profile (can even be "conformal").

• Easy to fabricate (use etching and photolithography).

• Easy to feed (coaxial cable, micro strip line, etc.).

• Easy to use in an array or incorporate with other microstrip circuit elements.

• Patterns are somewhat hemispherical, with a moderate directivity (about 6-8 dB is typical)

Disadvantages :

- Low bandwidth (but can be improved by a variety of techniques).
- Efficiency may be lower than with other antennas. Efficiency is limited by conductor and dielectric losses, and by surface-wave loss.
- Conductor and dielectric losses become more severe for thinner substrates.
- Surface-wave losses become more severe for thicker substrates (unless air or foam is used).

TEXT / REFERENCE BOOKS

1. K.D.Prasad, "Antennas and Wave Propagation", 3rd Edition, Satya Prakasan, New Delhi, 2003.
2. R.L. Yadava, "Antennas and Wave Propagation", 2nd Edition, PHI Learning Private Limited, New Delhi, 2011.
3. Balanis C.A., "Antenna Theory and Design", 4th Edition, John Wiley & Sons, 2016.
4. Jordan E.C., Balmain, K.G., "Electromagnetic Waves and Radiating Systems", 2nd Edition, Prentice Hall of India, 2006.
5. Collin R.E., "Antennas and Radio Wave Propagation", McGraw Hill, 1985.

PART A

1. List the advantages of Rhombic Antenna?

2. List out the uses of loop antenna?

3 .Evaluate the elements of Yagi-Uda Antenna?

4. Enumerate the application of Horn antenna?

5.List out high frequency antennas.

6. Explain grounded antennas?

7. Estimate the loop antennas?

8. Give the types of horn antenna.

9. Evaluate log periodic antenna?

10. List the advantages of parabolic reflectors?

PART B

1.Describe the construction, principle of operation and design of rhombic antenna.

2.Explain the principle of operation of Log-Periodic antennas and its applications

3. Illustrate the working principle of loop antenna, with neat sketch

4. Categorize the various feeding techniques for parabolic reflector antenna

5. Demonstrate the operation of rectangular microstrip antenna

6. Estimate the principle of operation of horn antenna with neat sketch

7. Determine a three element yagi-uda antenna which operates at 5 GHz in free space

8. Estimate a detailed account of antennas used for high, medium and low frequency applications.

9. Illustrate rhombic antenna with maximum field intensity design with a neat sketch.

10. Analyze the construction and working of frequency independent antenna and give their applications.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF ELECTRICAL AND ELECTRONICS
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT – IV – Antenna and Wave Propagation- SECA1505

UNIT IV WAVE PROPAGATION

Factors involved in the propagation of Radio waves – Ground wave propagation, structure of Ionosphere and its effect on radio waves- Refraction and Reflection of sky wave by the Ionosphere, Ray paths- Measure of Ionosphere propagation, critical frequency, skip distance, virtual height, maximum usable frequency, fading of signals, selective fading – Diversity reception, space wave propagation- consideration in space wave propagation, Atmospheric effects in space wave propagation, super refraction – Duct propagation.

4.1. FACTORS AFFECTING THE RADIO WAVES PROPAGATION

There exist a number of factors which affect the propagation of radio waves in actual environment. The most important of these are –

(a) Spherical shape of the earth:- since the radio waves travel in a straight line path in free space, communication between any two points on the surface of earth is limited by the distance to horizon. Therefore, for establishing a communication link beyond the horizon, the radio waves need to undergo a change in the direction of propagation. Several mechanisms can be made use of to effect the change.

(B) The atmosphere:- The earth's atmosphere extends all the way up to about 600 km. The atmosphere is divided into several layers, viz., troposphere, stratosphere, mesosphere, and ionosphere. The propagation of the radio waves near the surface of earth is affected mostly by the troposphere which extends up to height of 8-15 km. Higher up in the atmosphere; it is the ionosphere which interacts with radio waves.

(C) Interaction with the objects on the ground:- The radio waves travelling close to the surface of earth encounter many obstacles such as building, trees, hills, valleys, water bodies, etc. The interaction of such objects with the radio waves is mostly manifested as the phenomena of reflection, refraction, diffraction, and scattering.

4.2. GROUND WAVE PROPAGATION

The ground wave is a wave that is guided along the surface of the earth just as an electromagnetic wave is guided by a wave guide or transmission line as shown in figure 4.1. This ground wave propagation takes place around the curvature of the earth in the frequency bands up to 2 MHz. This also called as surface wave propagation The ground wave is vertically polarized, as any horizontal component of the E field in contact with the earth is short-circuited by it. In this mode, the wave glides over the surface of the earth and induces charges in the earth which travel with the wave, thus constituting a current, while carrying this current, the earth acts as a leaky capacitor. Hence it can be represented by a resistance or conductance shunted by a capacitive reactance.

As the ground wave passes over the surface of the earth, it is weakened due to the absorption of its energy by the earth. The energy loss is due to the induced current flowing through the earth's resistance and is replenished partly, by the downward diffraction of additional energy, from the portions of the wave in the immediate vicinity of the earth's surface.

Applications

Ground wave propagation is generally used in TV, radio broadcasting etc.

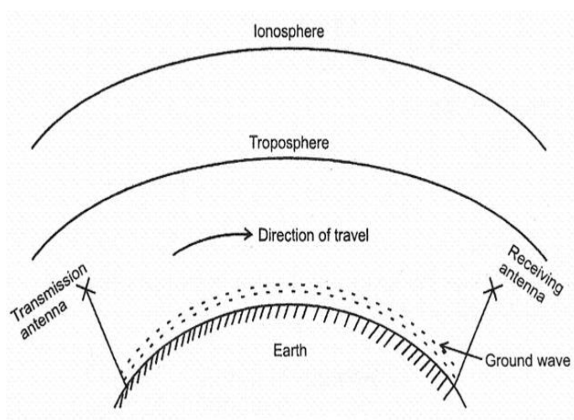

Fig 4.1 Ground wave Propagation

4.3 STRUCTURE OF THE IONOSPHERE

As the medium between the transmitting and receiving antennas plays a significant role, it is essential to study the medium above the earth, through which the radio waves propagate. The various regions above the earth's surface are illustrated in Figure 4.2.

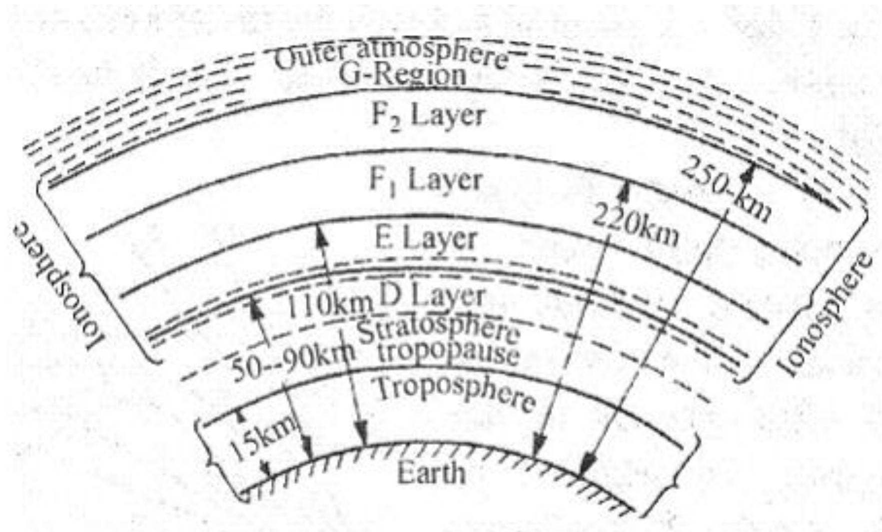

Fig 4.2 Structure of the ionosphere

The portion of the atmosphere, extending up to a height (average of 15 Km) of about 16 to 18 Kms from the earth's surface, at the equator is termed as troposphere or region of change. Tropopause starts at the top of the troposphere and ends at the beginning of or region of calm. Above the stratosphere, the upper stratosphere parts of the earth's atmosphere absorb large quantities of radiant energy from the sun. This not only heats up the atmosphere, but also produces some ionization in the form of free electrons, positive and negative ions. This part of the atmosphere where the ionization is appreciable, is known as the ionosphere. The most important ionizing agents are ultraviolet UV radiation, ά , β and cosmic rays and meteors. The ionization tends to be stratified due to the differences in the physical properties of the atmosphere at different heights and also because various kinds of radiation are involved.

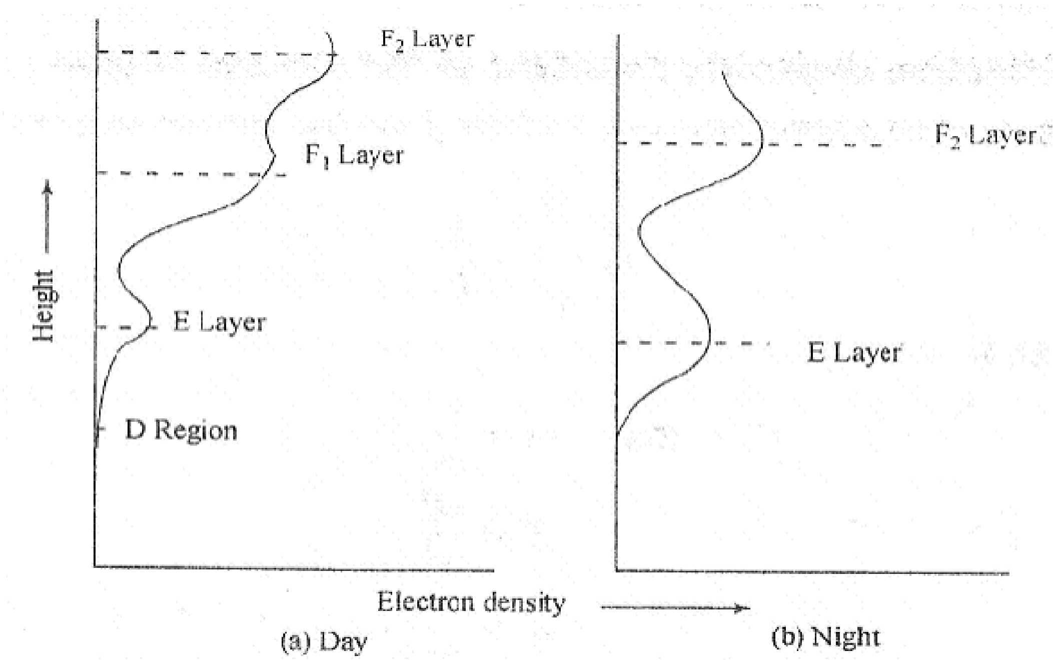

Fig. 4.3 Electron Density Layers

The levels, at which the electron density reaches maximum, are called as layers. The three principal day time maxima are called E, F1, and F2 layers. In addition to these three regular layers, there is a region (below E) responsible for much of the day time attenuations of HF radio waves, called D region. It lies between the heights of 50 and 90 Km.The heights of maximum density of regular layers E and F1are relatively constant at about 110 Km and 220Km respectively. These have little or no diurnal variation, whereas the F2 layer is more variable, with heights in the range of 250 to 350 Km as shown in figure 4.3.

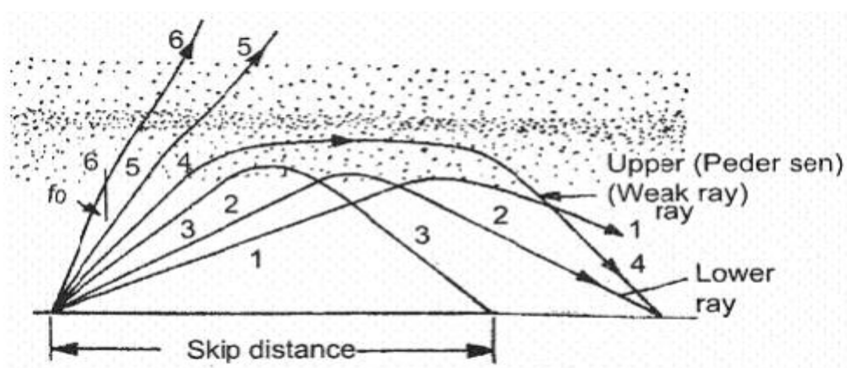

Fig 4.4 Effect of ionosphere on rays

At night F1 and F2 layers combine to form a single night time F2 layer .The E layer is governed closely by the amount of UV light from the sun and at night tends to decay uniformly with time. The D layer ionization is largely absent during night A sporadic E layer is not a thick layer. It is formed without any cause. The ionization is often present in the region, in addition to the regular E ionization. Sporadic E exhibits the characteristics of a very thin layer appearing at a height of about 90 to 130 Kms. Often, it occurs in the form of clouds, varying in size from 1 Km to several 100 Kms across and its occurrence is quite unpredictable. It may be observed both day and night and its cause is still uncertain as shown in figure.4.4.

Basically the troposphere is the region atmosphere. It is adjacent to the earth and is located up to about 1 kilometers with the height temperature of this region decreases 6.5▫c per kilometer it is observed that up to upper boundary of the troposphere, temperature may decreases up to 5 in this region the clouds are formed next to the troposphere. Troposphere. The propagation through the troposphere takes place due to mechanisms such as diffraction normal refraction, abnormal reflection and refraction and troposphere scattering. Let us consider few of them in brief it clear that the radius of curvature depends on the rate of change of the dielectric constant with the height .thus it is observed that the radius of curvature varies from hour to hour, day to day and season even though there is such a variation in radius of curvature, for the practical calculation, average value of four times the radius of earth is used.

In the analysis of propagation problems practically ray in the straight path is considered. then to compensate for the curvature, the effective radius of the earth is selected very large. the actual path of radius a is .the imagined straight line path.Thus when the radius of curvature p equals to four times radius of the earth, then the effective radius of the earth equals to 4/3 times actual radius of the earth.

Abnormal Reflection and Refraction

As discussed previously, the refraction of waves take place in the troposphere even under normal conditions. along with this, there are chances of further refractions and reflections which are due to the abrupt variation in the refractive index and its gradient. The important point here is that where the permittivity of the medium changes abruptly, the reflections are resulted can produce usable signal beyond the range compared with only ground wave propagation

Reflection

Reflection occurs when an electromagnetic wave falls on an object, which has very large dimensions as compared to the wavelength of the propagating wave. For example, such objects can be the earth, buildings and walls. When a radio wave falls on another medium having different electrical properties, a part of it is transmitter into it, while some energy is reflected back. Let us see some special cases. If the medium on which the EM wave is incident is a dielectric, some energy is reflected back and some energy is transmitted. If the medium is a perfect conductor, all energy is reflected back to the first medium. The amount of energy that is reflected back depends on the polarization of the EM wave particular case of interest arises in parallel polarization, when no reflection occurs in the medium of origin. This would occur, when the incident angle would be such that the reflection coefficient is equal to zero. This angle is the Brewster's angle.

Mechanism of ionospheric propagation _reflection &refraction

Ionospheric propagation involves reflection of wave by the ionosphere .In actual mechanism; refraction takes place as shown in fig. 4.5

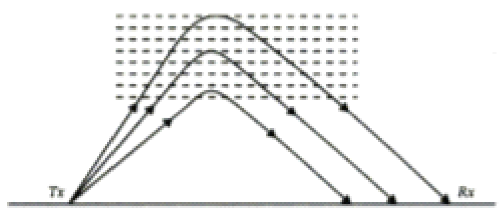

Fig 4.5 Ionospheric reflection and refraction

At ionization density increases at an angle for the incoming wave, the refraction index of the layer decreases and the dielectric constant also decreases; hence the incident wave is gradually bent away from the normal. Sufficient, the refracted ray finally becomes parallel to the layer .then it bends downwards and returns from the ionized at an equal to the angle of incidence. Although, some absorption takes place depending on the frequency the wave is returned by the ionosphere to the receiver on earth. As a result ionosphere propagation takes place through reflection and refraction of EM waves in the ionosphere.

The bending of wave produced by the ionosphere as shown in figure.4.6 follows the optical laws the direction of propagating wave at a point in the ionosphere is given by Snell's law that is,

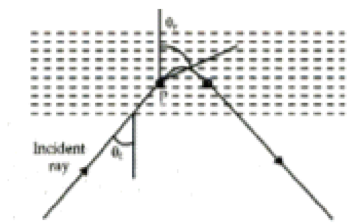

Fig 4.6 Refraction of EM waves in ionosphere

The skip distance defined as the shortest Distance from the transmitter that is covered by a fixed Frequency (>fc).When the angle of incident is large ,ray 1 returns to ground at a long distance from the transmitter. If the angle is reduced,ray 2 returns to a point closer to the transmitter .So there is always possibility that short distance may not be covered by sky-wave propagation under certain conditions. The Transmission path is limited by the skip distance and curvature of the earth.

4.4 SKY WAVE PROPAGATION

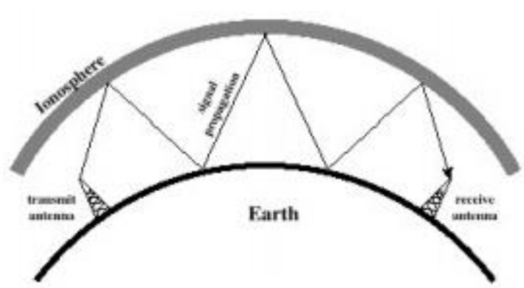

Fig 4.7 Sky wave propogation

When the critical angle is less than 90 degree there will always be a region around the transmitting site where the ion spherically propagated signal cannot be heard, or is heard weakly. This area lies between the outer limit of the ground-wave range and the inner edge of energy return from the ionosphere. It is called the skip zone, and the distance between the originating site and the beginning of the ionosphere return is called the skip distance. This terminology should not to be confused with ham jargon such as "the skip is in," referring to the fact that a band is open for sky-wave propagation. The signal may often be heard to some extent within the skip zone, through various forms of scattering, but it will ordinarily be marginal in strength. When the skip distance is short, both ground wave and sky-wave signals may be received near the transmitter. In such instances the sky wave frequently is stronger than the ground wave, even as close as a few miles from the transmitter. The ionosphere is an efficient communication medium under favorable conditions. Comparatively, the ground wave is not.

Sky wave propagation is practically important at frequencies between 2 to 30 MHz Here the electromagnetic waves reach the receiving point after reflection from an atmospheric layer known as ionosphere as shown in figure 4.7. Hence, sky wave propagation is also known as 'ionospheric wave propagation'. It can provide communication over long distances. Hence, it is also known as point-to-point propagation or point-to-point communication.

Virtual heights: The virtual height (h) has the great advantage of being easily measured, and it is very useful in transmission path calculations. For fiat earth approximation and assuming that ionosphere conditions are symmetrical for incident and refracted waves,

The transmission path distance,

$TR=2h/\tan\beta$

Where β=Angle of elevation

h =Virtual height

Critical frequency: When the refractive index n has decreased to the point where $n = \sin \varphi i$ the angle of refraction φ will be 90° and wave will be travelling horizontally. The higher point reached by the wave is free. If the electron density at some level in a layer is sufficient great to satisfy the above condition. Then the wave will be returned to earth from that level. If maximum electron density in a layer is less than n', the wave will penetrate the layer (Though it may be reflected back from a higher layer for which N is greater). The largest electron density required for reflection occurs when the angle of incident φi is zero, i.e., for vertical incidence. For any given layer the highest frequency that will be reflected back for vertical incidence.

The characteristics of the ionosphere layers are usually described in terms of their virtual heights and critical frequencies, as these quantities can be readily measured. The virtual height is the height that would be reached by a short pulse of energy showing the same time delay as the actual pulse reflected from the layer travelling with the speed of light. The virtual height is always greater than the true height of reflection, because the interchange of energy taking place between the wave and electrons of the ionosphere causes the velocity of propagation to be reduced. The extent of this difference is influenced, by the electron distributions in the regions below the level of reflection. It is usually very small, but on occasions may be as large as 100 Kms or so.

The critical frequency is the highest frequency that is returned by a layer at vertical incidence. For regular layers,

fc =√max electron density in the layer

i.e. fc =√Ne

The critical frequencies of the E and F1 layers primarily depend on the zenith angle of the sun. It, therefore, follows a regular diurnal cycle, being maximum at noon and tapering off an either side. The fc of the F2 layer shows much larger seasonal variation and also changes more from day to day. It can be seen that the critical frequencies of the regular layers decrease greatly during night as a result of recombination in the absence of solar radiation. But the fc of sporadic E shows regular variation throughout the day and night suggesting that sporadic E is affected strongly by factors other than solar radiation. There is a long term variation in all ionosphere characteristics closely associated with the 11 year sunspot cycle. From the minimum to maximum of the cycle, fc of F2 layer varies from about 6 to 11 MHz (ratio of 1:1.8), fc of E layer varies from 3.1 to 3.8 MHz (a ratio of mere 1 to 1.2). Long term predictions of ionosphere characteristics are based on predictions of the sunspot number.

Maximum usable Frequency: Although the critical frequency for any layer represents the highest frequency that will be reflected back from that layer at vertical incidence, it is not the highest frequency that can be reflected from the layer. The highest frequency that can be reflected depends also upon the angle of incidence, and hence, for a given layer height, upon the distance between the transmitting and receiving points. The maximum, frequency that can be reflected back for a given distance of transmission is called the maximum usable frequency

(MUF) for that distance. It is seen that the MUF as shown in figure.4.8. is related to the critical frequency and the angle of incidence by the simple expression

MUF =f cr secφi

The MUF for a layer is greater than the critical frequency by the factor sec φi the largest angle of incidence φi that can be obtained in F-layer reflection is of the order of 74°. This occurs for a ray that leaves the earth at the grazing angle Where φimax =sin - 1 (r/r+h)

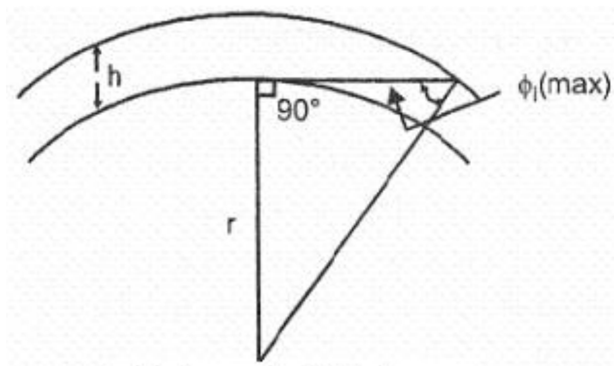

Fig. 4.8 Geometry of MUF

Geometry of MUF

The MUF at this limiting angle is related to the critical frequency of the layer by MUFmax = f cr/ cos 74 o =3.6 f cr

Disadvantage

Sky wave propagation suffers, from fading due to reflections from earth surface; fading can be reduced with the help of diversity reception.

Applications

1. It can provide communication over long distances.
2. Global communication is possible.

4.5 FADING

The term fading, or, small-scale fading, means rapid fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a short period or short travel distance. This might be so severe that large scale radio propagation loss effects might be ignored.

Factors Influencing Fading

The following physical factors influence small-scale fading in the radio propagation channel:

(1) Multipath propagation – Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. The effects of multipath include constructive and destructive interference, and phase shifting of the signal.

(2) Speed of the mobile – The relative motion between the base station and the mobile results in random frequency modulation due to different doppler shifts on each of the multipath components.

(3) Speed of surrounding objects – If objects in the radio channel are in motion, they induce a time varying Doppler shift on multipath components. If the surrounding objects move at a greater rate than the mobile, then this effect dominates fading.

(4) Transmission Bandwidth of the signal – If the transmitted radio signal bandwidth is greater than the "bandwidth" of the multipath channel (quantified by coherence bandwidth), the received signal will be distorted.

Selective Fading

This type of fading produces serious distortion in modulated signal. Selective fading is important at higher frequencies. Selective fading generally occurs in amplitude modulated signals. SSB signals become less distorted compared to the AM signals due to selective fading.

Interference Fading

Interference fading occurs due to the variation in different layers of ionosphere region. This type of fading is very serious and produces interference between the upper and lower rays of sky wave propagation. Interference fading can be reduced with the help of frequency and space diversity reception.

4.6 DIVERSITY RECEPTION

- To reduce fading effects, diversity reception techniques are used. Diversity means the provision of two or more uncorrelated (independent) fading paths from transmitter to receiver

- These uncorrelated signals are combined in a special way, exploiting the fact that it is unlikely that all the paths are poor at the same time. The probability of outage is thus reduced.

- Uncorrelated paths are created using polarization, space, frequency, and time diversity

Frequency Diversity

Different frequencies mean different wavelengths. The hope when using frequency diversity is that the same physical multipath routes will not produce simultaneous deep fades at two separate wavelengths.

Space Diversity

Deep multipath fade have unlucky occurrence when the receiving antenna is in exactly in the 'wrong' place. One method of reducing the likelihood of multipath fading is by using two receive antennas and using a switch to select the better signal. If these are physically separated then the probability of a deep fade occurring simultaneously at both of these antennas is significantly reduced. ·

Angle Diversity: In this case the receiving antennas are co-located but have different principal directions. ·

Polarization Diversity: This involves simultaneously transmitting and receiving on two orthogonal polarizations (e.g. horizontal and vertical). The hope is that one polarization will be less severely affected when the other experiences a deep fade. ·

Time Diversity: This will transmit the desired signal in different periods of time. The intervals between transmissions of the same symbol should be at least the coherence time so that different copies of the same symbol undergo independent fading.

4.7 FREE SPACE RADIO WAVE PROPAGATION

There are two basic ways of transmitting an electro-magnetic (EM) signal, through a guided medium or through an unguided medium. Guided mediums such as coaxial cables and fiber optic cables are far less hostile toward the information carrying EM signal than the wireless or the unguided medium. It presents challenges and conditions which are unique for this kind of transmissions. A signal, as it travels through the wireless channel, undergoes many kinds of propagation effects such as reflection, diffraction and scattering, due to the presence of buildings, mountains and other such obstructions. Reflection occurs when the EM waves impinge on objects which are much greater than the wavelength of the traveling wave. Diffraction is a phenomena occurring when the wave interacts with a surface having sharp irregularities. Scattering occurs when the medium through the wave is traveling contains objects which are much smaller than the wavelength of the EM wave. These varied phenomena's lead to large scale and small scale propagation losses. Due to the inherent randomness associated with such channels they are best described with the help of statistical models. Models which predict the mean signal strength for arbitrary transmitter receiver distances are termed as large scale propagation models. These are termed so because they predict the average signal strength for large Tx-Rx separations, typically for hundreds of kilometers.

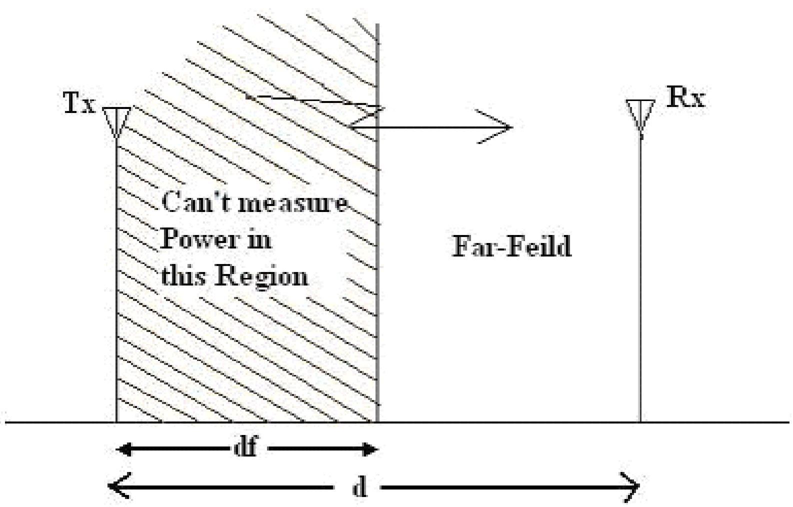

Fig 4.9 Space wave propagation

4.8 CONSIDERATION IN SPACE WAVE PROPAGATION

The space wave field strength is affected by the following

1. Curvature of the earth

2. Earth's imperfections and roughness

3. Hills, tall buildings and other obstacles

4. Height above the earth.

5. Transition between ground and space wave

6. Polarization

4.9 ATMOSPHERIC EFFECTS IN SPACE WAVE PROPAGATION

There is a significant effect of the atmosphere through which the space wave travels on the propagation. This is basically because of presence of gas molecules particularly of a water vapor. Water vapor has a high dielectric constant and its presence causes the air of the troposphere to have a dielectric constant and its presence causes the air of troposphere to have a dielectric constant slightly greater than unity. the distribution of water vapor is not uniform through out of the air and along with it the density of the air varies with height .As a consequence of the dielectric constant and in turn the refractive index of air also depend upon the height it is in general observed to be deceasing with increasing height gives rise to a variety of phenomena like reflection, refraction ,scattering, duct transmission and fading of signals. The behavior of the space wave under the different conditions can be better studied by changing the co - ordinates in such a manner that the particular ray path of interest is a straight line instead of a curve. for this , the radius of curvature of the earth is required to be simultaneously readjusted to preserve the correct relative relation.

4.10 **DUCT PROPAGATION**

Duct propagation is phenomenon of propagation making use of the atmospheric duct region. The duct region exits between two levels where the variation of modified refractive index with height is minimum. It is also said to exist between a level .where the variation of modified refractive index and a surface bounding the atmosphere. The higher frequencies or microwaves are continuously reflected in the duct and reflected by the ground.So that they propagate around the curvature for beyond the line of sight. This special refraction electromagnetic waves is called super refraction and the process is called duct propagation. Duct propagation is also known as super refraction. Consider the figure .4.10

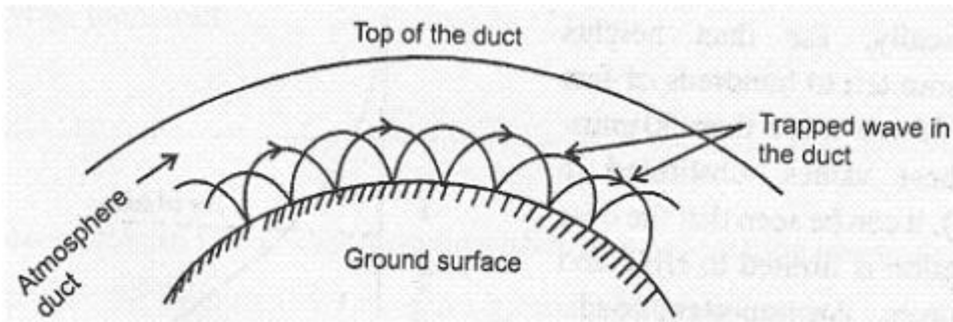

Fig. 4.10 Duct Propagation

Here, two boundary surfaces between layers of air form a duct or a sort of wave guide which guides the electromagnetic waves between the walls. Temperature inversion is one of the important factor for the formation of duct. For proper value of curvature, the refractive index (n) must be replaced by a modified refractive index (N). N = n + (h/r) The term modified index of refractive modules (m) is related to N as N = n + (h/r) (N-1) = n-1+ h/r (N-1) x 106 = [n-1+ h/r] x 106 m = (N-1) x 106 = [n-1+ h/r] x 106 Where, n = Refractive index h = Height above ground r = Radius of the earth = 6370 km Duct can be used at VHF, UHF and microwave frequencies. Because, these waves are neither reflected nor propagated along earth surface. So, the only possible way to transmit such signal is to utilize the phenomenon of refraction in the troposphere.

TEXT / REFERENCE BOOKS

1. K.D.Prasad, "Antennas and Wave Propagation", 3rd Edition, Satya Prakasan, New Delhi, 2003.
2. R.L. Yadava, "Antennas and Wave Propagation", 2nd Edition, PHI Learning Private Limited, New Delhi, 2011.
3. Balanis C.A., "Antenna Theory and Design", 4th Edition, John Wiley & Sons, 2016.
4. Jordan E.C., Balmain, K.G., "Electromagnetic Waves and Radiating Systems", 2nd Edition, Prentice Hall of India, 2006.
5. Collin R.E., "Antennas and Radio Wave Propagation", McGraw Hill, 1985.

PART A

1. Explain fading?

2. Define skip distance.

3. Classify propagation of radio waves.

4. State diversity reception?

5. State MUF.

6. Analyze super refraction?

7. List the factors that affect the propagation of radio waves?

8. State duct propagation?

9. Interpret critical frequency?

10. Define Gyro frequency.

PART B

1. Demonstrate an expression for effective dielectric constant of the Ionosphere.
2. Illustrate the following : a) skip distance b) Fading c) Duct-wave propagation
3. Compare the space wave and sky wave propagation.
4. Give explanation about the Ground wave propagation.
5. Analyze and explain the mechanism of Ionospheric propagation and the different layers in it.
6. Interpret fading of signal and its types.
7. Demonstrate the expression for the refractive index of the ionosphere.
8. Summarize the effects of earth's magnetic field on ionosphere radio wave propagation.
9. Illustrate the various diversity reception methods.
10. Demonstrate the troposphere and explain how ducts can be used for microwave propagation.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF ELECTRICAL AND ELECTRONICS
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT – V – ANTENNA AND WAVE PROPAGATION- SECA1505

UNIT V SMART ANTENNAS

Concepts and Benefits of Smart antennas - Fixed weight beamforming- Adaptive beamforming – Design of Planar array antennas for Beamforming applications – Feed techniques for Planar arrays - Role of Smart Antennas in Green Communications and 5G wireless communications –Software Tools for Antenna Design and Analysis

5.1 Smart Antennas

Recently and over the last decade, the wireless and mobile technologies in addition to the new and improved services have grown rapidly at exponential and formidable rate. In the evolution of the modern telecommunication networks and multiple access systems, the employment of the spatial processing approaches and techniques becomes essential according to the related standards. The spatial processing is considered as the main idea behind the use of adaptive and smart antennas, antenna arrays, beam forming algorithms, interference cancelation, bandwidth-efficient signaling systems, and direction of arrival (DOA) estimation schemes (in the case of non-blind beam forming).

Smart antenna system basically consists of multiple antennas or antenna arrays and digital signal processing algorithms that are in charge of very important functions such as DOA estimation of the signals. In general, the wireless communication systems development stages can be classified based on the adopted technologies driven by the challenges of capacity demand and quality of service (QoS) requirements. These stages are summarized as follows:

Omni-directional systems: with conventional cellular structure, frequency reuse (7 cells reuse patterns), Omni-directional antenna types in the base station at the center of each cell.

Cell splitting and sectorized systems: smaller cells (micro-cells), cell sectoring with several directional antennas in the base station.

Smart antenna systems : with dynamic cell sectorization, multiple antennas (antenna arrays), innovative signal processing algorithms, and beam forming techniques (user location based beam assignment).

The aforementioned smart antenna systems are widely implemented in two forms, namely, the switched beam approach where the system can choose one of many predefined antenna beam patterns (the antenna radiation or propagation pattern is defined as graphical representation of the power variation and radiation properties of the antenna as a function of the direction and space coordinates), and the adaptive array approach where the antenna adapts the radiation pattern beams in real time in accordance with the radio environment.

The smart antennas systems achieve higher capacity increase in comparison with the switched beam systems especially in the case of densely populated coverage areas and reduce more effectively the negative impacts of the interference. Additionally, there are more advantages that can be counted in favor of adaptive array systems such as range increasing, security enhancement (more difficult to tap any connection), and location-based services improvements especially for emergency situations (spatial detection characteristics).

As in the case of any system or technology, some disadvantages or drawbacks of the smart antenna systems are found like the complexity of transmitters and receivers design, the high computation intensity with the need of powerful digital signal processors (DSPs), and the overall system employment cost.

Advantages of Smart Antenna System

Numerous advantages of Smart Antenna System include:

- It improves the wireless system performance
- It is economic for a large range of potential users
- It increases in signal quality, capacity as well as the coverage
- It is now possible to multiple channels in spatial dimension

Disadvantages of Smart Antenna System

It comes with disadvantages along with the advantages mentioned above. They are:

- Smart Antenna System is complex in design
- Very expensive
- Larger size than traditional one
- Applications of Smart Antenna System
- It is efficiently used in cellular and wireless networks
- It is highly usable in radars
- Electronic warfare is used as a countermeasure to the electronic jamming
- It is used in the satellite systems

5.2 Fixed weight Beam forming:

Fixed beam forming generally describes a conventional technique where the antenna array pattern is obtained from fixed element weights that do not depend on the signal environment. Conventional beamformers, such as the Butler matrix, use a fixed set of weightings and time-delays (or phasings) to combine the signals from the sensors in the array, primarily using only information about the location of the sensors in space and the wave directions of interest. In contrast, adaptive beamforming techniques (e.g., MUSIC, SAMV) generally combine this information with properties of the signals actually received by the array, typically to improve rejection of unwanted signals from other directions. This process may be carried out in either the time or the frequency domain.

5.3Antenna arrays

In many applications, it is necessary to design antennas with very directive characteristics (very high gains) to meet demands for long distance communication. In general, this can only be accomplished by increasing the electrical size of the antenna. Another effective way is to form an assembly of radiating elements in a geometrical and electrical configuration, without necessarily increasing the size of the individual elements. Such a multi element radiation device is defined as an *antenna array*. The total electromagnetic field of an array is determined by vector addition of the fields radiated by the individual elements, combined properly in both amplitude and phase.

Antenna arrays can be one-, two-, and three-dimensional. By using basic array geometries, the analysis and synthesis of their radiation characteristics can be simplified. In an array of identical elements, there are at least five individual controls (degrees of freedom) that can be used to shape the overall pattern of the antenna. These are:

i. geometrical configuration of the overall array (linear, circular, rectangular, spherical,etc.)

ii. relative displacement between the elements

iii. amplitude excitation of the individual elements

iv. phase excitation of the individual elements

v. relative pattern of the individual elements

5.4 Smart Antennas

Many refer to smart antenna systems as smart antennas, but in reality antennas by themselves are not smart. It is the digital signal processing capability, along with the antennas, which make the system smart. Although it may seem that smart antenna systems are a new technology, the fundamental principles upon which they are based are not new. In fact, in the 1970s and1980s two special issues of the *IEEE Transactions on Antennas and Propagation* were devoted to adaptive antenna arrays and associated signal processing techniques.

The use of adaptive antennas in communication systems initially attracted interest in military applications. Particularly, the techniques have been used for many years in electronic warfare (EWF) as counter measures to electronic jamming. In military radar systems, similar techniques were already used during World War-II. However, it is only because of today's advancement in powerful low-cost digital signal processors, general-purpose processors and ASICs (Application Specific Integrated Circuits), as well as innovative software-based signal processing techniques (algorithms),that smart antenna systems are gradually becoming commercially available.

Need for Smart Antennas

Wireless communication systems, as opposed to their wire line counterparts, pose some unique challenges:

i. the limited allocated spectrum results in a limit on capacity

ii. the radio propagation environment and the mobility of users give rise to signal fading and spreading in time, space and frequency

iii. The limited battery life at the mobile device poses power constraints

In addition, cellular wireless communication systems have to cope with interference due to frequency reuse. Research efforts investigating effective technologies to mitigate such effects have been going on for the past twenty five years, as wireless communications are experiencing rapid growth. Among these methods are multiple access schemes, channel coding and equalization and smart antenna employment.

Human auditory function and Smart Antenna System

The basic idea on which smart antenna systems were developed is most often introduced with a simple intuitive example that correlates their operation with that of the human auditory system. A person is able to determine the Direction of Arrival (DoA) of a sound by utilizing a three-stage process:

- One's ears act as acoustic sensors and receive the signal.
- Because of the separation between the ears, each ear receives the signal with a different time delay.
- The human brain, a specialized signal processor, does a large number of calculations tocorrelate information and computes the location of the received sound.

To better provide an insight of how a smart antenna system works, let us imagine two persons carrying on a conversation inside an isolated room as illustrated in Fig. 5.1. The listener among the two persons is capable of determining the location of the speaker as he moves about the room because the voice of the speaker arrives at each acoustic sensor, the ear, at a different time. The human "signal processor," the brain, computes the direction of the speaker from the time differences or delays received by the two ears. Afterward, the brain adds the strength of the signals from each ear so as to focus on the sound of the computed direction.

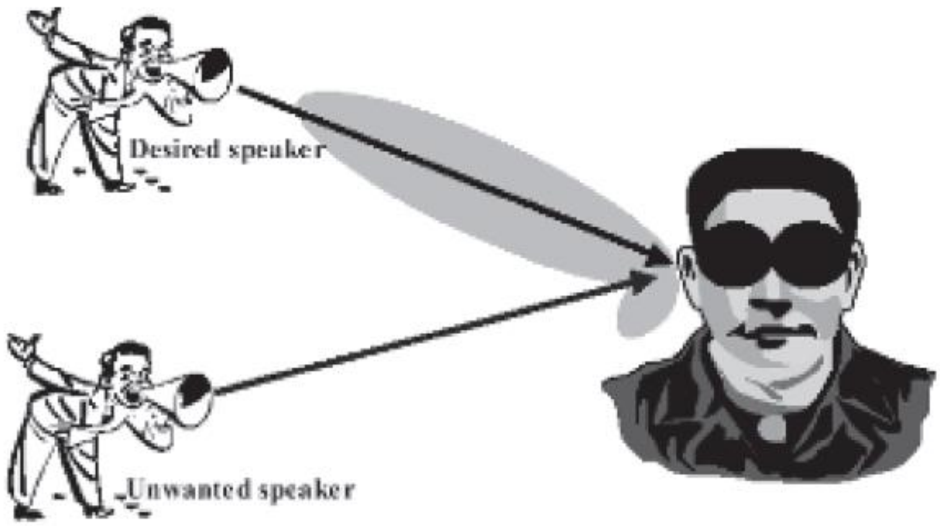

Fig 5.1: Human auditory function.

Utilizing a similar process, the human brain is capable of distinguishing between multiple signals that have different directions of arrival. Thus, if additional speakers join the conversation, the brain is able to enhance the received signal from the speaker of interest and tune out unwanted interferers. Therefore, the listener has the ability to distinguish one person's voice, from among many people talking simultaneously, and concentrate on one conversation at a time. In this way, any unwanted interference is attenuated. Conversely, the listener can respond back to the same direction of the desired speaker by orienting his/her transmitter, his/her mouth, toward the speaker.

Smart antenna systems work the same way using two antennas instead of two ears, and a digital signal processor instead of the brain as seen in Fig. 5.2.

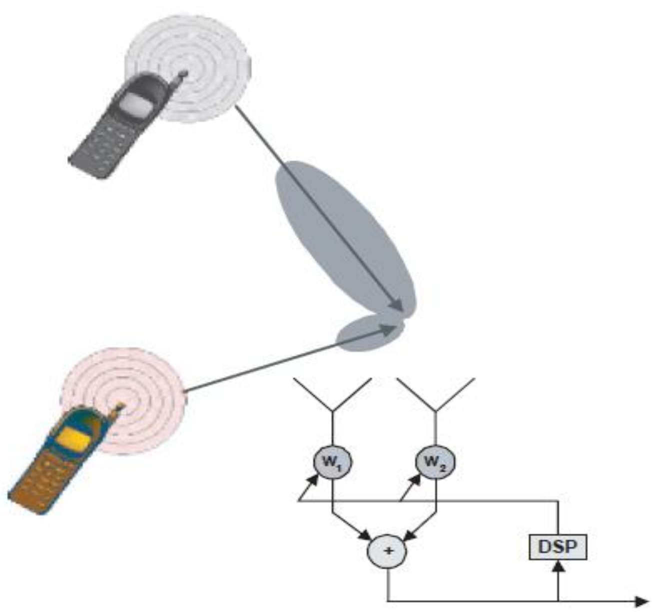

Fig 5.2. A two-element electrical smart antenna

Thus, based on the time delays due to the impinging signals onto the antenna elements, the digital signal processor computes the direction-of-arrival (DOA) of the signal-of-interest (SOI), and then it adjusts the excitations (gains and phases of the signals) to produce a radiation pattern that focuses on the SOI while tuning out any interferers or signals-not-of-interest (SNOI).Transferring the same idea to mobile communication systems, the base station plays the role of the listener, and the active cellular telephones simulate the role of the several sounds heard by human ears. The principle of a smart antenna system is illustrated in Fig. 5.3.

A digital signal processor located at the base station works in conjunction with the antenna array and is responsible for adjusting various system parameters to filter out any interferers or signals-not-of-interest (SNOI) while enhancing desired communication or signals-of-interest (SOI). Thus, the system forms the radiation pattern in an adaptive manner, responding dynamically to the signal environment and its alterations. The principle of beam forming is essentially to weight the transmit signals in such a way that the receiver obtains a constructive superposition of different signal parts. Note that some knowledge of the transmission channel at the transmitter is necessary in order for beam forming to be feasible.

5.5 Smart Antenna Configurations

Basically, there are two major configurations of smart antennas:

- Switched-Beam: A finite number of fixed, predefined patterns or combining strategies (sectors).
- Adaptive Array: A theoretically infinite numbers of patterns (scenario-based) that are adjusted in real time according to the spatial changes of SOIs and SNOIs.

In the presence of a low level interference, both types of smart antennas provide significant gains over the conventional sectorized systems. However, when a high level interference is present, the interference rejection capability of the adaptive systems provides significantly more coverage than either the conventional or switched beam system.

5.5.1 Switched-Beam Antennas

A switched-beam system is the simplest smart antenna technique. It forms multiple fixed beams with heightened sensitivity in particular directions. Such antenna system detects signal strength, chooses from one of several predetermined fixed beams, and switches from one beam to another as the cellular phone moves throughout the sector, as illustrated in Fig.5.3.

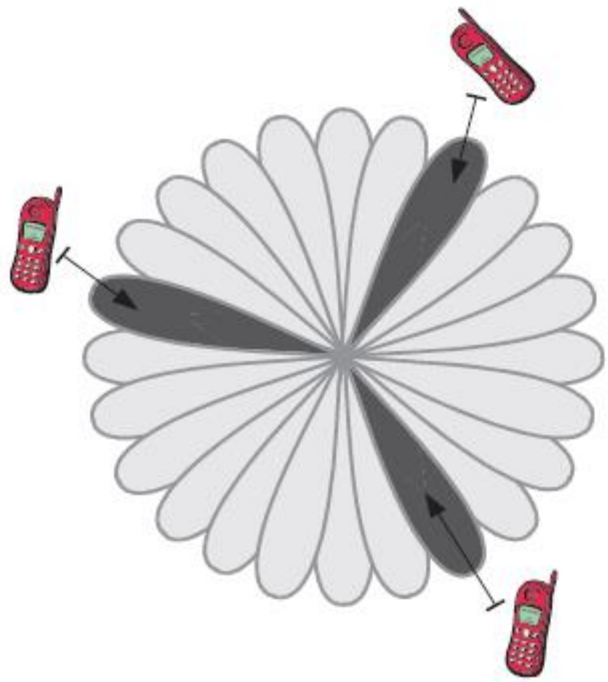

Fig.5.3: switched-beam coverage pattern

The switched-beam, which is based on a basic switching function, can select the beam that gives the strongest received signal. By changing the phase differences of the signals used to feed the antenna elements or received from them, the main beam can be driven indifferent directions throughout space. Instead of shaping the directional antenna pattern, the switched-beam systems combine the outputs of multiple antennas in such a way as to form narrow sectorized (directional) beams with more spatial selectivity that can be achieved with conventional, single-element approaches. Other sources in the literature define this concept as *phased array* or *multi-beam antenna*. Such a configuration consists of a number of fixed beams either with one beam turned on toward the desired signal or a single beam that is steered toward the desired signal.

A more generalized to the Switched-Lobe concept is the Dynamical Phased Array (DPA). In this concept, a direction of arrival (DOA) algorithm is embedded in the system. The DOA is first estimated and then different parameters in the system are adjusted in accordance with the desired steering angle. In this way, the received power is maximized but with the trade-off of more complicated antenna designs. The elements used in these arrays must be connected to the sources and/or receivers by feed networks.

One of the most widely-known multiple beamforming networks is the *Butler matrix*. It is a linear, passive feeding, $N \times N$ network with beam steering capabilities for phased array antennas with N outputs connected to antenna elements and N inputs or beam ports. The Butler matrix performs a spatial fast Fourier transform and provides N orthogonal beams, where N should be an integer power of 2 (i.e. $N = 2^n$, $n \in Z^+$)]. These beams are linear independent combinations of the array element patterns. A Butler matrix-fed array can cover a sector of up to 360◦ depending on element patterns and spacing. Each beam can be used by a dedicated transmitter and/or receiver and the appropriate beam can be selected using an RF switch. A Butler matrix can also be used to steer the beam of a circular array by exciting the Butler matrix beam ports with amplitude and phase weighted inputs followed by a variable uniform phase taper. The only required transmit/receive chain combines alternate rows of hybrid junctions (or directional couplers) and fixed phase shifters. Fig. 5.4 shows a schematic diagram of a 4 × 4 Butler matrix.

A total of $(N/2) \times \log_2 N$ hybrids and $(N/2) \times \log_2(N-1)$ fixed phase shifters are required to form the network. The hybrids can be either 90° or 180° 3 dB hybrids, depending on if the beams are to be symmetrical distributed about the broadside or whether one of the beams is to be in the broadside direction. A Butler matrix serves two functions:

- distribution of RF signals to radiating antenna elements and
- orthogonal beam forming and beam steering.

By connecting a Butler matrix between an antenna array and an RF switch, multiple beam forming can be achieved by exciting two or more beam ports with RF signals at the same time. A signal introduced at an input port will produce equal excitations at all output ports with a progressive phase between them, resulting in a beam radiated at a certain angle in space. A signal at another input port will form a beam in another direction, achieving beam steering.

If ports 1*R* and 4*L* are excited at the same time with RF signals of equal amplitude and phase, beams 2*R* and 3*L* will radiate simultaneously. Although multiple beam forming is possible, there is a limitation. Two adjacent beams cannot be formed simultaneously as they will add to produce a single beam.

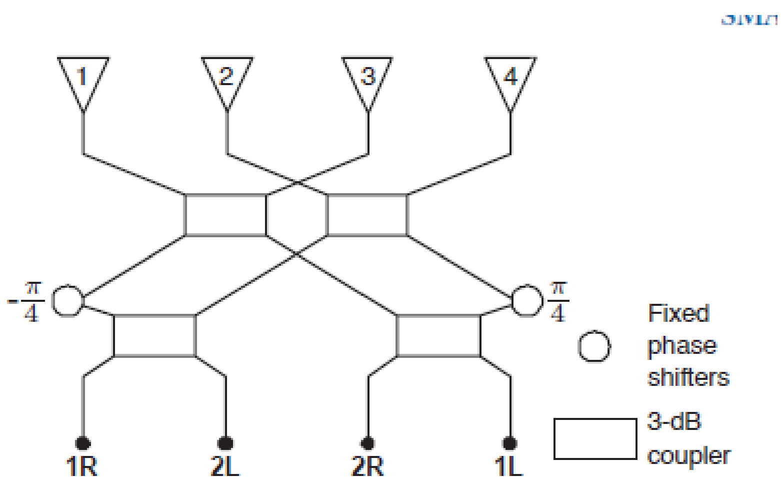

Fig. 5.4 a schematic diagram of a 4 × 4 butler matrix.

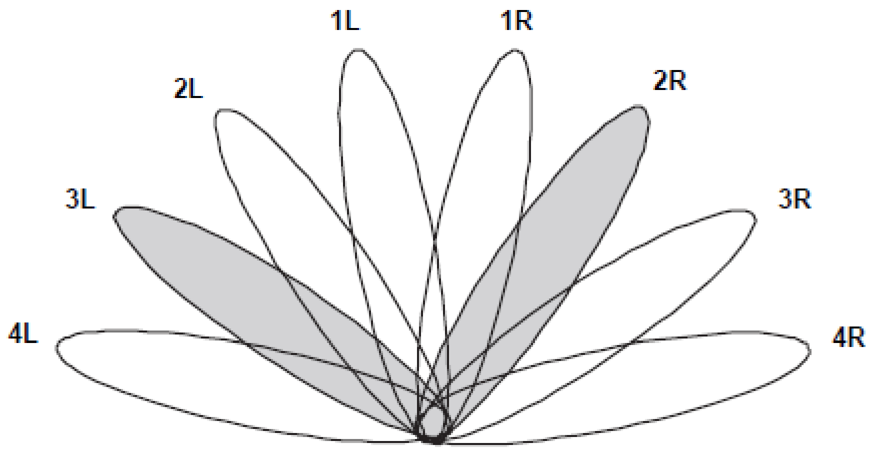

Fig.5. 8 orthogonal beams formed by an 8 × 8 butler matrix.

5.5.2Adaptive Antenna Approach

The adaptive antenna systems approach communication between a user and a base station in a different way by adding the dimension of space. By adjusting to the RF environment as it changes (or the spatial origin of signals), adaptive antenna technology can dynamically alter the signal patterns to optimize the performance of the wireless system.

Adaptive array systems provide more degrees of freedom since they have the ability to adapt in real time the radiation pattern to the RF signal environment; in other words, they can direct the main beam toward the pilot signal or SOI while suppressing the antenna pattern in the direction of the interferers or SNOIs. To put it simply, adaptive array systems can customize an appropriate radiation pattern for each individual user. Fig. 5.6 illustrates the general idea of an adaptive antenna system.

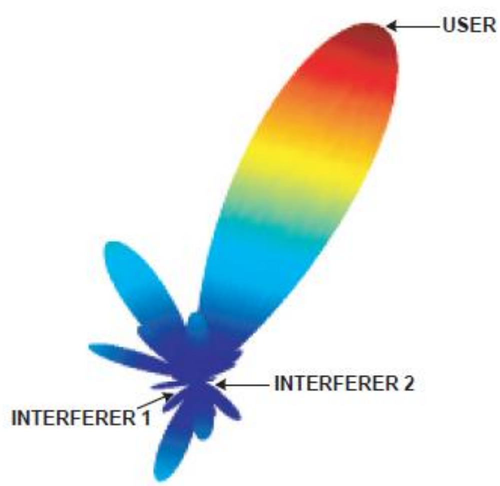

Fig. 5.6: adaptive array coverage

The adaptive concept is far superior to the performance of a switched-beam system. Adaptive array systems can locate and track signals (users and interferers) and dynamically adjust the antenna pattern to enhance reception while minimizing interference using signal processing algorithms .A functional block diagram of the digital signal processing part of an adaptive array antenna system is shown in Fig. 5.7.

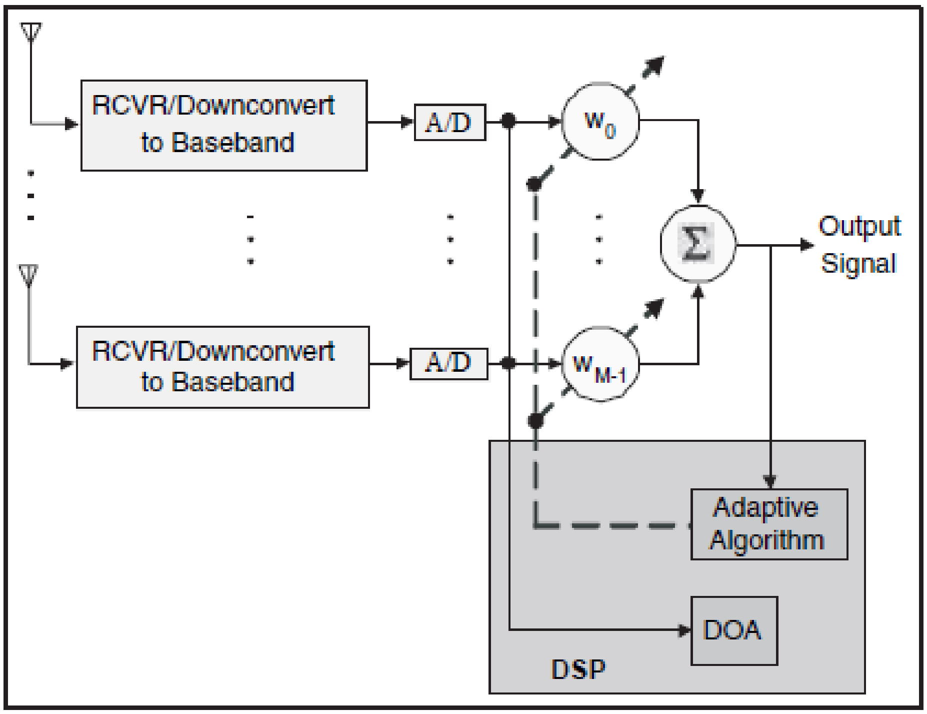

FIGURE 5.7: Functional block diagram of an adaptive array system.

After the system down converts the received signals to baseband and digitizes them, it locates the SOI using the direction-of-arrival (DOA) algorithm, and it continuously tracks the SOI and SNOIs by dynamically changing the complex weights (amplitudes and phases of the antenna elements). Basically, the DOA computes the direction-of-arrival of all the signals by computing the time delays between the antenna elements, and afterward, the adaptive algorithm, using a cost function, computes the appropriate weights that result in an optimum radiation pattern. Because adaptive arrays are generally more digital processing intensive and require a complete RF portion of the transceiver behind each antenna element, they tend to be more expensive than switched-beam systems.

Adaptive arrays utilize sophisticated signal-processing algorithms to continuously distinguish between desired signals, multipath, and interfering signals, as well as calculate their Directions of Arrival (DOA). This approach updates its transmit strategy continuously based on changes in both the desired and interfering signal locations. A number of well-documented algorithms exist for estimating the DOA; for example, MUSIC, ESPRIT, or SAGE. These algorithms make use of a data matrix with the array snapshots collected within the coherence time of the channel. In essence, spatial processing dynamically creates a different sector for each user and conducts a frequency/channel allocation in an ongoing manner in real time. Fig. 5.8 illustrates the beams of a fully adaptive antenna system supporting two users.

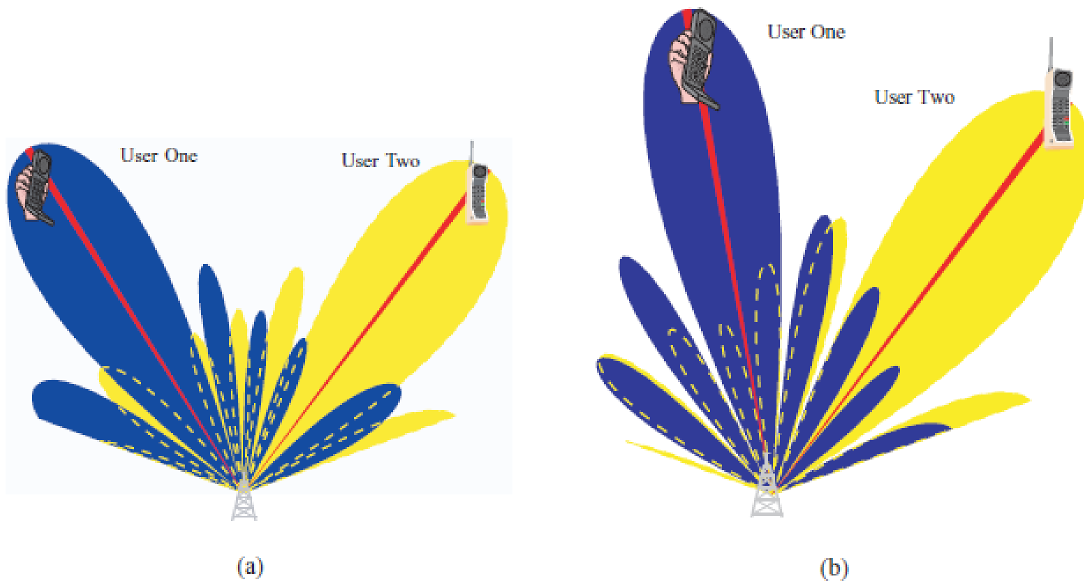

Fig 5.8: fully adaptive spatial processing supporting two users on the same conventional channel

In adaptive beam forming techniques, two main strategies are distinguished. The first one is based on the assumption that part of the desired signal is already known through the simultaneously in the same cell use of a training sequence. This known signal is then compared with what is received, and the weights are then adjusted to minimize the Mean Square Error (MSE) between the known and the received signals. In this way, the beam pattern can be adjusted to null the interferers. This approach optimizes the signal-to-interference ratio (SIR), and is applicable to non-line-of-sight (NLOS) environments. Since the weights are updated according to the incoming signals, not only the interference is reduced but the multipath fading is also mitigated. In the second one, the directions of arrivals from all sources transmitting signals to the array antenna are first identified.

The complex weights are then adjusted to produce a maximum toward the desired angle and null toward interfering signals. This strategy may turn out to be deficient in practical scenarios where there are too many DOAs due to multipath, and the algorithms are more likely to fail in properly detecting them. This is more likely to occur in NLOS environments where there are many local scatterers close to the users and the base station, thus resulting in wider spread of the angle of arrival.

Another significant advantage of the adaptive antenna systems is the ability to share spectrum. Because of the accurate tracking and robust interference rejection capabilities, multiple users can share the same conventional channel within the same cell. System capacity increases through lower inter-cell frequency reuse patterns as well as intra-cell frequency reuse. Fig. 5.9 shows how adaptive antenna approach can be used to support simultaneously two users in the same cell on the same conventional channel.

In each of the two plots, the pattern on the left is used to communicate with the user on the left while the pattern on the right is used to talk with the user on the right. The drawn lines delineate the actual direction of each signal. Notice that as the signals travel down the indicated line toward the base station, the signal from the right user arrives at a null of the left pattern or minimum gain point and vice versa. As the users move, beam patterns are constantly updated to insure these positions. The plot at the bottom of the figure shows how the beam patterns have dynamically changed to insure maximum signal quality as one user moves toward the other.

5.6 Architecture of a Smart Antenna System

Any wireless system can be separated to its reception and transmission parts. Because of the advanced functions in a smart antennas system, there is a greater need for better co-operation between its reception and transmission parts.

Smart Antenna Receiver

Fig. 5.9 shows schematically the block diagram of the reception part of a wireless system employing a smart antenna with *M* elements. In addition to the antenna itself, it contains a radio unit, a beam forming unit, and a signal processing unit.

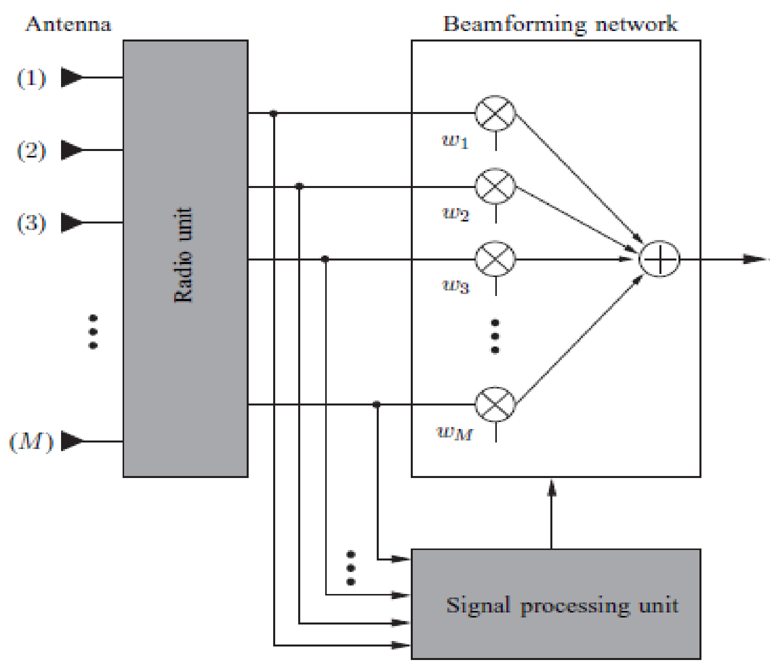

Fig. 5.9 reception part of a smart antenna

The number of elements in the array should be relatively low (the minimum required), in order to avoid unnecessarily high complexity in the signal processing unit. Array antenna scan be one-, two-, and three-dimensional, depending on the dimension of space one wants to access.

Fig. 5.10 shows different array geometries that can be applied in adaptive antennas implementations. The first structure is used primarily for beam forming in the horizontal plane (azimuth) only. This will normally be sufficient for outdoor environments; at least in large cells. The first example (a) shows a one-dimensional linear array with uniform element spacing of Δx. Such a structure can perform beam forming in one plane within an angular sector. This is the most common structure due to its low complexity. The second example (b) shows a circular array with uniform angular spacing between adjacent elements of $\Delta\phi = 2\pi/N$, where N represents the number of elements. This structure can perform beam forming in any direction but, because of its symmetry, is more appropriate for azimuthal beam forming.

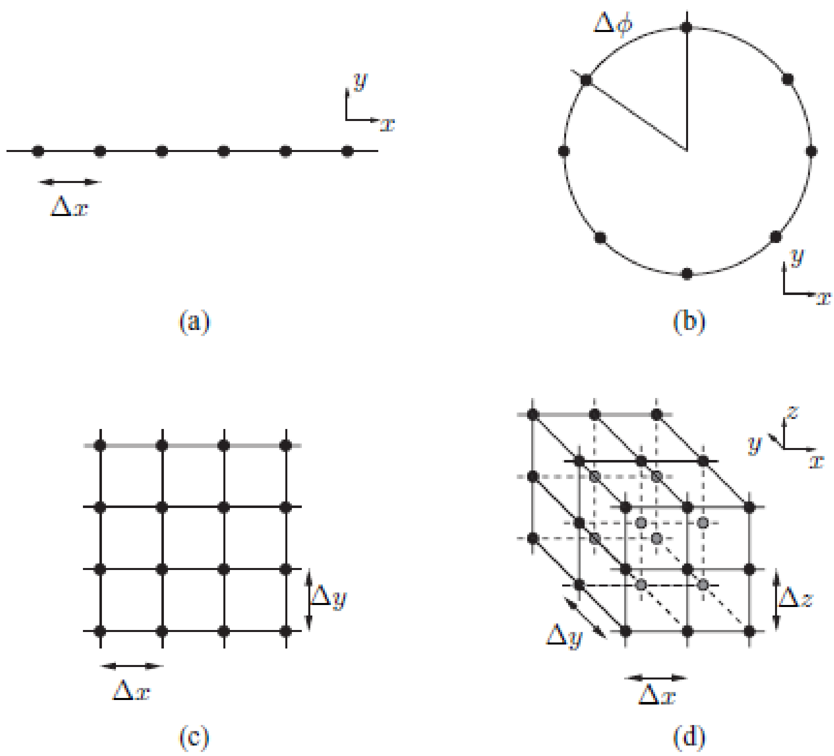

Fig 5.10: different uniform array geometries for smart antennas

The last two structures are used to perform two-dimensional beam forming, i.e. in both azimuthal and elevation angles .Such specifications are usually desirable for indoor or dense urban environments. The front view of a two-dimensional rectangular array with horizontal element spacing of Δx and vertical element spacing of $\Delta y$is shown in (c). Beamforming in the entire space, within all angles, requires some sort of cubic or spherical structure (three-dimensional configuration). The fourth example (d) shows a cubic structure with element separations of Δx, Δy, and Δz, respectively, in each direction in space.

The radio unit consists of down-conversion chains and (complex) analog-to-digital conversion (A/D). There must be M down-conversion chains, one for each of the array elements. The received signals from the mobile units are combined into one, which is the input to the remaining part of the receiver (amplifier, channel decoding, etc.).Based on the received signal, the signal-processing unit calculates the complex weights$w_1, w_2, \ldots, w_M$ with which they received signal from each of the array elements is multiplied. These weights will determine the antenna pattern in the uplink direction.

The estimate of the weights can be optimized using one of the two main criteria depending on the application and complexity:

a. Maximization of the power of the received signal from the desired user (e.g., switched beam or phased array), **or**
b. Maximization of the SIR by suppressing the signal received from the interference sources (adaptive array).

In theory, with M antenna elements, (M–1) sources of interference can be "nulled out", but this number will normally be lower due to the multipath propagation environment. The method for calculating the weights differs depending on the type of optimization criterion. When the switched-beam (SB) is used, the receiver will test all the predefined weight vectors (corresponding to the beam set) and choose the best one giving the strongest received signal level.

If the phased array approach (PA) is used, which consists of directing a maximum gain beam toward the strongest signal component, the weights are calculated after the direction-of-arrival (DOA) is first estimated. In the adaptive array approach (AA), where maximization of SIR is needed, the optimum weight vector (of dimension M) $\mathbf{w}opt$ can be computed using a number of algorithms such as optimum combining and others.

When the beam forming is done digitally (after A/D), the beam forming and signal processing units can normally be integrated in the same unit (Digital Signal Processor, DSP).

Smart Antenna Transmitter

Normally the adaptive process is applied to the uplink/reception only (from the mobile to the base station). In that case the mobile unit consumes less transmission power, and the operational time of the battery is extended. However, the benefits of adaptation are very limited, if no beam forming is applied in the downlink transmission (from the base station to the mobile). In principle, the methods used in the uplink can be carried over the downlink. The transmission part of a smart antenna system is schematically similar to its reception part as shown in Fig. 5.11.The signal is split into N branches, which are weighted by the complex weights

$w_1, w_2, \ldots, w_N$ in the lobe-forming unit. The signal-processing unit calculates suitably the weights, which form the radiation pattern in the downlink direction. The radio unit consists of

D/A converters and the up-converter chains. In practice, some components, such as the antennas themselves and the DSP, will be the same as in reception.

The principal difference between uplink and downlink is that since there are no smart antennas applied to the user terminals (mobile stations), there is only limited knowledge of the *Channel State Information*(CSI) available. Therefore, the optimum beamforming in downlink is difficult and the same performance as the uplink cannot be achieved.

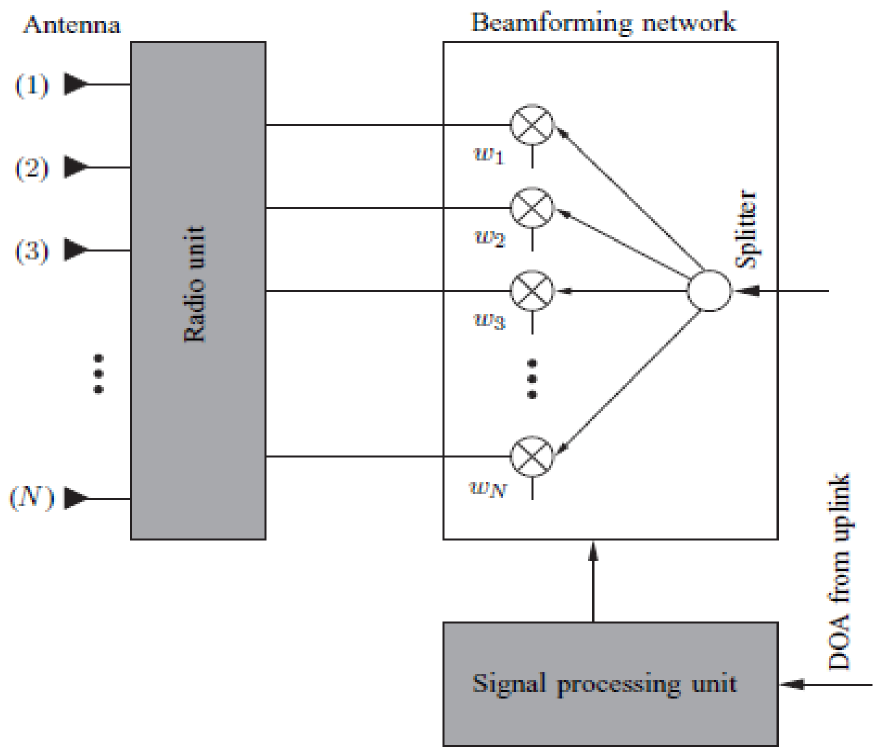

Fig. 5.11: transmission part of a smart antenna.

5.7 Benefits and Drawbacks of Smart Antennas

The introduction of smart antennas is expected to have a large impact on the performance of cellular communications networks. It will also affect many aspects of both the planning and deployment of mobile systems. The great interest in smart antennas is the increase in capacity and range. In densely populated areas the main source of noise is the interference from other users. The deployment of adaptive arrays is to simultaneously increase the useful received signal level and lower the interference level, thus providing significant improvement in the Signal to Interference Ratio (SIR).

Another added advantage of smart antenna systems is security. In a society that becomes more dependent on conducting business and distributing personal information, security is an important issue. Smart antennas make it more difficult to tap a connection because the intruder must be positioned in the same direction as the user as "seen" from the base station to successfully tap a connection.

Finally, due to the spatial detection nature of smart antenna systems, the network will have access to spatial information about users. This information may be exploited in estimating the positions of the users much more accurately than in existing networks. Consequently, exact positioning can be used in services to locate humans in case of emergency calls or for any other location-specific service.

Although the benefits of using smart antennas are considered many, there also exist some important drawbacks. A smart antenna transceiver is much more complicated than a traditional base station transceiver. Separate transceiver chains are needed for each of the array antenna elements and accurate real-time calibration of each of them is required.

Moreover, adaptive beam forming is a computationally intensive process; thus the smart antenna base station must include very powerful numeric processors and control systems.

5.8 Role of smart antennas in 5G wireless communication

A smart antenna system combines multiple antenna elements with a signal- processing capability to optimize its radiation and/or reception pattern automatically in response to the signal environment. Smart antennas will improve 5G coverage and optimize capacity by focusing RF signals where they are needed the most. In addition, smart antennas enhance 5G application and service mobility by facilitating a more continuous connection, which may become particularly useful at 5G coverage.

Key elements of the 5G NR infrastructure are the active antenna arrays, allowing multi-user MIMO technologies. These antenna modules use beam forming for targeted radio contact with the receiver. Simulation of a 5G massive MIMO array antenna in a network environment. 5G will use 'massive' MIMO (multiple input, multiple output) antennas that have very large numbers of antenna elements or connections to send and receive more data simultaneously. ... The overall physical size of the 5G base station antenna is expected to be similar to a 4G base station antenna.

5G cellular networks promise to improve many aspects of wireless communications, supporting enhanced mobile services, greater scalability for IoT systems, and ultra-reliable communications for mission-critical applications. A portion of these benefits will be based on the evolution of 4G LTE technologies as well as unique capabilities enabled by 5G New Radio, or 5GNR, based on new infrastructure supporting mm Wave RAN equipment.

5G will provide ultra-low latency (less than 1 millisecond delay) required for certain portable or mobile apps and services such as industrial automation, robotics, haptic Internet, and virtual reality. This will enable portability/mobility for many previously tethered-only applications and services such as streaming 4K video, real-time remote control, haptic communications, and more.

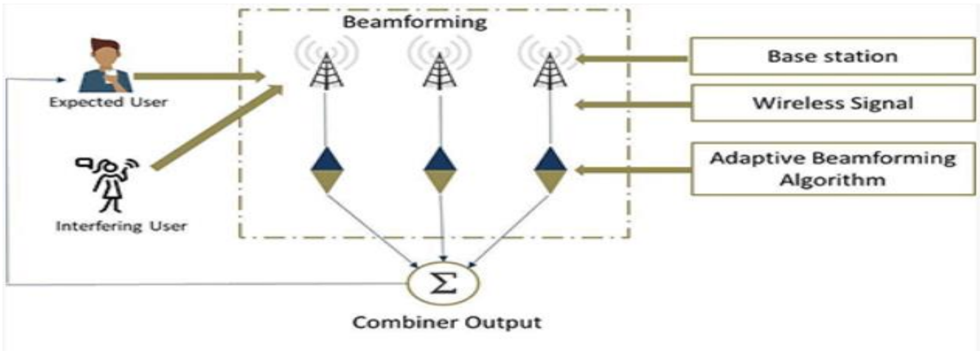

Fig. 5.12: architecture

Smart Antennas use a few key technologies to improve 5G capacity and coverage. One such technology is beam forming in which RF energy is focused in a narrow beam to exactly where it is needed rather than emanating the same energy in a broad area. Beamforming is especially useful for 5GNR as the higher frequency mm Wave RF is subject to fading over distance and attenuation loss caused by hitting objects (buildings, cars, foliage, etc.). A more directed beam of RF energy helps to ensure a greater probability of optimal bandwidth and signal quality. However, it is important to note that line of sight is still an issue as beamforming advantages are diminished with attenuation.

Another technology leveraged is multiple antennas (e.g., antenna arrays), which use Multiple Input/Multiple Output (MIMO) at both the source (transmitter) and the destination (receiver) to improve signal quality. This is in contrast to non-array systems in which a single antenna (and signal path) is used at the source and the destination. MIMO/MIMO is advantageous as multiple signal paths can compensate for attenuation. A given path may experience signal gain while another attenuates or is blocked altogether. Optimal signals will change frequently during the course of a given 5G data or voice connection, meaning that the best signal will change from antenna to antenna in an antenna array.

5G systems will also need Smart Antennas to optimize coverage, mobility, and minimize the need for hand-over from 5G to 4G RAN. Smart Antennas are useful to optimize LTE, but they are absolutely necessary to provide mobility support for many new and enhanced 5G apps and services such as virtual reality, self-driving cars, connected vehicles, and Voice over 5G. Physics dictates that higher frequencies need more power and/or more coverage as an RF signal fades more than a lower frequency signal. This is why there will need to be at least an order of magnitude more antennas than required for LTE. Putting this into perspective, the US will go from roughly 30,000 antennas to 300,000 or more nationally.

Smart Antennas for 5G will improve coverage and optimize capacity by focusing RF signals where they are needed the most. In addition, Smart Antennas enhance 5G application and service mobility by facilitating a more continuous connection, which may become particularly useful at 5G coverage seams. Otherwise, a 5G enabled user experience may degrade as hand-over from 5G to LTE occurs.

5.9 Smart-Antennas-Supported 5G Application Use Cases

There are many 5G-enabled applications that will benefit from Smart Antennas, many of which require ultra-reliability and ultra-low latency. Mind Commerce 5G smart antenna market research points towards 4 application use case areas that will benefit greatly from Smart Antenna operation: public safety, robotics, connected vehicles, and drones. In addition, the market research firm sees Smart Antennas used most frequently in an urban environment and critical for support of many Smart City solutions.

Applications

1.Mission Critical Communications

The public safety community increasingly relies upon IP-based solutions for first responder (ambulance, police, and fire) and dispatch communications as well as overall coordination in the event of a disaster. Accordingly, the market for mission critical public safety related communications is rapidly developing as developing technologies supply solutions necessary to meet emerging demand for improved voice, data, and machine-oriented communications.

2. Industrial Automation and Robotics

Robotics is increasingly used to improve enterprise, industrial, and military automation. In addition, robots are finding their way into more consumer use cases as the general public's concerns fade and acceptance grows in terms of benefits versus risks. Emerging areas for industrial robotics include robotics-as-a-service, cloud robotics, autonomous robotics, and general-purpose robotics. 5GNR will provide the bandwidth, reliability, and low-latency necessary to allow various industries to leverage the next phase of robotics evolution.

3. Self-Driving Vehicles

Connected vehicles leverage many different wireless communications technologies including WiFi, Satellite, LTE, and soon 5G. Vehicle-to-Everything (V2X) refers to a vehicle's ability to communicate with other vehicles, infrastructure (traffic signals, buildings, kiosks/billboards, parking lots, etc.), and even pedestrians. V2X will benefit greatly from 5GNR as dramatically improved bandwidth and latency improvements enhance existing solutions and enable new applications. Self-driving vehicles require high-capacity, low-latency communications for safe operation.

5.10 Software tools for antenna design and analysis

1. HFSS(High Frequency Structure Simulator)

HFSS, which is an acronym for high frequency structural simulator, is one of the most advanced 3D EM software that is commonly used in antenna design and for the design of complex RF electronic circuits. IT bases its design and analysis method on the Finite Element Method. Ansys HFSS is a commercial finite element method solver for electromagnetic structures from Ansys. HFSS is one of several commercial tools used for antenna design, and the design of complex radio frequency electronic circuit elements including filters, transmission lines, and packaging.

2. CST Studio Suite

Antenna Magus is a software tool to help accelerate the antenna design and modelling process. It increases efficiency by helping the engineer to make a more informed choice of antenna element, providing a good starting design tuned to the specifications of the application.

3. FEKO

FEKO is a method of Moment (MoM) tool that can be used to calculate the impedance, radiation pattern and gain of an antenna while mounted on a defined geometry. In addition, it can calculate the isolation or mutual coupling S_{12} between pairs of antennas, the near fields around an antenna and the electric currents that flow on an antenna or the surrounding structure.

4. IE 3D

Method of moment based electromagnetic simulator *IE3D* was used for parametric calculation and optimization of proposed patch *antenna design*.

5. Advanced Design System (ADS)

ADS is used for circuit co simulations where active components are also involved. It can be used for planar antennas as well and is based upon MoM (Method of Moment). With the aid of simulation, electromagnetic analysis in the design flow of electronic circuits is essential to avoiding expensive reworks. Achieving precise designs requires the consideration of physical properties, multiple technologies, interactions, and packaging that only EM modeling and simulation can provide.

TEXT / REFERENCE BOOKS

1. K.D.Prasad, "Antennas and Wave Propagation", 3rd Edition, Satya Prakasan, New Delhi, 2003.
2. R.L. Yadava, "Antennas and Wave Propagation", 2nd Edition, PHI Learning Private Limited, New Delhi, 2011.
3. Balanis C.A., "Antenna Theory and Design", 4th Edition, John Wiley & Sons, 2016.
4. Jordan E.C., Balmain, K.G., "Electromagnetic Waves and Radiating Systems", 2nd Edition, Prentice Hall of India, 2006.
5. Collin R.E., "Antennas and Radio Wave Propagation", McGraw Hill, 1985.

PART A

1. List out the applications of Smart Antennas
2. Illustrate the architecture of smart antenna transmitter.
3. Compare beam steering and beamforming.
4. Outline the drawbacks of fixed weight beamforming.
5. Contrast switched multi-beam and Adaptive array antenna.
6. Distinguish MIMO, MISO and SIMO.
7. Compare and Contrast linear and planar antenna arrays.
8. Mention the key features of Green Communications
9. List the algorithms widely used for Direction of Arrival estimation of signals in antenna arrays.
10. Mention the drawbacks of MUSIC algorithm.

PART B

1. Determine the complex weights of a two-element linear array, half-wavelength apart, to receive a desired signal of unity magnitude $\theta = 0^0$◦ while tuning out an interferer at $\theta = 30^0$. Assume the antenna elements are isotropic and the impinging signal is sinusoidal.
2. Propose a feasible solution using the concept of antennas arrays and signal-processing techniques, to increase the coverage area, user capacity and signal quality of a mobile base station without increase in transmit power.
3. Suppose that using an omnidirectional antenna, a particular base station can cover an area of $10Km^2$. The path loss for the free space channel is estimated using an exponential path loss model with $\gamma = 35$. If a smart antenna system is deployed to provide an additional 6 dB of gain, estimate the coverage area of the base station.
4. Derive the expression for direction of arrival (DOA) in degrees for a linear two-element antenna array with element spacing d based on time delays of received signals.
5. Illustrate the effect of mutual coupling in beamforming, by considering a two-element isotropic antenna array spaced half-wavelength apart excited by sinusoidal signals.
6. Determine the relative amplitude and phase excitation for an eight-element linear array of isotropic antennas with a spacing of 0.5λ between them, to obtain pattern maximum at $\theta =$ 20degrees.
7. Analyze the effect of different feed techniques used for planar array antennas and identify the merits and demerits of each configuration.
8. Evaluate the beneficial aspects of employing smart antennas in 5G mobile communication systems in terms of signal quality, channel capacity and interference rejection.